

Assignment for FTech-301 Food Science

Organic Chemistry

All the components of food, with the exception of water and the mineral salts, are organic compounds. Therefore, a knowledge of organic chemistry is essential in the study of food science and nutrition. Organic chemistry is the study of covalent carbon compounds.

Alcohols

Alcohols are a homologous series of compounds in which one of the hydrogen atoms of a hydrocarbon molecule is replaced by a hydroxyl (—OH) group. The simplest members of the series are methanol and ethanol.

Carboxylic acids

Carboxylic acids known as organic acids, contain one or more carboxyl (—COOH) groups. These compounds are weak acids.

Esters

Esters are compounds formed when carboxylic acids react with alcohols.

For eg, Acetic Acid + Ethanol \longrightarrow Ethyl acetate (Ester) + Water

A large variety of esters are found in foods, especially in fruits. They are responsible for some of the characteristic flavours and odours of foods. Esters can be produced synthetically and are used in the production of artificial flavours. For eg, ethyl lactate is used in synthetic grape flavouring. Fats and oils are esters of fatty acids and glycerol.

Solutions and Colloids

All foods contain a high percentage of water and the other nutrients present in the food are dispersed in this water. Solids, liquids and gases may be dispersed in water to form either solutions or colloids.

Solutions

If sugar (solute) is placed in water (solvent) it dissolves and produces a solution. A solution is homogeneous. A solution is made up of two components; the solute which is the substance dissolved, e.g. sugar and the solvent, the liquid in which the solute is dissolved, e.g. water.

Solutions are not composed of a solid dissolved in a liquid. Soda water is a solution of a gas (carbon dioxide) dissolved in a liquid (water). Vinegar is a solution of one liquid (acetic acid) dissolved in a second liquid (water).

Dissolved substances cause an increase in the boiling-point and a depression of the freezing-point of solutions.

Solutions are formed by inorganic compounds, in which the particles or ions have an affinity for water. If the particles of a compound have a greater attraction for each other than they have for water, the compound will be insoluble.

Mineral elements found in foods, such as sodium and chlorine, are usually present as ions and form true solutions. Small organic molecules, such as sugars[^] which have an affinity for water, also form true solutions. Vitamins, depending on their structure, may be either dissolved in the water or in the fat present in foods.

Colloids

If a substance such as albumin, the protein in egg white, is mixed with water it does not dissolve but forms a colloidal dispersion. This dispersion is not a solution and is not homogeneous, since the molecules of protein do not dissolve. The molecules are dispersed throughout the water producing a heterogeneous or two-phase system. The substance which is dispersed is known as the disperse phase and it is suspended in the continuous phase. For eg, protein is the disperse phase and water the continuous phase.

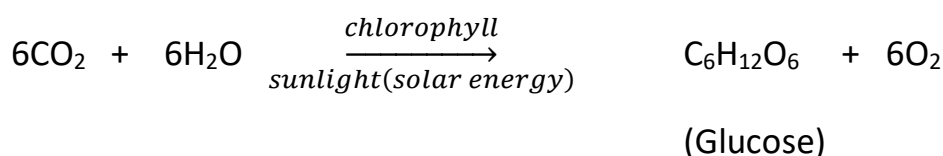
There are various types of colloidal system depending on the physical state (solid, liquid or gas) of the two phases.

Colloids are formed by large organic molecules or by aggregates of smaller organic molecules. Some inorganic materials may also form colloids if they are of a suitable particle size. In foods, proteins, polysaccharides, such as starch, and fats are often present in the form of colloids. Most colloidal dispersions are fairly

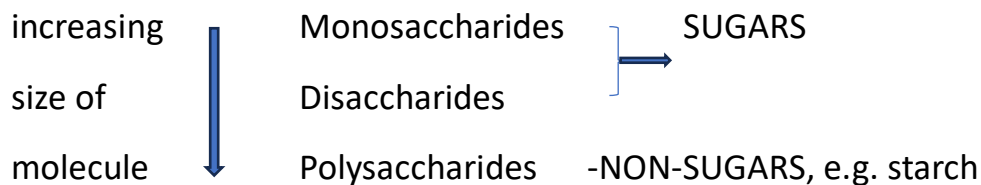
stable but the two phases may separate out over a long period of time. The rate of separation is accelerated by increase in temperature or by mechanical agitation. Many colloids separate out on freezing; this causes problems when foods containing emulsions of fat and water are deep-frozen.

Carbohydrates

Carbohydrates are a group of nutrients important in the diet as a source of energy. They contain the elements carbon, hydrogen and oxygen and are produced in plants by the process of photosynthesis, which may be represented by the following equation :



Chlorophyll is a green pigment which absorbs energy from sunlight and enables plants to build up carbohydrates from carbon dioxide and water. There are various different carbohydrates but they may be divided into three groups according to the size of their molecules :



Monosaccharides

The monosaccharide sugars commonly found in food contain six carbon atoms and have the general formula $\text{C}_6\text{H}_{12}\text{O}_6$. The three most important members of this group are :

(a)Glucose (also known as dextrose)

Glucose is found in varying amounts in fruits and vegetables. Large amounts are found in fruits such as grapes and smaller quantities in vegetables such as young peas and carrots. It is also found in the blood of animals. Glucose syrup or

commercial glucose is not pure glucose but a mixture of glucose, other carbohydrates and water.

(b)Fructose (also known as laevulose)

This is chemically similar to glucose except that the arrangement of the atoms within the molecule is slightly different. Fructose is found, together with glucose, in many fruits and in honey.

(c)Galactose

This sugar is also chemically similar to glucose. It does not exist as such in foods but is produced when lactose, a disaccharide, is broken down during digestion.

Disaccharides

These sugars are formed when two monosaccharide molecules combine with the elimination of a water molecule.



(a)Sucrose

This is ordinary household sugar and is produced in plants by the condensation of glucose and fructose.

(b)Lactose

This sugar is formed by the condensation of glucose and galactose. It is found only in milk, where it is the sole carbohydrate.

(c)Maltose

A molecule of maltose is formed by the condensation of two glucose molecules. During the germination of sprouting of barley, starch is broken down into maltose. Malt, a vital ingredient in brewing, is produced by this process.

Polysaccharides

Polysaccharides are condensation polymers of monosaccharides and are made up of many monosaccharide molecules joined together, with the elimination of one water molecule at each link. They have the general formula $(C_6H_{10}O_5)_n$, where 'n' represents a large number. Polysaccharides members are Starch, Cellulose, Glycogen, Pectin, Agar and Alginates.

Fats

Fats, like carbohydrates, contain the elements carbon, hydrogen and oxygen. They are esters of glycerol and fatty acids. Glycerol is a trihydric alcohol, i.e. it has three $—OH$ groups. The general formula of a fatty acid is $R.COOH$ where R represents a hydrocarbon chain. Each $—OH$ group of the glycerol reacts with the $—COOH$ of a fatty acid to form a molecule of fat.

Fats are mixtures of triglycerides. A triglyceride consists of one molecule of glycerol combined with three fatty acid molecules. Diglycerides consist of glycerol combined with two molecules of fatty acid, and in monoglycerides only one fatty acid molecule is present. Diglycerides and monoglycerides occur in small quantities in foods containing fat. The simplest type of triglyceride is one in which all three fatty acids are the same. Most triglycerides contain two or three different fatty acids and are known as mixed triglycerides. Naturally occurring fats are mixtures of different mixed triglycerides and may contain a number of different fatty acids. There are two types of fatty acids:

1. **Saturated fatty acids** in which the hydrocarbon chain is saturated with hydrogen.

2. **Unsaturated fatty acids** in which the hydrocarbon chain is not saturated with hydrogen and therefore has one or more double bonds.

Some of the more important fatty acids are butyric acid, palmitic acid, stearic acid, oleic acid, linoleic acid. Linoleic and linolenic acids are described as polyunsaturated fatty acids and they contain more than one double bond.

Fats and oils have the same general chemical structure. The difference between a fat and an oil may be explained by the presence of different fatty acids. Fats contain a large proportion of saturated fatty acids distributed among the

triglycerides, and oils a large proportion of unsaturated fatty acids. Fats are obtained from animal sources and oils from vegetable sources. Both fats and oils contain small amounts of non-triglyceride; in particular, fatty acid complexes containing phosphate, called phospholipids. Vegetable oils should not be confused with either mineral oils or essential oils. Mineral oils are obtained from crude oil and are mixtures of hydrocarbons. Essential oils are found in plants but are not triglycerides. They are volatile organic compounds, i.e. they evaporate easily, and are responsible for the flavour of many spices and other foods. For eg, Eugenol is responsible for the flavour of cloves. Vegetable oils are more available than animal fats. Vegetable oil produced is converted into fat by a process of hydrogenation. Unsaturated fatty acid is turned into a saturated fatty acid. In this way, vegetable oils can be used in the manufacture of margarine and cooking fats.

Proteins

Proteins are a very important group of nutrients. They are found in the cytoplasm of all living cells, both animal and plant. Proteins are organic substances and they resemble fats and carbohydrates in that they contain the elements carbon, hydrogen and oxygen. All proteins also contain nitrogen and some contain sulphur and phosphorus. Proteins show a greater variety and complexity of structure than either fats or carbohydrates. Plants are able to synthesise protein from inorganic materials. Carbon dioxide from the air and water from the soil provide the carbon, hydrogen and oxygen necessary for protein synthesis. Nitrogen is obtained from the soil in the form of inorganic compounds, usually nitrates and nitrites. Some plants are able to utilise nitrogen from the air, with the aid of bacteria. Animals cannot synthesise protein from inorganic compounds, therefore protein is an essential nutrient in the diet of all animals.

Protein molecules are extremely large and consist of long chains of amino acids chemically combined. Each amino acid molecule contains at least one amino group (—NH_2) and at least one acidic group (—COOH). Therefore amino acids show both basic and acidic properties. Proteins structure can be classified into two main groups, according to the shape of the molecules.

1.Globular Proteins: Molecules of globular proteins are rounded in shape but are not spherical. The amino acid chain is folded and the molecule is kept in shape by cross-linkages within the amino acid chain.

2. Fibrous Proteins: Molecules of fibrous proteins are straighter. They may be almost completely straight or coiled in a spiral. In fibrous proteins, there is usually an organised arrangement and the molecules are closely packed together. There are cross-links between adjacent amino acid chains and it is difficult for water molecules to penetrate the structure. Fibrous proteins are not soluble in water.

Vitamins

The vitamins are a group of complex organic compounds required in small quantities by the body for the maintenance of health. They are not usually synthesised in the body and are essential in the diet. They are present in foods in small amounts.

A diet containing carbohydrate, fat, protein and minerals was sufficient to maintain health. The effects of vitamin deficiencies can cause of these diseases. Scurvy, a disease caused by a dietary lack of vitamin C.

Unlike other groups of nutrients, the vitamins are not chemically similar to each other. Each vitamin has a specific chemical structure and a specific function or set of functions in the body. Many of the vitamins are involved in enzyme systems in the body.

A varied, Balanced diet will supply all the necessary vitamins in sufficient quantity. It is unnecessary to waste money on vitamin tablets. With few exceptions, most notably babies, young children and pregnant women, people do not require vitamin supplements. Vitamins can be divided into two main groups.

1. Fat-Soluble Vitamins: Vitamin A and vitamin D are the two most important vitamins in this group. They will dissolve in fats and oils but not in water. Both of these vitamins can be stored in the body, in the liver. In extreme circumstances it is possible to have an excessive intake of these vitamins.

2. Water-Soluble Vitamins: The vitamins of the B group (thiamin, riboflavin, nicotinic acid) and vitamin C will dissolve in water but not in fats. They are water soluble and they are not stored in the body, any excess being excreted in the urine.

Vitamins groups are involved **Vitamin A** (retinol), **Vitamins B** (thiamin- vitamin B1, riboflavin- vitamin B2, nicotinic acid, folic acid- folate, cyanocobalamin - vitamin B12, pyridoxine - vitamin B6, biotin, pantothenic acid, choline, para aminobenzoic acid and inositol), **Vitamin C** (ascorbic acid), **Vitamin D** (cholecalciferol), **Vitamin E** (the tocopherols), **Vitamin K**.

Mineral Elements

The mineral elements are chemical elements, other than carbon, hydrogen, oxygen and nitrogen, which are required by the body. They are present in food mostly in the form of inorganic salts, e.g. sodium chloride, but some are present in organic compounds, e.g. sulphur and phosphorus are constituents of many proteins. Some mineral elements such as calcium and phosphorus, are present in the body in relatively large amounts whereas others occur in very small quantities and are known as trace elements. Mineral elements have various functions in the body. Calcium, phosphorus and magnesium are constituents of bones and teeth. Some elements such as potassium, phosphorus and sulphur, are found inside the cells of the body whereas others are found in the fluid surrounding the cells, such as sodium and chlorine.

Many of the trace elements are concerned in enzyme systems of the body. From a nutritional point of view calcium and iron are the most important mineral elements since these are the two elements most likely to be deficient in the diet. Iodine is the most important trace element.

Milk and some milk products, such as cheese and yoghurt, are good sources of **calcium**. Small fish, such as sardines, sprats and whitebait, which are eaten with the bones contain very useful quantities of calcium. Fruits and vegetables contain variable but usually quite small amounts of calcium. People obtain a certain amount of calcium from drinking water. Calcium is necessary for the formation and development of bones and teeth. vitamin D is essential for calcium absorption the effects of a dietary deficiency of calcium are the same as a deficiency of vitamin D. Calcium deficiency causes rickets in children and osteomalacia in adults.

Liver and kidney are two of the best sources of **iron**. Other meats, although not containing quite as much iron, are good sources. Egg yolks have a high iron content but there is very little iron in egg white. Iron is found in cereals. The majority of this occurs in haemoglobin, a red pigment present in the red blood corpuscles. Haemoglobin is responsible for transporting oxygen from the lungs to the cells of all body tissues. All cells require oxygen in order to break down nutrients and obtain energy. A deficiency of iron causes anaemia. In an anaemic person the number of red blood corpuscles is reduced and the amount of oxygen carried to the tissues is also reduced. This results in a lack of energy and a feeling of lethargy. Other symptoms of anaemia include headaches and dizziness.

The main sources of **iodine** in the diet are cereals, vegetables and milk. The amount of iodine in these foods varies and depends on the amount of iodine in the soil of the area where the foods are produced. Iodine occurs in very low concentrations in sea-water but organisms living in the sea have the ability to concentrate these small amounts. Sea fish is a good source of iodine and seaweed is a particularly rich source. Iodine is needed by the body in very small amounts. It is required by the thyroid gland for the formation of thyroxin, a hormone involved in the regulation of the rate of oxidation of nutrients in body cells. An insufficient intake of iodine results in goitre, an enlargement of the thyroid gland. Goitre caused by a lack of iodine. The diet being deficient in iodine, 'iodized salt' may be used to increase the intake of iodine. This is ordinary table salt with a small quantity of potassium iodide added.

Water

Water is essential to life. All living organisms contain water; the human body is about 60% water. The body of an adult man contains about 40 litres of water. About 15 litres are present in the extracellular fluid (3 litres in the blood plasma and 12 litres in the tissue fluid). The remaining 25 litres make up the intracellular fluid, i.e. the fluid found within the cells. Water provides a medium in which nutrients, enzymes and other chemical substances can be dispersed and in which the chemical reactions necessary for maintaining life can take place. It is also necessary as a means of transport within the body. Nutrients are carried to cells and waste products are transported from the cells by blood plasma which is

90% water. Waste products are removed from the blood by the kidneys and excreted in the urine.

Cells

All organisms, whether plant or animal, are made up of small units called cells. The human body is composed of thousands of millions of cells which are organized into tissues with specialized functions. For example, muscle is a tissue composed of long, spindle-shaped cells which by contraction and relaxation enable the body to move. Since food is of either plant or animal origin most natural, unprocessed foods have a cellular structure. Cells themselves, although very small, have a complex structure.

Animal cells have cell membrane, cytoplasm, nucleus, endoplasmic reticulum, ribosome and mitochondrion. Plant cells have cellulose cell wall, cell membrane, cytoplasm, chloroplast, nucleus, endoplasmic reticulum, ribosome and mitochondrion.

Cell membrane

Surrounding every cell is a non-rigid, semi-permeable membrane which allows small molecules to pass in and out of the cell.

Cell Wall (plant cells)

This is a more rigid structure which surrounds the cell membranes of plant cells. Plant cells tend to have a more definite shape than animal cells. Cellulose is one of the main components of the cell wall.

Nucleus

The nucleus controls the activity of the rest of the cell. It contains nucleic acids which form the chromosomes, the particles which carry the genetically inherited information required for the maintenance of the whole cell.

Cytoplasm

Cytoplasm is a colloidal solution of protein and other substances dispersed in water.

Endoplasmic Reticulum and Ribosomes

The endoplasmic reticulum is a complex network of strands which, together with the ribosomes, is responsible for the building up of protein molecules from amino acids.

Mitochondria

The mitochondria are sometimes called the 'power houses' of the cell. It is in these structures that nutrients are oxidised and energy is released.

Chloroplasts

Chloroplasts occur only in the cells of green plants. They contain the green pigment chlorophyll which can convert light energy into a form that can be used for forming complex organic compounds. Chloroplasts are therefore involved in the process of photosynthesis.

Metabolism

Metabolism is used to include all the chemical processes involved in maintaining life. It is the total of all chemical reactions by which nutrients are used by the body to produce energy and material for growth and maintenance.

Metabolism involves two types of reaction. Catabolism is the breakdown of large molecules into smaller molecules and anabolism is the synthesis, or building up, of large molecules from smaller molecules. In any one cell of the body catabolic and anabolic processes are carried out simultaneously. Each chemical reaction requires a catalyst. Enzymes are protein substances, produced in cells, which act as biological catalysts. Two of the most important metabolic processes which take place in cells are energy production (respiration) and protein synthesis.

Enzymes

Enzymes are substances produced by living cells which act as catalysts in the chemical reactions taking place in an organism. A catalyst is a substance which speeds up a reaction but is itself unchanged at the end. All cells produce a large number of different enzymes and the function of a cell is determined by the enzymes present in it. Some cells release enzymes which act outside the cell, e.g. the cells lining parts of the alimentary canal produce enzymes which digest food.

Names of Enzymes

Most enzymes are named by adding the suffix -ase either to a word indicating the nature of the compound affected by the enzyme or to the name of the type of chemical reaction which the enzyme catalyses. Hydrolases catalyse hydrolytic reactions. For eg. Carbohydrases break down carbohydrates. Oxidases bring about oxidation reactions. For eg, ascorbic acid oxidase is responsible for the oxidation of ascorbic acid (vitamin C).

Characteristics of Enzymes

1. **Specificity:** The action of enzymes is highly specific. In general a given enzyme will catalyse only one reaction. For example, lactase hydrolyses the sugar lactose but it has no effect on other disaccharides. Lactose is the only molecule which will slot into the active site on the lactase molecule.
2. **Effect of temperature:** The activity of enzymes is greatly affected by temperature. For animal enzymes the optimum temperature is between 35 °C and 40 °C, i.e. body temperature. At temperatures above and below the optimum, enzyme activity is reduced. Above 50 °C enzymes are gradually inactivated since being proteins they are denatured. At 100 °C all enzymes are destroyed. At very low temperatures they are not actually destroyed but their activity is very greatly reduced.
3. **Effect of pH:** Each reaction catalysed by an enzyme is most rapid at a particular pH. For most enzymes the optimum is about pH7 (neutral) and if the medium becomes strongly acid or alkaline the enzyme is inactivated. Some enzymes, however, only operate in acid or alkaline conditions. For example, pepsin, an

enzyme released into the stomach, can only function in acid conditions; its optimum pH is 2.

4. Co-enzymes and activators: Enzymes frequently require the help of another substance in order to function effectively. Co-enzymes are non-protein substances which activate enzymes. Some of the B vitamins function as co-enzymes. In addition some inorganic ions, e.g. calcium and chloride ions, increase the activity of some enzymes and are known as activators.

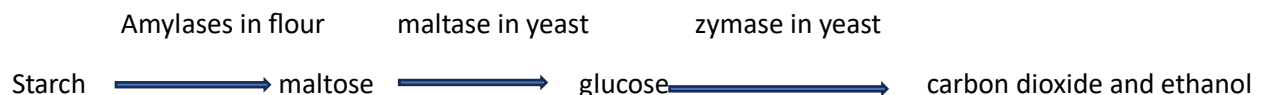
Some Enzymes of importance in Food Production

Some Enzymes of importance in Food Production are:

- 1) Enzymes in breadmaking
- 2) Production of alcoholic drinks
- 3) Cheese Production
- 4) Meat tenderising enzymes
- 5) Tea Production

Enzymes in Breadmaking

Enzymes play a very important role in breadmaking. Flour contains amylases (diastase) which, in the presence of water, convert starch into maltose. The enzyme maltase which is secreted by yeast continues the breakdown by splitting maltose into glucose. Glucose is subsequently fermented by a number of enzymes in yeast, known collectively as zymase. The products of the fermentation process are carbon dioxide which aerates the dough and ethanol (ethyl alcohol) which is driven off during baking.



Proteases, present in flour and yeast, are also important in breadmaking. They act on the protein in flour, gluten, making it more extensible and capable of retaining the carbon dioxide produced by the fermentation.

Some Undesirable Effects of Enzymes in Foods

Some Undesirable Effects of Enzymes in Foods are:

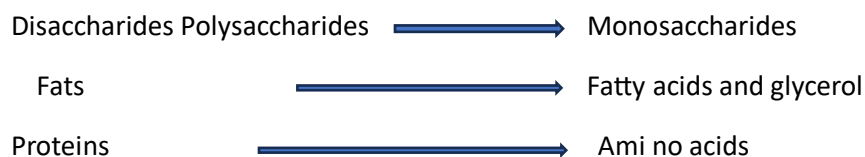
- 1) Autolysis
- 2) Microbial Spoilage
- 3) Enzymic browning
- 4) Oxidation of Ascorbic acid (Vitamin C)

Autolysis

Enzymes naturally present in the tissues of plants and animals continue to act after the harvesting of plants and the slaughter of animals and may bring about undesirable chemical changes in food during storage. This destruction of plant and animal cells by their own enzymes is known as autolysis and is one cause of food spoilage.

Digestion

Food taken into the mouth is of no use to the body until it has been absorbed through the lining of the alimentary canal (digestive tract) and carried by the blood to the cells. Digestion is the breakdown of complex nutrient molecules into molecules small enough to be absorbed through the lining of the intestine. Certain components of food, monosaccharides, salts, vitamins, water and alcohol, do not need to be digested since they are composed of small soluble molecules. Digestion is mainly a chemical process of hydrolysis. Hydrolytic enzymes are produced in various organs and are released into the alimentary canal in digestive juices. The nutrients hydrolysed by digestive enzymes are shown below :



Digestion is also, in part, a physical process. Food particles are reduced in size by the grinding and chewing action of the teeth and by the muscular action of the alimentary canal.

Alimentary Canal

The various parts of the alimentary canal are:

Mouth

Food is broken into smaller pieces by the grinding and chewing action of the teeth, a process known as mastication. At the sight and smell of food the salivary glands are stimulated and a steady flow of saliva enters the mouth. Saliva is composed of water together with :

1. **Mucin**: a slimy, protein substance which lubricates food and makes it easier to swallow.
2. **Salivary amylase**: an enzyme which initiates the breakdown of starch into maltose.

Stomach

The stomach acts as a reservoir, so that, rather than eating continually, food need only be consumed at intervals. It is also the site of some digestion. The cells lining the stomach produce gastric juice. Secretion of gastric juice is stimulated by the sight, smell and taste of food and also by the presence of food in the stomach. Gastric juice contains:

1. **Pepsin**: an enzyme which breaks down some proteins into smaller molecules called polypeptides.
2. **Rennin**: an enzyme which coagulates the protein in milk making it easier to digest.
3. **Hydrochloric acid**: which activates pepsin and to a limited extent kills bacteria.

Small intestine

The majority of digestive processes take place in the small intestine. The small intestine, it is acted on by three digestive juices:

1. **Pancreatic juice** which, as its name suggests, is produced in the pancreas and which contains:

(a) Trypsin: an enzyme which continues the digestion of protein.

(b) Pancreatic amylase: an enzyme which breaks down starch into maltose. It is more effective than salivary amylase.

(c) Lipase: an enzyme which hydrolyses fats (triglycerides) into fatty acids and glycerol. Some fats are only partially hydrolysed to diglycerides and monoglycerides.

2. **Bile** which is a yellow-brown fluid produced in the liver and stored in the gall bladder. The presence of fat and other foods in the duodenum brings about contraction of the gall bladder and the flow of bile into the duodenum. Bile does not contain an enzyme but contains bile salts which aid pancreatic lipase by emulsifying fats. Both pancreatic juice and bile are alkaline and they neutralise the acidic chyme entering the duodenum from the stomach.

3. **Intestinal juice** which is secreted by the cells lining the small intestine and which contains:

(a) Peptidases: a group of enzymes which complete the breakdown of proteins by splitting polypeptides into their constituent amino acids.

(b) Disaccharide splitting enzymes: maltase, sucrase (invertase) and lactase which hydrolyse maltose, sucrose and lactose into their respective monosaccharides.

Large intestine (colon)

The main function of the large intestine is to remove water from the fluid mixture which enters from the small intestine. Water is absorbed through the lining of the colon so that undigested food leaves the body in a semi-solid state. The large intestine contains a very large number of bacteria which break down some undigested food by the action of their own enzymes and which synthesise certain vitamins. The vitamins can be absorbed into the blood-stream. Undigested food materials, residues from digestive juices, bacteria and water form faeces which are passed out of the body through the anus.

Food and Energy

All living organisms require a source of energy. The earth's primary source of energy is the sun. Plants, by the process of photosynthesis are able to convert the sun's energy into chemical energy. Animals are unable to utilise the sun's energy directly and so they eat plants or other animals in order to obtain energy. The chemical energy in food is released in the cells of animals by oxidation, this process is known as internal respiration. Some of the energy released is used to maintain metabolic processes in the cells; some is converted into heat to maintain body temperature and some is converted into mechanical energy which is used for physical activity.

The unit of energy is the joule (J). The three groups of nutrients such as carbohydrates, fats and proteins which provide the body with energy. Energy is required by the body for **basal metabolism**, i.e. for maintaining basic body processes, and for **physical activity**.

Basal metabolism is used to describe the basic metabolic processes which keep the body alive. Energy is needed to keep the heart beating and the lungs functioning, to maintain body temperature and muscle tone and for the numerous chemical reactions taking place in body cells. The rate at which energy is used up in maintaining basal metabolism is called basal metabolic rate (BMR).

Physical activity, energy is used by the body for muscular activity. The energy requirements for various activities have been determined by measuring oxygen uptake during different activities. Activities which involve moving the body about, particularly those involved in moving the body upwards, e.g. walking upstairs, require a large amount of energy.

Commodities:

Meat

Meat is the flesh or muscle of animals. It is composed of microscopic fibres, each fibre being an elongated cell. The fibres are held together by connective tissue to form bundles, which are clearly visible in most meats. Fat, blood-vessels and nerves are found in the connective tissue between bundles of fibres. The fat

content varies from 10% to 50% depending on the animal and the part of the animal from which the meat has come. Water content is inversely proportional to fat content, i.e. a meat with a high fat content has a low water content. The cells of the muscle fibres contain two soluble proteins, actin and myosin, which are responsible for the contraction of muscles. Two insoluble proteins, collagen and elastin, are found in connective tissue. Deposits of fat, marbling, are found in the connective tissue between bundles of fibres. Fat is also stored in the bodies of animals under the skin and around certain organs. Meat is a valuable protein food and an important source of B vitamins (especially nicotinic acid) and iron. It is a poor source of calcium. Although liver and kidney contain vitamins A and D, meat does not.

Offal

Certain organs of animals, such as the liver, kidney and heart, can be eaten and are known collectively as offal. Other types of offal include tripe (the tissues of the stomach) and sweetbreads (the pancreas). Most offal has a high nutritional value. For eg, Liver is a very good source of iron, riboflavin, nicotinic acid and vitamin A. Liver is also a good source of protein, thiamin and vitamin D.

Fish

Fish differs from meat in that it has less connective tissue and no elastin. The protein offish is more easily digested. Fish normally contains more water than meat. There are two main types or groups offish. Oily fish, such as herring, mackerel, salmon and sardines, contain between 10 and 18% fat. White fish, which includes cod, haddock, and plaice, contains less than 2% fat. Oily fish contain vitamin A and are important sources of vitamin D. Small fish, e.g. sardines which are eaten with the bones, are good sources of calcium.

Eggs

A hen's egg is made up of three major parts: shell, white and yolk. The porous shell is composed mainly of calcium carbonate. The colour of the shell does not indicate the quality of the egg but depends on the breed of hen. Inside the shell two thin membranes separate the shell from the white. The white is divided into regions of thick and thin white. The yolk is suspended in the white and is held in position by strands of protein called chalazae. The white of an egg is

basically a colloidal solution of protein (mainly albumin) in water, together with small quantities of vitamins and mineral salts. The yolk is a fat-in-water emulsion. The main protein is vitellin. The yolk also contains vitamins and mineral salts. Eggs are normally considered as protein foods but they also provide substantial quantities of iron, vitamins A and D, and riboflavin. They provide smaller amounts of other B vitamins.

Milk

Milk from other animals, such as ewes, goats and even camels and buffalo, is often an important constituent of the diet. Milk is composed of a variety of nutrients either dissolved in water or dispersed in the form of a colloid. The colloidal system is complex but is basically a fat-in-water emulsion. The proteins in milk are colloiddally dispersed in the water phase. The most important proteins are caseinogen and the whey proteins, lactalbumin and lactoglobulin. During digestion caseinogen is converted by the action of rennin into a coagulated form called casein. The fat in milk is in an easily digestible, emulsified form. The carbohydrate in milk is the disaccharide, lactose, which is less sweet than other sugars. Milk, being a complete food for young calves, is of high nutritional value. It is a valuable source of protein, riboflavin and calcium and provides important quantities of other B vitamins and vitamin A. It is not, however, a complete food for humans as it is relatively deficient in iron, vitamin C and vitamin D.

Cream

Cream is a fat-in-water emulsion. It is separated from milk by centrifugation, a process which involves spinning milk in a centrifuge so that the heavier particles are forced to the outside and the lighter particles, which make up the cream, remain nearer the centre. Cream contains all of the fat and a proportion of the protein and lactose in milk. Compositions of single and double cream. By law single cream must have a minimum fat content of 18% and double cream of 48%. All types of cream contain useful quantities of vitamins A and D. Double cream has a higher energy value than single cream.

Butter

The conversion of cream into butter. Butter is a water-in-fat emulsion. The composition of butter is containing at least 80% milk fat. The composition of margarine is included. Both butter and margarine are valuable sources of vitamins A and D. Butter and margarine both have a high fat content.

Yoghurt

Yoghurt is made by souring milk, using a pure culture of bacteria. The two species of bacteria normally used are *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. They convert the lactose in milk into lactic acid which together with a variety of minor products is responsible for the characteristic flavour of yoghurt. The acid also brings about coagulation of the milk proteins and helps to preserve the product. The composition and food value of yoghurt are similar to milk. 'Fat-free' yoghurt is produced from skimmed milk. Fruit yoghurts are normally higher in carbohydrate as well as fruit, they normally contain added sugar.

Cheese

Cheese making is a traditional method of preserving surplus summer milk. Cheese can be concentrated form of milk (1 litre of milk produces approximately 100 grams of cheese). However, unlike milk, cheese does not contain carbohydrate; the lactose is partly converted into lactic acid and the remainder is lost in the whey. Cheese has a lower water content than milk it is a more concentrated source of nutrients. Cheese is particularly rich in calcium and is a good source of protein, vitamin A and riboflavin. It also provides useful quantities of other B vitamins and vitamin D but contains no vitamin C and is a relatively poor source of iron.

Cereals

Cereal grains are the seeds of cultivated grasses. Cereals are the most important source of food for man and they form the staple food in most countries. Cereals may be used as the whole grain, e.g. rice, or they can be ground into a flour, e.g. wheat flour. The most important cereals are wheat, rice, maize (corn), barley, oats and rye. The nutrients in the grain as a whole the endosperm contains: 70-75% of the protein, 32% of the riboflavin, 12% of the nicotinic acid,

3 % of the thiamin. The nutrients in the whole grain the bran and aleurone layer contain : 86% of the nicotinic acid, 42% of the riboflavin, 33% of the thiamin, 19% of the protein. The nutrients in the whole grain the germ contains : 64% of the thiamin, 26% of the riboflavin, 8% of the protein, 2% of the nicotinic acid.

Vegetables

Vegetables have no common biological structure. They are obtained from different parts of many plants. Some vegetables, like cabbage and lettuce, are leaves; others, such as carrots and radishes, are roots; cucumbers and tomatoes are fruits; celery is a stalk; cauliflower is a flower and peas and broad beans are seeds. All vegetables possess some similar nutritional properties. They have a high water content. Many vegetables are good sources of vitamin C, carotene and mineral elements, particularly iron. Root vegetables, with the exception of carrots, are not of any great nutritional value in the diet though like all vegetables they provide fibre. Carrots are an important source of carotene. All root vegetables contain vitamin C but generally not in such large quantities as are found in green vegetables.

Fruits

Fruits, like vegetables, contain a high percentage of water and are low in energy value. Also, like vegetables, they are an important source of indigestible fibre. One of the main differences between fruits and vegetables is in the nature of the carbohydrates present. In general fruits have a higher sugar content than vegetables and ripe fruits contain little or no starch. The sugar in fruit is usually a mixture of glucose and fructose. Fruits also contain a variety of organic acids, in particular citric, malic and tartaric acids. These acids are responsible for the sourness of unripe fruit. During ripening the concentration of these acids falls and that of sugar rises. The main importance of fruit in the diet is as a source of vitamin C. The vitamin C content of many fruits does not compare very favourably with that of vegetables. Dried fruits have a high energy value due to the removal of water but they do not contain any vitamin C.

Applied Nutrition

Nutrient and energy requirements vary according to the age, sex, activity and type of work of the person concerned.

Infants and Young Children: The energy and nutrient requirements of infants and young children. For the first few months of life these requirements are met by a single food, milk. Babies may be either breast-fed or bottle-fed. There are various dried products on the market available for infant feeding; these are based on modified cow's milk. However, there are several advantages of breast feeding. Human milk is the natural food for babies and it contains nutrients in the correct proportions. Cow's milk contains more protein but less fat, lactose and vitamins A and C. There is the possibility that dried milk products may be unhygienically prepared or made up to incorrect concentrations with water. Milk is a satisfactory food for the first few months of life but from about four months, solid foods, such as infant cereal products, should be introduced into the diet. Babies are born with a store of iron which lasts for four to six months. Milk is a poor source of iron, and iron-containing foods, such as pureed fruit and vegetables, egg yolk and minced meat, should be included in the diet at this age. The recommended daily intake of vitamin D for children up to five years is very high and a vitamin D supplement is strongly advised up to five years of age, especially since milk is also a poor source of vitamin D.

School Children: Energy requirements are high in relation to body-weight since children are normally very active and are growing fast. Children should be encouraged to eat sensibly from an early age. Foods such as meat, liver, cheese, bread, potatoes, fruits, vegetables and milk are good sources of many nutrients. Foods such as sweets, potato crisps, sweet biscuits and soft drinks which often displace other more nutritious foods in the diet should be discouraged. In addition, these types of foods encourage tooth decay. Girls during adolescence should be persuaded to eat more of the iron-rich foods since iron losses occur due to menstruation. The school meal is to protect children from any ill effect resulting from poor nutrition. These regulations state that dinners should be suitable as the main meal of the day. The edible portion of food should provide an average of 3680 kJ (880 kcal) and 29 g protein. The meal should provide children with at least

one-third of their daily energy requirement and one-third to one-half of their protein requirement.

Adults: For most women the recommended daily energy intake is 9000 kJ (2150 kcal). For those whose work requires a lot more physical activity 10,500 kJ (2500 kcal) is recommended. In addition to a person's occupation, their leisure time and recreational activities may make very varied demands on their energy needs. It is important that energy intake does not exceed energy needs since this will lead to obesity. People with sedentary occupations are most likely to over-eat.

Women During Pregnancy and Lactation: Energy and nutrient requirements are increased during pregnancy and lactation (breast-feeding). The mother's diet must provide for the laying down of extra tissue in her body and the growth and development of the foetus during pregnancy, and the provision of milk during lactation. Nutrients of particular importance during this period are vitamins C, D and folic acid, together with iron and calcium. The intake of foods rich in these nutrients such as milk, cheese, eggs, fruits and vegetables should be increased to meet these higher requirements. Energy intakes should not be excessive but should be such as to ensure optimum weight gain during pregnancy.

Old People: Elderly people do not need as much energy as younger people since they are less active and since basal metabolic rate declines with age. They need less food but that the food they do eat must be rich in nutrients. Nutritious foods are not necessarily the most expensive or those which need elaborate cooking. Relatively cheap foods which need little preparation include milk (fresh or dried), eggs, cheese, canned fish (e.g. sardines), canned fruit juice, potatoes (fresh or dried), bread and margarine.

Microbiology

Microbiology is the study of microorganisms (microbes). Microorganisms are very small, usually single-celled, organisms which are not individually visible to the naked eye. They can only be seen with the aid of a microscope. They are widely distributed in the environment and are found in foods. If present in food in large enough numbers, can cause food poisoning. Microorganisms are the main cause of food 'going off', i.e. food spoilage. However, not all microorganisms are

undesirable. They are essential to all forms of life since they break down complex organic matter and return nutrients to the soil. Microorganisms are used by man in the production of certain foods, e.g. bread and yoghurt. A microscope made with lenses of sufficiently good quality. Microorganisms in a variety of materials such as teeth scrapings and pond water. In fermentation processes, microorganisms which caused an undesirable sour taste in some wines. A process of heating wine to kill the microorganisms which caused the souring. This process is still used today to kill undesirable organisms in many food products and is known as pasteurisation.

Microorganisms can be classified into five biological types:

- (1) Protozoa
- (2) Algae
- (3) Viruses
- (4) Microscopic fungi—moulds and yeasts
- (5) Bacteria

This list classifies microorganisms according to their structure. It is sometimes more convenient to classify them according to their role in relation to human beings. In this functional classification there are four groups:

Pathogens: These are microorganisms which cause disease. All viruses are pathogenic but only some are pathogenic to man. Certain bacteria also cause disease in man. Some of these diseases can be transmitted by food, e.g. food poisoning, cholera and typhoid.

Spoilage Organisms: These microorganisms do not cause disease but they spoil food by growing in the food and producing substances which alter the colour, texture and odour of the food, making it unfit for human consumption. Examples of food spoilage including the souring of milk, the growth of mould on bread and the rotting of fruits and vegetables.

Beneficial Organisms: Many microorganisms have a beneficial effect. Microorganisms are essential to life since they are responsible for the rotting or decay of organic matter. The complex organic components of dead plants and animals are broken down by microbial activity into simpler, inorganic compounds which are made available for new plant growth, and the whole cycle of life is able

to continue. Microorganisms are used at various stages during the manufacture of certain foods. Their activities are essential in the production of foods such as bread, beer, wine, cheese and yoghurt. Antibiotics, such as penicillin, are substances used to destroy pathogens in the body. Many are produced as a result of microbial activity. For example, penicillin is obtained from a mould called *Penicillium*. Certain microorganisms may be used as concentrated protein foods in the future.

Inert Organisms: Those organisms which are neither harmful nor beneficial to man. Commensals are organisms which live in humans but which do not cause disease in the part of the body where they are normally present. For example, *Streptococcus faecalis* is a bacterium which is harmless in its normal habitat, the large intestine. For eg, *Streptococcus faecalis* causes disease if it infects the kidneys.

Food Poisoning

Food poisoning is an illness caused by eating harmful or contaminated food. The most usual symptoms are stomach pains, vomiting and diarrhoea. Food which can cause food poisoning may appear harmless, i.e. the colour, taste and appearance are normal and there is no evidence of spoilage. If food spoilage occurs, the food is unpalatable because the colour, taste and appearance have been changed, although the food may be completely harmless. There are three types of food poisoning: 1. Chemical, 2. Biological, 3. Bacterial.

Chemical Food Poisoning: Chemical food poisoning is caused by the presence of toxic chemicals in food. These substances may be agricultural chemicals, which are used intentionally in crop production. The use of weed-killers and insecticides is essential to ensure good yields. Some of these substances may be dangerous if used indiscriminately, since they may be toxic if they are consumed in large doses. Small quantities do not usually accumulate in the body causing harmful effects. Poisoning may also be caused by the accumulation of certain metals (e.g. lead, mercury and cadmium) in the body. High levels of mercury and cadmium have been found in fish taken from waters polluted by industrial waste. Cases of lead

poisoning have arisen as a result of drinking water that has passed through lead pipes.

Biological Food Poisoning: Biological food poisoning is caused by eating plants containing naturally occurring substances which are harmful. There are many species of poisonous mushrooms, such as *Amanita phalloides*, which have caused illness and in some cases death. These mushrooms are very similar in appearance to the edible variety and may easily be eaten by mistake. All parts of the plant contain the drug belladonna, which is sometimes used in medicine to relieve illnesses such as asthma, bronchitis and heart disease.

Bacterial food poisoning: Bacterial food poisoning is the most common cause of food poisoning and stringent hygiene precautions must be taken in order to prevent outbreaks of this type of illness. There are three main types of bacterial food poisoning:

1. The infective type which is caused by eating food containing a large number of living bacteria. After being eaten the bacteria establish themselves in the alimentary canal and when they die they release an endotoxin.
2. The toxin type which is caused by eating food containing an exotoxin. The toxin is released into the food while the bacteria are growing and multiplying in the food. The bacteria themselves may be dead when the food is eaten.
3. The third type is also caused by a toxin. The toxin is not produced in the food but is released into the alimentary canal after the bacteria have been eaten and while they are growing in the alimentary canal.

Prevention of food poisoning

To prevent food poisoning strict standards of hygiene must be maintained. It is also aesthetically pleasing if food is prepared under hygienic conditions. The main aims of food hygiene are:

- (1) To prevent food becoming contaminated with food poisoning bacteria.
- (2) To prevent the multiplication of any food poisoning bacteria which do get into food.

Food poisoning bacteria come from three sources.

- 1. The food handlers:** Staphylococcus aureus, Salmonella and Clostridium perfringens may all be carried by personnel involved in food preparation.
- 2. The environment:** The spores of Clostridium perfringens and Bacillus cereus may be found in dust in food-preparation rooms. Also, all types of food-poisoning bacteria may be spread by cross-contamination.
- 3. The food:** The food itself may contain food-poisoning bacteria when it is brought into the kitchen or the bacteria may enter the food due to faulty handling during preparation.

Food Spoilage

All food was once living tissue and is of organic origin. Some foods, such as meat and fish, are killed before being distributed to the consumer. Other foods, such as fruits and vegetables, may be stored and distributed in the living state. Because of its organic nature, food is susceptible to deterioration or spoilage by saprophytic and parasitic microorganisms. When food spoilage takes place, two distinct processes are involved.

- 1. Autolysis:** The autolysis means self-destruction and is used to describe the cellular breakdown caused by enzymes contained within the food itself. This breakdown starts immediately after slaughter or harvest. In many instances a limited amount of enzyme activity may be beneficial; for example, in the ripening of fruit and the tenderisation of meat.
- 2. Microbial spoilage:** Once the cellular structure becomes disorganised, the food is vulnerable to attack by microorganisms. The main agents of microbial spoilage are bacteria, moulds and yeasts. These organisms break down the complex organic components of the food into simpler compounds and so cause alterations in the flavour, texture, colour and smell of the food.

Food Preservation

The main aims of food preservation are to prevent autolysis and microbial growth. Preservation may be short-term or long-term and may be achieved in a variety of ways. Blanching food in order to inactivate enzymes and prevent autolysis may be regarded as a short-term means of preservation. Cooking food has the same effect and also destroys some microorganisms; it is also a short-term method. In any method of preservation involving the use of heat to destroy microorganisms can be assumed that most enzymes will be inactivated. Long-term methods of preservation usually involve the removal of more than one of the requirements necessary for growth. A method of destruction of microorganisms, e.g. heating, is sometimes involved in the process. The food preservation methods are:

- (1) Heat Treatment (heat sterilisation, pasteurisation)
- (2) Freezing
- (3) Dehydration
- (4) Addition of Chemical Inhibitors

Assignment for FTech-302 Food Engineering

Supercritical fluid extraction

Supercritical fluid extraction (SFE) is a separation method that is based on the same basic principle with the more conventional separation processes of distillation and liquid solvent extraction, that is, they exploit phase equilibrium behavior between different states of matter at different operating conditions. SFE is a typical solvent extraction with the basic difference to be that the supercritical (SC) solvent undergoes a change of state prior to the extraction process and changes the state again after the end of the process. SFE takes advantage of the high dissolving ability of supercritical fluids (SCFs) under specific temperature and pressure conditions. SFE processes using CO₂ are advantageous compared to distillation processes, for example, in food, pharmaceutical, and cosmetic industries, when thermolabile compounds with low vapor pressures have to be separated.

The main reasons that gave a significant boost to the use of benign solvents, such as SCCO₂, are

- The high increase of the energy costs made traditional energy-intensive separation methods such as distillation, very expensive, and turned the interest toward others, which require less energy, such as SFE.
- The new health regulations and prohibitions imposed on the use of classical industrial solvents, and the new stricter environmental regulations for the treatment and disposal of industrial wastes, have led to growing interest in the potential uses of CO₂ as a nontoxic solvent.
- The increasing consumer awareness of the identity and use of chemical solvents in food and natural products.

Some Basic Properties of SCFs

The most common SCFs along with their critical properties— temperature and critical pressure. The following are observed:

- Most hydrocarbons have P_c close to 50 atm.
- Critical temperatures of light hydrocarbons, such as ethylene and ethane, are close to that of the ambient temperature, while those of the cyclic and aromatic hydrocarbons are much larger.
- Carbon dioxide has a low T_c , while P_c is somewhat higher.
- Ammonia and water have a high T_c and P_c , because of their polarity and hydrogen bonding.

The most attractive and commonly used SCF at laboratory, pilot, and industrial scale is CO_2 . It is a low-cost fluid, widely abundant in pure form, nonflammable, not toxic and environmentally friendly. The critical point of CO_2 allows operations at moderate temperatures (typically 40–70°C) and accessible pressures; the maximum operating pressure is usually set at 300 bar for the most current applications. The use of CO_2 avoids various problems of classical separation techniques such as distillation and liquid extraction, are avoided; problems such as (a) recycling and disposal of organic solvents, and (b) chemical and thermal deterioration of the product obtained when high temperatures and/or organic solvents are employed. Another widely used SCF is water, despite its high values of T_c and P_c and the corrosive properties in some cases. Generally, water is a common solvent with many applications because of its nontoxicity. In SC conditions, water acquires some interesting properties. A liquid it exhibits a strong polar character, as an SCF it behaves almost like a nonpolar substance, while its acidity increases. This is because of the phenomenon of splitting into ions in the region near and above its critical point. Water presents better solvating capacity. These properties coupled with the fact that they can be modified by small changes in pressure and temperature, allow the use of SC water as (a) solvent in separation processes (usually it is used at SC pressures, but at temperature less than its critical one; so, it is characterized as superheated water), (b) solvent in chemical reactions, which is the most common application, and (c) as acid catalyst in processes such as oxidation of organic toxic substances.

Solubility Measurements in SCFs

Solubility of the solute in the SC solvent is determined by measuring the amount of solute in the solution, giving the result in terms of mass fraction or mole fraction. Extensive reviews of experimental solubilities of solid and liquids in SCFs. Two main methods for measuring the solubility of substances in SCFs exist, the static method and the dynamic method.

In the static method, equilibrium state between the solute and the solvent is achieved before any sample is taken out to analyze the solubility. Static method carries out the equilibrium process that include recirculation of the solvent, agitation by the magnetic stirrer, or simply trapping the solvent in the equilibrium cell for some time. Quantities of the substance to be dissolved and the SCF are fed to the desired pressure in a thermostated cell. The pressure is adjusted with an appropriate device and the whole system is agitated using a magnetic stirrer. The cell has an appropriate sapphire window through which it is possible to observe the phenomena within the cell with the help of a camera.

In the dynamic method, the solute that is the condensed phase remains in an equilibrium cell, while the SCF flows through the cell continuously. SCF is contacted with the solute and equilibrium is achieved during the residence time of the SCF in the equilibrium cell. Then, the equilibrated solution is extracted and its equilibrium concentration is determined. A sample of the solute is placed into an extraction cup with a porous bottom and top lid. The cup is placed into the extractor, which is located inside the oven of the apparatus. When the system is being charged by means of a fluid pump, the carbon dioxide flows from the loop control valve through the recirculation pump and a six-port valve into the extractor, which is loaded with the solute. Once the desired pressure level has been reached, the extraction loop is isolated from the carbon dioxide supply tank, the recirculation pump is activated, and the fluid is allowed to flow through the closed loop. The progress of the extraction process is monitored by a detector, for example, a UV detector. When the absorbance reading becomes constant with time, the equilibrium between the solute and the gaseous phase has been reached. The injection of the sample extract, which is trapped inside a fixed volume sample loop, into the analysis system, for example, a high-performance liquid chromatography (HPLC) column, is accomplished using a six-port injection

valve and an eight-port valve connected in tandem and controlled by a microprocessor.

Solvent Selectivity and CO-Solvent Effect

One of the major advantages of SCFs is their selectivity, which can be defined as the ability of a solvent to dissolve the desired compound to a greater extent than the other constituents of the mixtures. For example, from a mixture of benzoic acid and p-hydroxybenzoic acid, SCCO_2 prefers to dissolve benzoic acid at concentrations of about 1000 times greater than those of p-hydroxybenzoic acid. The selection of a suitable solvent is very important for the effective separation of a mixture with SFE. A significant increase of a compound solubility in an SCF may be achieved with the use of cosolvents, which are usually low-molecular-weight volatile compounds that are added to the SCF in small amounts, ca. up to 5% mole. The cosolvent effect is due to the strong interactions with the molecules of the solute, which results in a smaller quantity of the SCF needed for the extraction and less energy for the SFE process.

Phase Equilibrium in SCFs

The design and optimization of SCF processes require the accurate knowledge of the solubility of the high-boiling compound in the SCF as a function of pressure and temperature. Of course, a comprehensive database with experimental solubility data would be desirable to fix optimal process conditions, for example, which gas or gas mixture provides the best solvent properties, which are the optimal temperature and pressure conditions, which cosolvent is most suitable for improving the solubility and selectivity, and so on. Unfortunately, the number of reliable experimental data is very limited. The reliable measurement of the solubility of solids or high-boiling liquids in an SCF at high pressures requires sophisticated expensive experimental techniques. It is not possible to measure all the required solubilities for the various solutes in the different SCFs for a wide range of temperatures and pressures with and without cosolvents, thermodynamic models are applied. The calculation of the fugacities depends on

the phases involved. Three different cases of binary phase equilibrium in SCFs are considered :

- (a) between an SCF and a solid phase, that is, solid–gas (SG) equilibrium,
- (b) between an SCF and a liquid phase, that is, gas–liquid (GL) equilibrium, and
- (c) the three-phase equilibrium between an SCF, a solid, and a liquid phase, that is, solid–liquid–gas (SLG) equilibrium.

SCF Processing Schemes

(1) Supercritical Fluid Extraction

SFE is one of the most widespread applications of SCFs, which is mainly applied in the food industry and also in the pharmaceutical and cosmetic industries. On the basis of the specific properties of SCFs, SFE process presents some important characteristic features, which are summarized below:

- Operating temperatures are close to the solvent critical temperature. Therefore, high-boiling, heat-sensitive components may be extracted at relatively low temperatures. So, SFE is suitable for processing thermolabile substances such as essential oils, antioxidants, and generally bioactive compounds, whose recovery by conventional methods is difficult or impossible because they cause decomposition, denaturation, or loss of the active properties of the compounds. The low temperature involved leads to low-energy consumption as compared, for example, with the high energy demanding distillation.
- The selectivity and capacity of the process may be changed by varying the operating conditions, namely temperature and pressure, as well as the choice of solvent and/or the use of cosolvent.
- The recovery of the solute is accomplished in a simple depressurization/precipitation step, which is a distinct advantage over liquid extraction.
- Solute fractionation is possible.
- Solvents such as CO₂ are cheap, abundant, nontoxic, noncorrosive, non-flammable, and avoid environmental problems.

The SFE process mainly using CO₂ has found various applications in the food industry. SFE has been used in many fields of the food industry: extraction of cholesterol and other lipids from egg yolk, milk fat fractionation, extraction of lipids and cholesterol from meat and meat products, extraction of lipids and cholesterol from fish, extraction of natural colorings from foodstuffs, extraction–refining and fractionation of oils and vegetable fats, extraction and fractionation of natural flavorings, and extraction of antioxidants.

(2) Supercritical Fluid Fractionation

Fractionation of liquid mixtures with SC carbon dioxide in countercurrent columns is a process of the same family of extraction. This process generally operates in continuous mode with carbon dioxide as the solvent, with a cosolvent added to increase its polarity. This represents a big advantage over extraction from solids, which is usually carried out in batch or in a semicontinuous mode. Fractionation with high-pressure carbon dioxide may be ideal for difficult separations in liquid mixtures. It has been applied for various separations of valuable substances from natural products, such as vegetable food oils, fish oils, wine and beer, and so on. The feed is continuously fed to the fractionation column filled with a packing for ensuring a better contact between the two phases; the SCF is introduced through a sintered disk or perforated plate at the bottom of the column. Extract reflux must be applied when a high selectivity of the process is required. The extract exits at the top of the column and is partly depressurized and reheated to cause extract precipitation and collection through gravity or cyclonic separators. Extracts can be recovered through a series of pressure locks working alternatively, avoiding fluid losses and pressure variation upward in the column. The liquid raffinate exits at the bottom of the column through a valve controlled by a level gauge located at a place chosen by the operator to settle the liquid–fluid interface (generally in the bottom head of the column). To avoid significant fluctuation of pressure inside the column, raffinate can be depressurized using a series of two or three settlers maintained at decreasing pressures, where part of the entrained fluid dissolved in the raffinate is being recovered and recycled. The fluid is recycled according to the classical way. Finally, in certain cases where part of the extract is a very volatile compound or mixture, it is necessary to trap these light ends by adsorption on an adsorbent bed. The

adsorbate can be later recovered by SFE. When operating two parallel adsorbent beds, this can be conducted periodically without stopping the main SFF operation.

(3) Particle Design with SCFs

Except for the most common applications of SCFs in extraction and/or fractionation, particle formation processes using SCFs are now subjected to an increasing interest especially in the pharmaceutical and food industries. These processes mainly aim to increase bioavailability of poorly soluble molecules and to design sustained-release formulations. Several techniques have been proposed and investigated to produce particles from SCFs. Generally, the three following basic techniques are distinguished.

(i) Rapid Expansion of Supercritical Solutions: In the RESS technique, the substance is first dissolved in a SC solvent, after which the pressure is rapidly decreased in a specifically designed nozzle, resulting in supersaturation of the substance in the SC solvent and leading to the formation of small particles with a narrow particle size distribution.

(ii) Supercritical Antisolvent: In the SAS technique, the solid is dissolved in a conventional solvent and the solution is sprayed continuously through a nozzle into the SCF. The dispersion of solution in the SCF leads to an expansion of the droplets and at the same time, an extraction of the liquid into the fluid occurs. The solvent power of the conventional solvent decreases dramatically and supersaturation leads to the precipitation of particles.

(iii) Particle Generation from Supercritical Solutions or Suspensions: This process allows the formation of particles from substances that are insoluble in an SCF, but absorb a large amount of gas that either swells the substance or decreases its melting point (for polymers the glass transition temperature). In the PGSS technique, a saturated liquid solution or suspension of high-boiling substances with compressed gases is rapidly expanded at ambient pressure.

Safety and Scale-Up Issues

SCF technology may be potentially hazardous and should not be used without proper safety precautions that must be taken into account at every stage of process design and operation, that is, in equipment design, building and installation, operation, inspection, and maintenance. The main hazards associated with SCF applications are mechanical and chemical hazards. Industrial production on high-pressure equipment requires high reliability with drastic safety requirements as mechanical hazards, such as metal fatigue or brittle fracture, which must be eliminated. This requires a preventative maintenance, as many parts must be inspected and changed periodically. A rigorous operation plan must be enforced to eliminate any risk of deterioration of the basic parts, and safety sensors must be continuously logged. Maintenance mainly concerns the high-pressure pumps, autoclaves, and baskets to avoid solvent bypass or sintered disks to detect deformation prior to rupture due to plugging. Pressure vessels must be inspected and submitted to pressure tests according to official standards. The main process valves must be often checked, as they are the key of safe operation during autoclave opening for raw material change. Sensors must be recalibrated periodically, in comparison with traceable reference sensors, and data logging validated. Chemical hazards associated with SCF applications are particularly important when using flammable SCFs or cosolvents, which are used to increase SCF polarity and can be flammable or environmentally hazardous. A very important remark concerning safety issues is that operators must be trained by specialists prior to work on SCF equipment. SFE and SFF processes have proven to be technically and economically feasible, and they have been implemented at a large industrial scale. SFE and SFF, it is important to establish a methodology that allows predicting the behavior of the process at an industrial scale from laboratory or pilot unit data, considering the differences encountered in processes conducted in the equipment of significantly different sizes. For SFE, scale-up criteria include kinetic parameters such as solvent residence time and superficial velocity, empirical equations based on the bed's geometry, and the use of mathematical models. When using scale-up criteria, it is necessary to assess their applicability to different types of raw materials, since the mass transfer mechanisms may differ among species and parts of the raw material used for extraction. SFF industrial units are usually operated continuously in countercurrent columns. The methods used to design these types of columns are not essentially different from those for

a standard liquid–liquid extraction unit, where the concept of using the theoretical or equilibrium stage. The number of theoretical stages necessary to perform a certain separation can be calculated from phase equilibrium data alone. Although mass transfer and capacity of the column are also to be considered to obtain the actual size of a separation device, knowledge of relevant phase equilibrium ratios is a prerequisite in a design calculation.

Chilling and Freezing

Food preservation at low temperatures has been applied since ancient times. Chilling or refrigeration has been widely used in household and industrial applications (transportation, distribution, and retailing) to prolong the shelf life of perishable foods, especially meat, fish, dairy products, fruit, vegetables, and ready-made meals. Chilling is to be a minimal processing method and concerns storage at temperatures above the freezing temperature and below 15°C. Chilled foods will lose value or will be destroyed if frozen. Its purpose is to slow down :

- The activity of microorganisms and enzymes
- The postharvest and postslaughter metabolic activities of plant and animal tissues, respectively
- The deteriorative chemical (e.g., oxidation, Maillard browning, and formation of off-flavors) and biochemical reactions (e.g., glycolysis, proteolysis, enzymatic browning, and lipolysis)
- Moisture loss or other physical changes resulting from the interaction of food components with the environment

Chilling, is also used for non-preservative purposes, such as crystallization, aging of meat, wine, and cheese, or to facilitate operations such as pitting of cherries and peaches, cutting of meat, and slicing of bread.

Precooling

Good temperature management throughout the “field to fork” chain is the key for the preservation of quality. Precooling of most produce to a “safe” temperature is imperative in ensuring quality and increasing shelf life.

Chilling

Following precooling, it is important that the cold chain of the fresh product is maintained throughout transportation, storage, and preferably during retailing and domestic use. Road and sea containers are refrigerated, as are the storage units at exporters, importers, and retail distribution centers. Air freight is rarely cooled and relies on adequate precooling, good pack insulation, and the speed of transport to maintain adequate quality.

Cooling can be divided into two distinct phases,

- (i) the chilling operation itself, in which the foodstuff is cooled from either an ambient temperature or a cooking temperature of over 70°C, and
- (ii) the chilled storage, at a closely controlled temperature of between 15°C and -2°C, depending on the foodstuff.

Chilling equipment and chilled storage equipment are quite different in their requirements and their design, and although some chilling equipment may be used for chilled storage, storage equipment is not designed to cool products, only to maintain temperature.

The main objectives of chilled storage are:

- To extend the availability of fresh produce in the market,
- To ensure continuous supply of quality raw material to the processors,
- To extend the length of the processing season,
- To hold raw material obtained during favorable price situations,
- To condition certain commodities such as potatoes, onions, and garlic, and
- To ripen certain fruits such as mangoes and bananas.

Chilled foods can be grouped into three major categories according to their storage temperature range as follows:

(1) -1°C to 1°C (fresh fish, meats, sausages and ground meats, smoked meats, and breaded fish).

(2) $0-5^{\circ}\text{C}$ (pasteurized canned meat, milk, cream, yogurt, prepared salads, sandwiches, baked goods, fresh pasta, fresh soups and sauces, pizzas, pastries, and unbaked dough).

(3) $0-8^{\circ}\text{C}$ (fully cooked meats and fish pies, cooked or uncooked cured meats, butter, margarine, hard cheese, cooked rice, fruit juices, and soft fruits).

Chilling Effect on Microorganisms

Microbial growth in foods results in food spoilage with the development of undesirable sensory characteristics and off-flavors, and in certain cases, the food may become unsafe for consumption. The pathogenicity of certain microorganisms is a major safety concern in the processing and handling of foods in that they produce chemicals in foods that are toxic to humans. The activities of microorganisms, including growth are greatly affected by the chemical and physical state of their environment. Several factors can potentially affect the growth of microorganisms (e.g., pressure, radiation, or presence of inhibitors/competing microorganisms), temperature, pH levels, water availability, and oxygen are considered the key elements that control the growth of all microorganisms. Temperature is probably the most important environmental factor.

Chilling prevents the growth of thermophilic and many mesophilic microorganisms; the latter may become a problem in situations of temperature abuse. The psychotropic or psychrophilic microorganisms are able to grow at commercial refrigeration temperatures and can cause off-flavors and physical defects in foods. The psychotropic organisms have a rapid growth above 0°C . They grow slowly up to about -10°C , below which there exists little or no growth. In fact, there can even be a slow death at temperatures below -10°C . The activity of organisms of public health concern, such as those producing toxins, is largely limited below 4°C . Psychotrops include molds, yeasts.

Chilling Effect on Plant Tissues

Fruits are commonly derived from an ovary and the surrounding parts, while vegetables are derived from different plant parts. Vegetables can be grouped into three categories, namely: (1) seeds and pods; (2) bulbs, roots, and tubers; and (3) flowers, buds, stems, and leaves.

Plant foods, during harvest, are cut off from their normal supply of water, minerals, and organic matter, which is normally translocated to them from other parts of the plant. The tissues, however, remain alive and are capable of continuing a wide range of metabolic activities, breaking down the organic matter to meet their energy requirements. Since the stored food is not replaced, senescence (progressive loss of membrane integrity) follows and the produce will eventually decay. Immature products such as peas and beans tend to have much higher respiration rates and short shelf lives caused by natural senescence whereas the opposite is true for mature storage organs such as potatoes and onions. Since oxygen is necessary for the respiration of fruits and vegetables, their storage life can be extended considerably by modifying the atmosphere in the cold-storage rooms. This can be accomplished for certain plant tissues by reducing the oxygen level from 1% to 5% while increasing the CO₂ level.

Temperature reduction in fruits and vegetables is commonly used to slow the rate of aerobic respiration, thus delaying senescence and decay of plant tissues, and enables some fruits to be ripened at controlled rates. To achieve a maximum storage life of plant tissues at chilling temperatures, it is desirable that (1) aerobic respiration must be allowed at a slow rate so that the maintenance processes associated with life continue to function and the natural protective coating, which hinders invasion of microorganisms, remains intact and (2) the temperature must be suitably low so that major deteriorative reactions are slowed as much as possible.

Fruits and vegetables are particularly sensitive to temperature variations during handling and storage. Injury from temperature effects is caused by exposing the produce to extremes of temperature during postharvest handling. Heat injury is sustained by produce due to exposure to the sun after harvest, or with any warm surface such as the soil or a wall heated by the sun. Weight loss, softening, discoloration, and eventual desiccation of the affected tissue are its

most common effects. Undesirable changes may also occur when the temperature is reduced below a specific optimum for the individual fruit. This is termed chilling injury and results in various physiological changes including water-soaked appearance, surface and internal discoloration, pitting, failure to ripen, uneven ripening, development of off-flavors, and heightened susceptibility to pathogen attack.

There are 10 visual symptoms associated with chilling injury, namely:

- 1) Surface lesions—Pitting, large sunken areas, and discoloration
- 2) Water soaking of tissues—Disruption of cell structure and the accompanying release of substrates favoring growth of pathogens
- 3) Internal discoloration or browning of pulp, vascular strands, and seeds
- 4) Breakdown of tissues
- 5) Failure of fruits to ripen following removal from storage
- 6) Accelerated rate of senescence
- 7) Increased susceptibility to decay
- 8) Shortened shelf life due to one or more of the above responses
- 9) Compositional changes related to flavor and taste
- 10) Loss of growth capacity for stored propagules

The factors influencing the shelf life of plant tissues during chill storage are:

- Produce type, variety, or cultivar
- The part of the crop selected (the fastest growing parts have the highest metabolic rates and the shortest storage lives)
- Food's status during harvesting (e.g., integrity/mechanical damage, microbial contamination, infestation of pests and diseases, and degree of maturity)
- The temperature of harvest, storage, distribution, and retail display

- The relative humidity of the storage atmosphere, which influences dehydration losses.

Chilling Effect on Animal Tissues

(1) Red Meat and Poultry

After an animal is slaughtered, blood circulation stops within the body and muscles lose their oxygen supply necessary for normal aerobic respiration ($\text{glucose} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{energy}$). Without oxygen, the muscle turns to anaerobic glycolysis ($\text{glycogen} \rightarrow \text{glucose} \rightarrow \text{lactic acid} + \text{energy}$) to generate energy. Anaerobic glycolysis produces energy to contract the muscle and it also produces lactic acid, which causes the muscle pH to fall from a physiological value ($\text{pH} \approx 7$) to an ultimate value ranging from 5.1 to 6.5.

The main factors that affect the shelf life of meat are microbial growth and deleterious chemical reactions. Although the internal musculature of a healthy animal is essentially sterile after slaughter, due to the continued post-slaughter functioning of the immune system, all meat animals carry large numbers of different microorganisms on the outer surfaces of the body and in the alimentary tract. Meat animal carcasses and meat cuts can also be easily contaminated during slaughtering, dressing, chilling, and cutting processes when the muscles of animals are exposed to the environment. Contamination may vary depending on the characteristics of each animal, its geographic origin and the season of the year, as well as the sanitation and hygienic practices during the products' handling and processing. Meat may support growth and serve as sources of various spoilage and pathogenic microorganisms. Lipid oxidation is the main chemical reaction responsible for quality deterioration and shelf-life reduction in meat and meat products. The susceptibility of different meat species depends on the level of unsaturated fatty acids in the tissue, their availability, and the presence of activators or inhibitors. Fish tissue is most affected, followed by poultry, pork, beef, and lamb.

Animal tissues have been preserved in a variety of ways, with the most common methods being drying, curing, smoking, heat processing, fermentation, irradiation, canning, packaging, and refrigeration. Of all these alternatives, refrigeration has the key benefit (along with irradiation, to some extent) in that it leaves the form of the meat product almost unchanged and almost

indistinguishable from the original fresh product. By cooling the meat from the initial body temperature of the animal (about 38°C) to 10°C, the microbial growth rate drops by about 95%. The lowest cold-storage temperature for meat is –1.5°C while the minimum growth temperature of psychotropic bacteria is –3°C.

Decreasing refrigeration temperatures decrease growth of spoilage microorganisms, and affect the composition of the bacterial flora. Moisture lost during chilling also tends to decrease microbial growth as a result of reduced surface water activity (a_w). Refrigeration is also effective in reducing deterioration due to chemical reactions. When meat is chilled at temperatures below 10°C (especially between 0°C and 5°C), before rigor mortis has occurred (at pH > 6.2), the excised muscles will contract, resulting in poor water-holding capacity and undesirable changes to its texture. This phenomenon, known as “cold shortening,” entails hardening of meat and has been attributed to the negative impact of low chilling temperatures on the ability of the sarcoplasmic reticulum to regulate the distribution of calcium ions in muscles. Cold shortening has been extensively observed at prerigor excised muscle from poultry, beef, and lamb, while pork does not seem to be significantly affected. It is essential to subsequently chill meat quick enough to ensure that bacterial growth remains to the minimum, and slow enough to encourage mild respiration for aging to take place and prevent cold shortening.

(2) Fish and Seafood

Fish is recognized as one of the most perishable food products and its rate of spoilage increases with contamination or damage to fish tissue during catching, transport, and processing. As with red meat and poultry, several changes take place shortly after the catch of fish and other seafood, affecting their quality. The quality of fishery products is primarily influenced by both intrinsic (species, size, sex, composition, spawning, viruses and parasites potential, and cultivation conditions) and extrinsic factors (location, season and methods of catch, on-board handling, and storage conditions). Environmental conditions, such as temperature, relative humidity, as well as direct exposure to sunlight and airflow induce the rate of quality deterioration and spoilage. By far, temperature is the most influential factor affecting the physiological and biochemical processes associated with tissue degradation. Fish and seafood, being high-water-content foods, are maintained better under conditions of high relative humidity. Excessive airflow around fresh

fish should also be avoided as it contributes to the loss of surface moisture and undesirable changes in the skin and flesh quality. Mechanical handling can result in physical injury, such as bruises, cuts, and abrasion, affecting both appearance and creating a favorable substrate for contamination. Immediate gutting of fish removes a major reservoir of microbial contamination; it exposes internal surfaces to rapid spoilage. Filleting also exposes fish to microorganisms, enzymes, and oxygen, altering and accelerating spoilage. Deteriorative changes in fish and seafood are mainly attributed, at first, to autolytic enzymatic reactions and then followed by the action of microbial enzymes and the growth of microorganisms, eventually leading to fish spoilage. All these factors make refrigeration of fresh fish and fish products critical for maintaining their quality. Chilling can slow down biochemical reactions and microbial growth, reduce mass losses, and maintain the associated quality aspects of fish. Rapid cooling and storing of fish, close to 0°C, are the most recommended conditions to reduce the deterioration rates and extend shelf life.

A wide range of physical/chemical treatments have also been proposed by researchers for extending the shelf life of fish. These include electrical stimulation, decontamination with phosphate, hydrogen peroxide, chlorine, chlorine dioxide and ozone, surface treatment by organic acids, and the use of sorbate or sulfite. Coatings or films are finding increasing applications as well, as protective barriers against contact with air and water, delaying product deterioration during cold storage. Some are reported to additionally have antimicrobial, binding, and texturizing properties.

Chilling Effect on Processed Foods

Chilled foods were introduced in commercial catering and the retail food sector to satisfy the increasing consumers demand for fresh-like, convenience products with superior sensorial and nutritional quality, less/no preservatives, and environmental friendly packaging. The microbiological safety and quality of cook-chilled products, due to their

1. Formulation, containing little or no preservatives and having a low acid and high moisture (high a_w) content

2. Minimal thermal processing 3. Packaging, which provides a favorable environment for anaerobic pathogens to grow and produce toxins.

Their production relies on cook–chill or cook–pasteurize–chill processes under the combination of minimal processing (65–100°C) and storage under controlled chill conditions to prevent the growth of pathogenic organisms. It includes pasteurizing (in cook–pasteurize–chill products) to a minimum temperature of 80°C for 10 min at the thermal center, rapidly cooling, and holding food under chilled conditions (0–3°C), before reheating and consumption.

Class of food products may require different handling and safety/hygiene precautions. The shelf life of chilled processed foods is determined by

- The type of food
- The degree of microbial destruction or enzyme inactivation achieved during processing
- Packaging characteristics/properties
- Temperature conditions during processing, distribution, and storage

Freezing

Freezing is one of the ancient methods of preservation, but its commercialization took place later than canning due to the lack of commercial refrigeration equipment. Freezing is a process of removing heat from a product, to bring down its temperature below its freezing point, accompanied by a phase change from water to ice. The common frozen storage temperature is –18°C or 0°F. There are two main factors that make freezing an appropriate preservation method. The first factor is related to the role of temperature in food stability. It is well established that reducing temperature leads to reduced rates of degradation phenomena and quality changes, thus stabilizing product quality. The second important factor is the change of water to ice, which implies the decrease of the concentration of the unfrozen phase. The liquid water promotes the microbiological, enzymatic, and chemical activity in the stored foods, reducing its storage life. The freezing of water to ice basically puts a stop to most of these activities. The freezing of food is a complicated procedure that involves a variety

of phenomena (thermodynamic, kinetic, etc.) and leads to more stable products with different properties.

Freezing Process

During the freezing process, food undergoes three successive stages: the pre-freezing period, the freezing stage, and the temperature decrease to the final storage temperature. In the first pre-freezing process, there will be an initial drop in the temperature of the product until it reaches its initial freezing point, where the sensible heat of the product is removed. The temperature of the product remains relatively steady as the latent heat is removed. At the final stage of deep freezing, the sensible heat of ice and that of the nonfrozen phase are removed until the final storage temperature is reached. At the same time, an amount of the latent heat is removed due to the freezing of additional water as a result of the decreasing temperature. Freezing includes two successive processes when water is transformed in ice: the nucleation (formation of ice crystals) and the subsequent increase of the size of these crystals (crystal growth).

Nucleation: Thermodynamics describes the equilibrium between a liquid and a solid phase. When ice and water coexist at atmospheric pressure, the temperature of the system reaches the freezing point of pure water ($T_f = 0^\circ\text{C}$) and the amount of ice remains constant while no energy is either added or removed. Nucleation can then be described as the process by which a minimum crystal is formed with a critical radius that can then expand and grow. Nucleation can either occur spontaneously (homogeneous nucleation) in water free from all impurities or it can take place on a foreign catalytic center (heterogeneous nucleation) when water molecules aggregate in a crystalline arrangement on nucleating agents such as active surfaces; this type of nucleation predominates in food systems. Homogeneous nucleation requires a higher supercooling than heterogeneous nucleation, and it practically does not take place until a temperature approaching -40°C is reached.

Crystal Growth (Propagation): Crystal growth can begin at temperatures just below the freezing point. At temperatures near the freezing point, crystal growth is favored to the creation of more nuclei. So, the small number of nuclei formed around the heterogeneous materials will begin to grow in size under these conditions. As the temperature is lowered, the rate of crystal growth increases.

But at lower temperatures, nucleation overtakes crystal growth, with the result of many more tiny nuclei being formed before they begin to agglomerate into larger sizes.

Freezing Rate

The location, number, and size of the ice crystals formed determine the resulting texture of the frozen–thawed product. When the rate of heat removal is low, water can transfer from the interior of the cell fast, and the cell dehydrates, with water being incorporated into the external ice crystals. The freezing rate, there are other factors that influence the quality of the final frozen–thawed product. Fast freezing procedures to attain the formation of numerous tiny nuclei in preference to larger nuclei, if the subsequent storage conditions are not the proper ones (large temperature fluctuations), these tiny ice crystals undergo recrystallization, and tend to merge, resulting in larger crystals with the result being that the advantage of fast freezing is lost. Therefore, appropriate temperature conditions during storage are as important as the freezing process itself.

Modeling of Food Freezing

Thermodynamics of Phase Change

The thermodynamics of food freezing are related to the changes in water within a food product as the freezing process proceeds. Freezing of a food tissue is different from that of pure water in two important points: first, the temperature at which the initial ice crystals are formed is depressed below the temperature at which ice crystals begin to form in pure water (supercooling). The second differentiation is the gradual removal of latent heat of fusion as the product temperature decreases, giving a different shape to the freezing curve of food materials in comparison to that of pure water.

Thermophysical Properties of Frozen Foods

When considering the freezing process, the most important properties include density, thermal conductivity, specific heat, enthalpy, latent heat, thermal diffusivity, and freezing point.

Freezing Point: The equilibrium or initial freezing point is one of the most important physical properties of a food material because thermophysical properties change dramatically at the initial freezing point. The initial freezing point is required for the prediction of thermophysical properties of frozen foods. A freezing curve can be used to determine an initial freezing point for a food material.

Density: The overall influence of freezing on food density is relatively small, but an important change occurs just below the freezing point temperature. Above this temperature, the product density can be considered as constant. At the freezing point, as the freezing process proceeds, the fraction of frozen water in the product increases and the product density decreases rapidly. The volume changes associated with foods undergoing freezing are smaller than that associated with water. First, frozen food contains other components that reduce the weight percent of available water in the food. It is only water that is mostly responsible for expansion, the expansion will be much less when compared to that of pure water. Second, a certain fraction of water present in foods always remains as liquid water, which does not expand. And finally, there are several factors in the system (ice crystals, fat, and other components) that contract as temperature is lowered. Hence, the volume contracts as the temperature of the frozen product is lowered, which causes the density to increase.

Heat Capacity: Heat capacity is the heat required to raise the temperature of a unit mass of water by a unit of temperature [$C_p = Q/(m\Delta T)$]. The heat capacity of foods can generally be estimated based on the concentration of their components.

Enthalpy: Enthalpy is the heat content per unit mass of a food material with typical units of J/kg. Since it is difficult to define the absolute value of enthalpy, a zero value is usually arbitrarily defined at -40°C , 0°C , or any other convenient temperature. It is very convenient to use enthalpy for quantifying energy in frozen foods because it is difficult to separate latent and sensible heats in frozen foods as some unfrozen water exists in the foods even at very low temperature.

Thermal Conductivity: The thermal conductivity of a food product depends on water content and its structure. The thermal conductivity of ice is about 4 times that of water. The thermal conductivity of ice increases at lower temperatures.

Like heat capacity, thermal conductivity varies with temperature as with heat capacity, the thermal conductivity of foods is usually estimated based on its composition, and do not account for structural issues. To estimate the values of the thermal conductivity of frozen foods, some assumptions and approximations must be made about the structure of the food and the disposition of the various components dispersed in the food, including any air spaces in porous foods, and the direction (parallel or perpendicular) of heat flow relative to the layers of the components.

Thermal Diffusivity: The thermal property most often introduced into heat-transfer equations is thermal diffusivity and is numerically computed from thermal conductivity (k), heat capacity (C_p), and density (ρ).

Prediction of Freezing Time

The rate of freezing is of great importance for food quality, with fast freezing having the least detrimental effects. The objective, especially where texture is the main quality attribute, is to choose a freezing method that assures a rapid freezing. To assess the rate of freezing, a proper definition must be provided for freezing time. Freezing time is the time required for the thermal center of the food (defined as the point that is the most difficult to freeze) to reach a predefined temperature. Some other important definitions proposed are:

1. Nominal freezing time for a specific product, with known dimensions and a uniform initial temperature of 0°C is the time needed for its thermal center to reach a temperature 10°C below its initial freezing point.
2. The standard or effective freezing time is the total time needed for product temperature to reach from its initial value to a predetermined final value at the thermal center of the food. One end is fixed, in this case, but freezing time depends on initial temperature.
3. Another definition is the time taken to cross the zone of maximum ice crystal formation, that is, -1 to -5°C .

Freezing time can be either experimentally estimated with the freezing curve or theoretically calculated based on semiempirical or analytical models, or

numerical methods. At this point, it should be stressed out that the exact prediction of freezing time is inevitable due to the complex effect of food thermophysical properties. Actually, the effectiveness of each prediction model strongly depends on the assumptions made and on how realistic these assumptions are. The main factors involved in those mathematical equations are the thermophysical properties of food and the parameters of the freezing process.

Glass Transition in Frozen Foods

Glass transition is not related to the release of latent heat; yet, it can be observed by dramatic changes in dielectric, mechanical, and physicochemical properties of frozen foods and is a property of the unfrozen, concentrated phase of frozen foods. Glass transition is of high importance for frozen foods because it has been demonstrated that several quality degradation mechanisms (enzymatic reactions, recrystallization, etc.) are highly reduced or even eliminated when the unfrozen phase is in the glassy state. The kinetics of reactions affecting quality at temperatures close to the glass transition temperature. The difference between storage temperature (T) and T_g' is the crucial factor. Finally, when understanding the qualitative and quantitative effect of endogenous and environmental factors (e.g., temperature, freezing rate, composition, etc.) on glass transition phenomenon, it is possible to accordingly design its production or even selectively modify its composition to prolong its shelf life. Glass transition is defined as the phenomenon observed when a glass is heated until it starts behaving as a supercooled melt. The glass transition relates to the phenomena observed when a supercooled, malleable liquid, or rubbery material is changed into a disordered solid glass upon cooling, or conversely when a brittle glass is changed upon heating into a supercooled liquid or a rubbery material. This change is highly dependent on the temperature, time, food composition, and, where thermodynamics is concerned, it is a second-order transition. The derivative of Gibbs energy is discontinued at the glass transition temperature, whereas enthalpy, entropy, and the volume of the two phases remain unchanged.

Glass transition is a change occurring in a temperature zone, rather than at a specific temperature point. When a material is gradually subjected to a

temperature change in that temperature zone, the successive forms it assumes are :

1. Glassy state: When referring to a glass, we assume an amorphous, non-crystallized solid, which is actually a supercooled liquid of high viscosity which is met in a nonstable state that can support its own weight against flow, under gravity. When the material is in that state, changes occur in a very slow rate and are described with the term “physical aging.” Food matrices that are in the glassy state are considered stable.

2. Glass transition range: The glass is transformed into a viscous, supercooled liquid, followed by an important change in the mechanical properties of the material. In that temperature zone, with a range of 10–30°C, even a slight temperature change can lead to significant changes of structure and stability of the food matrix. The main change observed refers to molecular mobility that practically ceases below T_g , due to “freezing” of molecules in the glassy state.

3. Rubbery zone: This zone usually initiates—with the exception of low molecular compounds such as sugars or water—with a subzone where the mechanical properties of the material remain constant. The range of this subzone depends on the molecular weight and is strongly influenced by the linearity of molecules. After this subzone of constant mechanical properties, there is another zone where plastic materials behave either as viscoelastic or as plastic liquids, depending on the experimental time. Within the zone of viscoelastic behavior, there is no possibility for whole chains to exhibit mobility, whereas segments of chain can still move.

4. Zone of liquid flow: In this zone, normal flow is observed and complex polymers can behave as viscous liquids (melts). Mechanical properties of semi-crystallized polymers depend on the level of crystallinity. For $T_g < T < T_m$, increased hardness is observed before melting initiates at the melting point, T_m .

Quality of Frozen Foods: Physical and Chemical Changes During Frozen storage

For each particular food, there is a finite time period and after its production, it will retain a required level of sensory and safety quality characteristic under stated conditions of storage. This length of time can be defined as the shelf life of the food product or, alternatively, durability. Actually, there is not only one established and uniformly accepted definition for the term of “shelf-life,” but a variety of approaches. The shelf life in the case of frozen foods, HQL (high-quality life), which is the time from freezing of the product to the development of a just noticeable sensory difference (70–80% correct answers in a triangular sensory test) and PSL (practical storage life) that corresponds to the period of proper frozen storage after freezing of an initial high-quality product during which, the sensory quality remains suitable for consumption. Shelf life as “the time period within which the food is safe to consume and/or has an acceptable quality to consumers.” As for all food products, frozen foods are perishable, with a limited shelf life; during their life cycle from production to final consumption, they gradually deteriorate. Each type of frozen food loses its quality due to different mechanisms. Freezing extends food shelf life, maintaining at a satisfactory level its quality attributes and slowdown of most deterioration reactions that occur during storage of frozen foods. Quality does not cease to deteriorate during its commercial shelf life. The affect frozen food quality that can be divided into two categories: processing and compositional factors. The quality factors associated with processing parameters are mostly related to the ice phase and the characteristics of the ice crystals. For example, for frozen vegetables these factors are namely raw material, storage, and procedures before freezing, blanching, fluctuating temperatures, and packaging. Actually, time–temperature–tolerance (TTT) and product– processing–packaging (PPP) concepts are used to monitor and control the effects of temperature fluctuations on frozen food quality during production, distribution, and storage.

Changes of Plant Tissue (Fruits and Vegetables) Due to Freezing

Vegetables are among the most important frozen commodities. The industrial freezing of untreated vegetables can cause significant tissue damage, especially affecting microstructural integrity of plant cells. Many vegetables exhibit significant off-flavors, off-odors, discoloration, and loss of the original texture. These detrimental effects have been shown to be a consequence of the disruption of membranes and the activation of enzyme systems within the cells. Many vegetables must be blanched prior to freezing. The influence of the freezing rate on plant tissues is of great importance. When slow freezing is applied, ice crystals grow in intercellular spaces and may cause mechanical damage at adjacent cell walls. Owing to a water vapor gradient, water moves from the cells to the growing crystals. Cells become dehydrated and permanently damaged, ice crystals tend to grow to an undesirable size, and the overall cell structure tends to collapse. On thawing, cells do not regain their original shape and turgidity. As a consequence, food loses its original texture and cellular material leaks out from ruptured cells (termed “drip loss”). In fast freezing, smaller ice crystals form simultaneously within both cells and intercellular spaces, without forming water vapor gradients. The texture of the food is thus retained and there is little physical damage to cells.

The lower the temperature of frozen storage, the lower is the rate of microbiological and biochemical changes. Freezing and frozen storage do not inactivate enzymes and do not extinguish microorganism risks. Therefore, physical and chemical changes take place within the product during its storage; in the case of frozen vegetables, at the temperatures concerned microbial alterations are of minor concern since very few bacteria can grow below -5°C and no fungi or bacteria have been reported to grow below -12.5°C .

Physical changes influencing frozen vegetable quality during storage are related to recrystallization and ice sublimation, both affecting ice crystals stability. Recrystallization consists of modifications in the number, size, shape, and orientation of the ice crystals, which are present within and on the surface of the product after freezing.

Sublimation of ice at the surface of the product can also take place when packaging is not efficient, leading to desiccation and water accumulation inside

the packaging in the form of frost. The difference between the water vapor pressure on food surfaces and that in the surrounding atmosphere is the driving force for dehydration.

Chemical changes, mainly observed as enzymatic and nonenzymatic reactions occur in plant tissue of frozen foods during freezing, and their effect on quality is very important, as they significantly alter the sensory attributes of the original plant tissue.

Color Changes

Color is the most important attribute judged by the consumer, readily related to maturity, processing conditions, and the overall food quality. Frozen vegetables and fruits undergo several color changes during storage, due to alterations in natural pigments, chlorophylls, anthocyanins, carotenoids, or even by enzymatic browning. The characteristic green color of popular frozen vegetables, such as frozen beans, peas, spinach, broccoli, watercress, and so on gradually fades away, giving way to a brownish color during storage at temperatures near -18°C , due to the transformation of chlorophyll α and b into their corresponding pheophytins. Pheophytin formation leading to loss of green color due to the activity of enzymes such as chlorophyllase or lipoxygenase-induced oxidation of polyunsaturated fatty acids in the presence of oxygen.

Color loss is the destruction of anthocyanins, which are water-soluble pigments, responsible for the red colors. Under certain conditions, they may be destroyed by the enzyme-induced oxidation of polyphenols, leading to significant color loss, during subsequent frozen storage. The food pH is the most crucial factor affecting anthocyanin loss; at high pH values, with the presence of oxygen, the rate of color loss is rapid. Carotenoid oxidation is another cause of color change, mainly due to acids, catalyzed by certain enzymes and is sensitive to light.

The important cause of color degradation is enzymatic browning, when endogenous phenolic compounds are transformed into o-diphenols, and then into o-quinones, in the presence of oxygen and PPO. These quinones tend to condense and react with other phenolic compounds, amino acids, and so on, without the

presence of enzymes, leading to the formation of complex brownish polymers. These phenomena occur especially in vegetables such as cauliflowers, potatoes, and mushrooms when there is a cutting or peeling step in the procedure. Blanching can protect plant tissues from enzymatic browning, since PPO enzyme is rather sensitive to temperature. The degree of this sensitivity depends on the pH of the blanching solution as well as the pH of the food matrix.

Ascorbic Acid Degradation

When blanching is applied before freezing, important losses of water-soluble ingredients are recorded, among which vitamin C is of great concern. In unblanched or insufficiently blanched plant tissues, ascorbate oxidase catalyzes the oxidation of ascorbic acid during frozen storage, especially when oxygen-permeable packaging is used. The retention of ascorbic acid is often used as an estimate of the overall nutrient loss of food products, as vitamin C is highly sensitive during processing and subsequent frozen storage. Vitamin C loss even at very low storage temperatures. The role of blanching at the vitamin C retention, the ascorbic acid loss under fluctuating temperature conditions, which are more realistic than isothermal analysis. Blanching (immersion in hot water or steaming at 100°C) is an important thermal treatment commonly applied in vegetables (and less in fruit tissue) mainly to inactivate enzymes responsible for the alterations mentioned above (at sensory or nutritional characteristics). Therefore, blanching is actually applied as a preliminary step before freezing, to decrease quality losses during storage. As far as blanching conditions are concerned, many processors select heat treatment sufficient to inactivate peroxidase, one of the more stable enzymes present, and one of the enzymes whose activity is relatively easy to measure. Since blanching is a heat treatment, changes associated with mild thermal processing can be expected, such as partial degradation of cell wall polymers, pigment degradation, thermally induced degradation of nutrients such as ascorbic acid, or even leaching of nutrients. Blanching is necessary for a frozen product to retail a satisfactory quality level during its life, and, then a decision must be reached as to the extent and conditions of blanching needed to ensure optimum product quality.

Changes of Animal Tissue Due to Freezing

Freezing is one of the most important preservation methods for meat and meat products. A minimal loss of quality during long-term storage. The conditions for freezing meat appear to have little effect on the quality of the frozen product immediately after freezing. Freezing and subsequent thawing influence the water fraction of meat; during the freezing process, as water freezes, the concentration of the remaining solutes increases, thereby disrupting the homeostasis of the complex meat systems. Frozen storage is used to retard undesirable biochemical reactions in meat, but there is some cell disruption and destruction of muscle fiber due to the formation of ice crystals. During frozen storage, many reactions can occur between different meat components. These changes include oxidation of pigments and of lipids. There is also evidence for an insolubilization of proteins, which may contribute to the textural change.

The main quality attributes affected by freezing are mentioned: Moisture loss: When meat is frozen, its water-holding capacity is significantly reduced and the distribution of moisture is modified in meat tissues. This gives rise to “drip loss,” or other similar phenomena, such as “thaw loss,” “press loss,” and “cooking loss.”

Tenderness and texture: It is generally agreed in literature that meat tenderness increases with freezing and thawing. Other factors that play an important role at the toughness of the final product are the length of frozen storage and the degree to which the meat was aged prior to freezing. Different mechanisms are reported to contribute to texture changes: breakdown of muscle fibers by enzymes during proteolysis and loss of structural integrity caused by ice crystals formation.

Oxidation of lipids and proteins: The amount of unfrozen water into the frozen meat tissue, related to the final temperature of frozen storage, is of great importance for chemical reactions. Therefore, storing frozen meat at low temperatures, around -40°C decreases available water, decreasing the rate of chemical reactions. The fraction of unfrozen water influences oxidation processes, since primary lipid oxidation may initiate during frozen storage. This may lead to secondary lipid oxidation upon thawing, causing major undesirable changes in

odor flavor, color, and nutrition value. Actually, the formation of “off” or “rancid” flavors remains the main problem to extended storage of frozen meat.

Protein oxidation is concerned, it is closely related to lipid oxidation, as it can be linked to any of the pro-oxidative factors, such as oxidized lipids, free radicals, and so on. This kind of oxidation severely alters juiciness, tenderness, flavor, and color of meat, also causing amino acid destruction, protein unfolding, increased surface hydrophobicity, fragmentation, and protein cross-linking, all leading to the formation of protein carbonyls.

During freezing, denaturation of the myoglobin may occur, increasing its susceptibility to autoxidation and subsequent loss of bright-red color. Species greatly affect myoglobin concentration, with beef and lamb containing more than pork and poultry, accounting for the different (“red” and “white” meat correspondingly) colors. Another appearance problem related to freezing of meat tissues is “freezer burn,” which occurs when a dry, spongy layer is formed at the surface, due to desiccation. It is a common problem in unpackaged or inadequately wrapped meat, and can be further aggravated if stored in areas of low-humidity and poor temperature control.

Changes of Fish–Seafood Tissue during Freezing

Fish is unstable during frozen storage. There are several reasons for this instability, depending on fish species. High-fat fish tend to have a short shelf life in frozen storage due to lipid oxidation, which produces off-flavors. Freezing is a widely used preservation method for fish and other seafood, as it minimizes microbiological growth and some undesirable biochemical processes. Freezing procedure cannot inactivate microorganisms, it is necessary to select the appropriate raw material with initial microbial load, as low as possible. The frozen fish deteriorative changes is the myofibrillar protein denaturation, which can lead to textural and functional changes in the frozen fish. The production of free fatty acids (FFAs) and formaldehyde (FA), as well as storage temperature and time, have significant effect on protein changes during freezing and frozen storage. Myofibrillar protein denaturation and aggregation lead to loss of protein functionality and gel-forming ability in frozen fish. Factors influencing protein denaturation during freezing and frozen storage include salt concentration, pH,

ionic strength, lipid oxidation, enzymatic reaction, surface tension, and the physical effects of freezing and dehydration.

Ice crystal size, greatly depending on the freezing rate, is an important factor related to muscle deterioration, because the formation of large ice crystals leads to an extensive mechanical damage of cells; as a consequence, cellular components, such as lipids and proteins are free to interact with enzymes leading to protein denaturation and lipid degradation.

The damaging effects of freezing on proteins (denaturation and aggregation), it is suggested that cryoprotectants are used, such as sugars and other carbohydrates. Other compounds such as phosphates have also been used for fish tissue, in combination with sugar and sorbitol. Carbohydrates, polyols, some amino acids, and related compounds have shown the highest cryoprotective effectiveness.

Drying

Drying is a heat and mass transfer process to remove water or another solvent by evaporation, in most of the cases, from a solid, semisolid, or liquid. Solvent removal by sublimation takes place in freeze drying, while in osmotic dehydration, water is removed from a solid material as liquid due to osmotic pressure and concentration difference. It is used in the food, agricultural, ceramic, chemical, pharmaceutical, pulp and paper, mineral, polymer, and textile industries. Drying duration depends on the nature of the product, the drying method or technique applied, and the drying conditions. Drying of food materials is not just a heat and mass transfer process but also a technological process that has a significant effect on product quality as it contributes to preservation and to the improvement of the technological properties of products.

Psychrometry

Drying, humidification/dehumidification, and cooling (e.g., cooling towers) are processes that, along with vapor content measurements, include interfacial mass and energy transfer between a gas and a pure liquid when they are brought into contact with each other. Especially drying in the presence of air as a medium of heating and carrying away the evaporated moisture from the product is the most common way to dewater food materials (direct or convective dryers). The

knowledge of air properties such as its moisture content and temperature changes during its passage through the dryer is essential for the calculation of mass and energy balances for the streams involved in the process. Psychrometry is the thermodynamic branch that deals with the determination of moist air properties. The ideal gas law is used to predict the behavior of air–water vapor mixtures, since air temperature is high enough and water vapor pressure low enough in relation to their respective saturation points.

The most important terms and properties associated with humid air are the following:

- (1) Dry bulb temperature T ($^{\circ}\text{C}$): It is the temperature of the mixture measured by a common, nonmodified thermometer that is immersed in the mixture.
- (2) Absolute humidity or humidity ratio Y_v (kg water/kg dry air): It is the mass of moisture (water vapor) contained in the moist mixture per unit mass of dry air.
- (3) Relative humidity or relative saturation RH (%): It is the ratio of the partial pressure of water vapor in the system to the partial pressure of water vapor in a saturated condition (equilibrium vapor pressure) at the same temperature.
- (4) Specific volume or humid volume v (m^3/kg): It is the volume of unit mass of dry gas and its accompanying vapor at the mixture temperature and pressure.
- (5) Humid heat C_p ($\text{kJ/kg}/^{\circ}\text{C}$): It is the amount of heat required to raise the temperature of unit mass dry air and its associated water vapor by 1°C .
- (6) Enthalpy ΔH (kJ/kg): It is the internal energy and the flow work per unit mass and is expressed as the sum of enthalpies of the gas and its vapor content.
- (7) Dew point temperature T_d ($^{\circ}\text{C}$): It is the dry bulb temperature at which an air–vapor mixture becomes saturated when cooled at constant total pressure out of contact with a liquid.
- (8) Adiabatic saturation temperature T_{as} ($^{\circ}\text{C}$): It is the equilibrium gas temperature reached by unsaturated gas and vaporizing liquid under adiabatic conditions.

- (9) Wet bulb temperature T_w ($^{\circ}\text{C}$): It is the steady-state nonequilibrium temperature that a small amount of water reaches when exposed to a continuous stream of gas under adiabatic conditions. Wet bulb temperature is defined thermodynamically as the temperature at which water, by evaporating into moist air at a given dry bulb temperature and moisture content, can bring the air to saturation adiabatically, while constant pressure is maintained and the latent heat required for evaporation is supplied at the expense of the liquid sensible heat resulting in its temperature decrease. Wet bulb temperature is determined with a thermometer on which the bulb has been covered with a wet cloth and is immersed in a rapidly moving air stream. Its value is lower than the dry bulb temperature if the air stream is unsaturated.
- (10) Adiabatic saturation humidity Y_{as} (kg water/kg dry air): It is the absolute humidity that corresponds to adiabatic saturation temperature (T_{as}) and lies on the saturation curve.
- (11) Saturation: It is the state when a gas holds the maximum amount of vapor under the existing conditions of pressure and absolute humidity.
- (12) Wet bulb depression ($^{\circ}\text{C}$): It is the difference between dry and wet bulb temperature ($T - T_w$) and expresses a measurement of unsaturation of the air. It inclines to zero and then the air becomes saturated.
- (13) Water activity a_w (-): It is the ratio of vapor pressure exerted by water in solid to that of pure water at the same temperature.

Drying Mechanism

Drying food materials under the influence of a fluid (usually air or inert gas), the main mechanisms of drying are :

- Surface diffusion or liquid diffusion on the pore surfaces
- Liquid or vapor diffusion due to moisture concentration differences
- Capillary action in granular and porous foods due to surface forces

Thermal diffusion that is defined as water flow due to the vaporization–condensation sequence, and hydrodynamic flow that is defined as water flow due to shrinkage and pressure gradient may also take place during drying. Diffusion is a function of the moisture content and the structure of the material and it determines the drying rate. For hygroscopic products, generally, the product dries at a constant rate and subsequently, periods of falling rate; the process terminates when equilibrium is established. In the constant rate period, external conditions such as temperature and relative humidity of the drying medium, drying air velocity and flow direction, physical form of the product, the method of its supporting, and the desirability of agitation are the main parameters affecting drying, and the dominant diffusion mechanism is surface diffusion. As the constant rate period comes to an end, the moisture has to be transported from the inner layers of the solid to the surface by capillary forces. The drying rate may still be constant until the moisture content reaches the critical moisture content. At that stage, the surface moisture film has been reduced, dry spots appear on the surface, and the first falling rate period (unsaturated surface drying) begins. Liquid diffusion due to moisture concentration difference is the dominant drying mechanism at that stage. The second falling rate period begins when the surface liquid film has entirely evaporated and the rate of the process is controlled by the vapor diffusion due to moisture concentration difference. Internal conditions such as temperature, moisture content, and structure of the product are the main factors affecting the water removal rate in both falling rate periods. Biological materials, although they have high moisture content, generally do not present a constant rate period during drying, and in some cases, when the initial moisture content is not very high, only the second falling rate period appears, as in the drying of grains or nuts.

Drying Kinetics

Drying is a process governed by simultaneous and often coupled and multiphase heat, mass, and momentum transfer phenomena. That along with the different structure of food materials as well as the numerous physical, chemical, and biochemical transformations that occur during drying add a significant complexity, which makes the application of many transport models unsuitable for a precise prediction of drying time.

Drying processes are mathematically modeled with two main models:

- Distributed models that consider simultaneous heat and mass transfer
- Lumped parameter models that do not take into account the temperature gradient in the product and assume a uniform temperature distribution that equals the drying air temperature.

Thin-layer drying generally refers to the drying as one thin layer of particles or slices where the temperature distribution can be assumed as uniform and the lumped parameter models can be applied. Thin-layer models are theoretical and semi-theoretical or empirical.

Drying Methods

Various drying methods and techniques used in food processing. One of the most important features in drying technology is that prior to drying, a pre-drying process usually applies.

Liquids are:

- Vacuum concentrated, to reduce the food volume or strip aroma compounds in order to add them back to the dry powder.
- Treated with enzymes, to reduce the viscosity, avoiding gelling and haze formation, or subjected to removal of some compounds to assure a natural color of the product.

Solids are:

- Sulfated to retard nonenzymatic browning, reduce shrinkage and oxidation of liable food components, and improve rehydration.
- Soaked in solutions of different compounds to retard nonenzymatic browning, and affect texture and shrinkage (calcium salts) or reduce bacterial load (acid solutions) or reduce drying time (K_2CO_3).
- Blanched to inactivate enzymes, change the tissue structure, reduce drying time, and increase firmness and microbiological quality.

- Freezed to disorder tissue structure, increase diffusion, reduce drying time, and enhance rehydration.
- Treated by high pressure to preserve color.

Drum drying

Drum drying (DD) is one of the most energy-efficient methods in which drying takes place on the outer cylindrical surface of one or two slowly rotating drums, heated internally by steam, and is used for the treatment of sludge/slurries, suspensions, liquid solutions, pureed foods, and pastes over a wide viscosity range. The case of viscous materials (in their natural state or after concentration), drying in the form of very thin film is particularly effective. The material is spread in the form of a thin layer and after about three quarters of a revolution from the point of feeding the product is considered dried and its removal, many times in the form of a thin sheet, is achieved by a scraper, knife, or blade. The applied film is not in motion relative to the drum because of rapid drying and solidification. Product temperature is in the range of 120–170°C for most of the applications. Exposure to high temperature is limited to a few seconds and the method can be applied even in the cases of heat-sensitive products. Feed temperature and concentration are frequently regulated using preheating and preconcentration to optimize the amount of heat to be transferred per unit weight of dry material. Preconcentration is desirable only up to the point that does not prevent uniform adherence of the product to the dryer surface. DD is regarded as conduction drying method where the required heat for the vaporization of moisture is being obtained by the heat transfer from the steam condensation inside the drum through its metallic wall to the material film spread over its external surface. Energy efficiencies in DD may range between 70% and 90%, compared to 40–60% for hot air drying, while the corresponding steam consumption is 1.2–1.5 kg per kg of water evaporated. Hot water under high pressure could be used as the heating medium when low energy consumptions are required. The method is considered as one of the most reliable among the various drying methods. DD at atmospheric pressure may result in extensive quality loss of heat-sensitive bio-compounds due to the high temperature of the

drum while the high cost of the exchange surface, which must be precisely manufactured to allow scraping, is another limitation of the method. There are many drum dryer types and configurations, which include a single drum dryer with or without applicator rolls, double-drum dryers where the drums rotate toward each other, twin-drum dryers where drums rotate away from each other, and vacuum dryers that operate under reduced pressure. The latter presents the advantage of drying at lower temperatures but its high capital cost limits its applications. The drum(s) are mounted on a horizontal axis and mechanically rotated with variable speed control. Drum dryers may be dip or splash fed or equipped with applicator rolls, especially in the treating of highly viscous materials. The installation of a radiation heater in a zone near the sludge feeding point seems to improve drying performance. Common application of DD includes the production of flaky dry powder from thick suspensions of different types of starchy food materials. Drum dryers are commonly used for the industrial production of a variety of foodstuffs such as yeast creams, gelatin, breakfast cereal, fruit purees, fruit and vegetable pulp, applesauce, milk products, baby foods, mashed potatoes, dry soup mixtures, pregelatinized or cooked starches, fruit–starch mixtures.

Impingement Drying

Impingement drying or impingement jet drying (IJD) is a method in which the food material is stationary on a surface and hot air is fed to the drying chamber from a series of round nozzles at a short distance from the surface. The high-velocity turbulent jets of impinging air remove the boundary layer from the solid surface and the surrounding cold air creating a bed of hot air that surrounds the particles, they rapidly increase the temperature at the center of the product to the drying air temperature, and enhance the heat and mass transfer rate. The pseudofluidization of the bulk material aims at the good contact between a gas and a solid. When the particulate material is pneumatically agitated, a random distribution of dry, partly wet, and wet material is expected, which forms a random distribution of transport resistances partly in series and partly in parallel. The method ensures rapid dewatering of materials in the form of thin sheets or beds of coarse granules. The drying procedure is very fast and the moisture content distributes more uniformly due to the pseudofluidized bed created by the

high-velocity air flow that suspends and trembles the particles. IJD is recommended only if the major fraction of the moisture to be removed is unbound. As the drying rate is very high, evaporative cooling in the constant rate period is also high and holds the product surface temperature below its degradation or ignition temperature. If the remaining moisture is in the form of bound water and/or the controlling mechanism of the process is the internal diffusion (drying shifts to falling rate period), product temperature may rise rapidly due to the high heat transfer rate, which will result in degradation of heat-sensitive products. IJD requires simple equipment is general, as no moving mechanical devices or need for maintenance are required. In food processing, typical temperature and jet exit velocity values in IJD range from 100°C to 350°C and 10 to 100 m/s. The maximum (center) velocity decreases with increasing distance from the nozzle exit. An impingement dryer consists of a single gas jet or an array of such jets, while there is a large variety of nozzles available (multizones). IJD has been applied to a variety of granular food materials such as coffee and cocoa beans, rice, bakery, snacks, and nuts. Superheated steam instead of air can also be used in this method to improve the texture of food products as steam usually causes changes in the texture that lead to a crispier final product after drying. Comparison of drying with superheated steam and air reveals that at elevated temperatures, superheated steam provides higher drying rates and there is more starch gelatinization compared to air drying. IJD can be combined with infrared radiation to reduce drying time and improve product quality as the infrared radiation energy can be absorbed directly by the material without significant loss to the environment.

Impinging Drying

Impinging drying or impinging stream drying (ISD), the collision of two (or more) high-velocity gas streams (10–150 m/s) leads to the generation of a high shear rate and intense turbulence (in the case of turbulent impinging streams), which greatly enhances heat, mass, and momentum transfer in the impingement zone. The wet particles (0.2–3.0 mm diameter) are brought into an oscillatory motion by the impinging streams as they penetrate into the opposed stream(s) due to their inertia and decelerate due to the opposite flow of this opposed stream(s). At the end of the deceleration path, the particles accelerate and re-

enter their original stream, and after performing several such oscillatory motions, their velocity eventually vanishes and the particles are withdrawn from the dryer. This unique flow pattern increases the residence time of particulate materials in the drying zone under intense heat and mass transfer conditions. Drying time in this method is limited to a few seconds (0.5–15 s). The method is suitable only for the removal of surface moisture or weakly bound water in the unhindered drying rate period, making the method an alternative to flash drying. The equipment of ISD is relatively compact and simple in construction and operation, while the product quality is high. Pressure drop is an essential parameter of dryer operation and is in the range of 1–10 kPa, which is about 20 times lower than that of fluidized bed drying. ISD, compared to other drying methods, presents a smaller footprint and high robustness due to the lack of moving parts. The disadvantages of the method are the high energy consumption compared to traditional parallel-flow drying and the fact that it is not suitable for highly sensitive materials due to overheating. There are many types (configurations) of impinging dryers, such as coaxial gas solid, two tangentially fed impinging stream, four impinging streams, multistage two impinging streams dryers, and others. Important operating parameters of the dryer performance include inlet air temperature and velocity, feed rate of particles, and spacing between the opposed inlet streams. Wet particles are generally carried to the dryer by one (or both) of the inlet streams.

Refractance Window Drying

RWD is an emerging technology introduced by MCD Technologies. The method was patented for the dehydration of heat-sensitive foods. The design innovation of this method focuses on the usage of hot water as the heat transfer medium and at temperatures just below boiling at standard conditions, making it the unique drying method that utilizes hot water for heating. The application of RWD requires the distribution of the product in a very thin and uniform layer on a conveyor belt (film), which floats on the hot water. The belt is constructed of a special plastic; it has special characteristics regarding refraction and acts not only as a support for the material but also as an interface relatively transparent to infrared radiation. As this plastic conveyor is very thin, it reaches the hot water temperature almost immediately. The system works at atmospheric pressure and the hot water, usually at 95–97°C, circulates beneath the belt on shallow troughs

transmitting thermal energy for moisture evaporation from the wet solids by conduction and radiation with infrared transmission in the wavelength range that matches the absorption spectrum for water. During drying, infrared heat passes directly through the plastic belt to the product. RWD is a very efficient method as all heat transfer methods (conduction, convection, and radiation) take place simultaneously. Infrared radiation is the major heat transfer mechanism in the early drying stages as the moisture is quite high, while conduction becomes important when moisture no longer contacts with the belt. Heat losses are limited as the plastic belt is a poor heat conductor. Food materials dried with RWD retain their color and flavor to a great extent and are protected by oxidization as product temperature remains below the temperature of the circulating water beneath the belt. RWD is considered to be a state-of-the-art method and can be used for the treatment of high-value food products with superior quality, while drying time is very short. The rapid mass transfer from the wet product and the resulting high vapor saturation above it limits the product–oxygen interaction and contributes in maintaining product quality, while the intense evaporation cools the product to an actual temperature usually below 70°C. The equipment used is simple and relatively inexpensive and the operational cost is low. Products, which include juice, pulps, purees, suspensions, and sliced foods, are spread on the moving belt. Puree thickness is in the range of 1.0 mm and drying time may be less than 5 min. Thickness and moisture content are important parameters determining the absorbency of the puree. The recirculation and reuse of the hot water improves the thermal efficiency of the dryer. The cooling section at the discharge end of the dryer is intended to reduce the product temperature, preferably below its glass transition temperature, to facilitate product removal. The method has the ability to handle a wide range of liquid food materials, and has been applied for the transformation of fruits (strawberries, mangoes, blueberries, avocados, and lingonberries), vegetables (carrots, squash, and asparagus), and herbs and spices into value-added concentrates and powders. Meat, fish, poultry, eggs, flavorings, starches and grains, dairy, cereals, and beverages, as well as spirulina, β -carotene, lycopene, barley grass, tea blends, and homogeneous dried materials from mixtures of foods or herb or food extracts, have also been successfully dried by RWD. Some of the most important applications of the method include scrambled egg mix, avocado fruits for dips, high carotenoid-containing algae for treating macular degeneration and cancer, herbal extracts and nutritional supplements for

human use, food ingredients (e.g., spices), and nutritional supplements for shrimp farming. The method has also been used successfully for the dehydration of foods that are difficult to be spray dried without the addition of non-sugar carriers.

Fluidized Bed Drying

Fluidized bed drying (FBD) is one of the most versatile and successful drying techniques and is used extensively for cost-effective industrial drying of a wide range of granular materials that can be fluidized. During the fluidization process, a layer of solid body particles acquires properties that make it similar to a liquid and the particles mix in a manner that is dependent on the velocity of the gas flow that causes the state of fluidization. The method presents advantages, such as intense material mixing resulting in uniformly dried material, substantial intensification of heat and mass transfer between drying gas (usually air) and the particles being dried, resulting in shortening of drying time, rapid equalization of the gas temperature in the entire volume of the dried product, to the extent that the process practically takes place in a gradient-free field of gas temperature, and easy material transport inside the dryer.

Many different fluidized bed dryer designs are available, which range from small batch units to large continuous dryers capable of processing tens of tonnes of feed-stock per hour, while advanced versions in which the particle motion is enhanced by stirring or vibration are also employed to extend the range of materials that can be fluidized by conventional means. The continuous fluidized bed dryers are classified as well-mixed and plug-flow based on residence time distribution (RTD) of the material. The well-mixed fluidized bed dryers present a wide distribution of residence time, moisture content, and temperature of the particles at its outlet and typically they consist of a cylindrical vessel with solids inlet and outlet ports. The plug-flow fluidized bed dryers usually feature a long, narrow channel through which the fluidized solids flow. The bed length may be up to 20 m and the length-to-width ratio is in the range of 4:1 to 30:1. In a fluidized bed dryer, the pressure drop across the distributor must be high enough to ensure good and uniform fluidization and for upwardly directed flow, the pressure drop across the distributor must exceed 30% of the pressure drop across the bed.

Electrohydrodynamic Drying (High Electric Field Drying)

Electrohydrodynamic drying (EHDD) is a novel nonthermal and low-energy-consuming drying method. It is a variant of high electric field drying methods that uses a point-to-plate electrode system (in general, the electric field used for drying consists of a point-to-plate or two flat electrodes) and having the ability to produce food materials of high quality. It can be applied successfully in the processing of thermally sensitive biological materials and can be used both for postharvest treatment of foods and during food processing. EHDD complies with high product quality and can be used for the production of high-value foods for the outdoors, instant meals, nutraceuticals, baby foods, and seasonal and perishable foods and herbs of tomato, apple, potato, okara, spinach, scallop, and others.

- EHDD takes place under ambient temperature and pressure conditions.
- The corona current increases linearly with an increase in applied voltage for both positive and negative polarities and a negative corona discharge produces a larger corona current compared to a positive corona discharge.
- The specific energy consumption increases with an increase in applied voltage for both polarities but it is lower compared to conventional drying and it is also lower than that of the latent heat of vaporization, indicating water removal from the food surface by other means in addition to evaporation.
- Electrode configuration plays an important role in determining the efficiency of the process and multiple-needle electrode configurations present higher efficiency than wire and single-electrode configurations.
- The equipment is relatively simple does not include movable parts, and there are no wear and tear problems.
- The evaporation rate depends on current strength, electrode gap, as well as the properties of the fluid medium. During drying, no primary heat is involved although a slight temperature increase of the samples has been observed.

EHDD offers lower production costs along with superior quality in terms of properties such as color, shrinkage, flavor, and nutrient content compared to hot air drying. It also presents a simpler design and less energy consumption

compared to freeze drying, thus showing great potential for bulk and industrial applications. Less shrinkage represents the retention of the natural structure of the material.

Foam-Mat Drying

Drying of foamed materials dates are the method for the drying of foamed evaporated milk. Foam-mat drying (FMD) is a particularly helpful method for the processing of food materials that require long drying times or are heat sensitive, sticky, viscous, and generally difficult to dry. It has been applied in a variety of liquid and semiliquid materials, such as pastes (tomato), fruit pulps (mango, banana, guava, apple, pineapple, starfruit, cowpea, mandarin, bael, passion fruit, and papaya puree) and juices (tomato), coffee extract, soymilk, and egg melange drying. Foaming often converts a fluid material to a semisolid as it reduces its fluidity, altering the requirements for the support of the material during drying. Foam is a two-phase system having a dispersed phase (usually air), which is the larger one and is surrounded by a plateau border of a continuous phase. Foams are highly fragile and delicate in nature and the high level of surface energy at the air–water interface makes them thermodynamically unstable. During FMD, a liquid or semiliquid material is whipped to form stable foam and is dehydrated by thermal means. Foam density used in the method ranged between 300 and 600 kg/m³. The layer of the foamed material was in the range of 0.003–0.01 m. The chemical nature of the material to be dried, its soluble solids, the pulp fraction, and the type and concentration of the foaming agent and the foam stabilizer affect foam formation, density, and stability. The quality of the foam is described by properties such as foam expansion, stability, and density, which are determined by the type and concentration of each foaming agent. The main advantage of foam formation prior to dehydration is the increased drying rate mainly due to the expanded internal structure and increased exposure of the product surface area to the drying medium. The very thin material layers that can be used and their porous structure accelerate the diffusion of the water to the surface and allow the implementation of relatively low temperatures, which along with short drying times result in products of high quality that present favorable (good) rehydration characteristics, retention of volatiles, impaired losses of bioactive compounds (e.g., vitamins), and controlled density. The relatively simple and inexpensive

equipment and control required can also spread the applicability of the method. A disadvantage of the method lies in the reduced density of foamed materials, which leads to limited throughput of the material to the dryer, for a given film thickness, and low material-to-dryer surface loading. A critical subject in the application of the method is the lack of stability of the foam during heating, which causes cellular breakdown, resulting in serious impairment of the operation. The very low thermal conductivity of foams and the expanded nature of the film tend to limit heat transfer through the food in the later stages of drying and cause the increase of its temperature close to that of the heating medium. In many cases, the dried product sticks to the drying surface and its removal becomes difficult. To prevent these undesired events, a nonstick food-grade Teflon sheet can be used for the coating of the drying surface. In regard to the dried material, the foamed structure of the final product is very conducive to reconstitution and the food material tends to disperse readily in water. During storage, the open structure of foam-dried products tends to present problems of stability as they are sensitive to oxidative deterioration. Foamed foods is usually dried in a convectional manner (in a hot air dryer), FMD can be combined with infrared and microwave drying to induce convection with an irradiative supply of energy, while conduction heating can also be used.

Foam-Spray Drying

Foam-spray drying (FSD) is for the production of acid cottage cheese whey, skim milk, and whole milk with the use of foamed feed. The method is based on the drying of purposely foamed droplets, which are being formed by the introduction of a gas (air, CO₂, N₂, N₂O) or by using highly volatile liquids that are completely miscible with the feed material or by chemical reaction. Foamed droplet formation can take place before, during, or after atomization and before or during drying itself. The method has been applied in the production of tea, coffee, whey, fat, and skimmed milk products. Gas bubbles in FSD are much smaller than in FMD. The expansion of gas bubbles during FSD results in large particles with an increased surface area, reduced bulk density and increased porosity. The method are the improved dissolution and the enhanced retention of highly volatile substances. FSD is suitable for the production of free-flowing powders from materials that have a tendency to agglomerate and adhere to dryer

walls. It can also be used for the dehydration of hard-to-dry food materials and mixtures of biological substances such as protein, fat, vitamins, and mineral components, which are common in meat, detergent, and pharmaceutical industry.

Desiccant Drying

Desiccant drying (DCD) refers to a convective (hot air) drying technique where the drying medium passes through an adsorption column or similar device (e.g., desiccant wheel) to lower its moisture content before entering the drying section. Moisture adsorption is accompanied by heat release due to the heat of adsorption that raises air temperature and increases the efficiency of the drying system. The introduction of hot air with minimum relative humidity increases the driving force of moisture removal and the water uptake capacity, accelerating the drying process or making it possible to maintain drying duration even at lower drying temperatures. This is useful in food drying to protect heat-sensitive compounds and the overall functionality of the product. Desiccant materials are able to remove practically all the moisture content from an air stream and produce dry air when they operate before the breakthrough point of the column appears. DCD can increase the energy efficiency of convective dryers, which is around 50%, while it can be even less for dryers working at low inlet temperature. Desiccant materials present advantages, such as low energy consumption, continuous operation, increased drying rate, increased product quality especially for heat-sensitive products, ease to design the system and replace the material after cycles of operations, and no requirement for maintenance over long periods. The disadvantages of this technique are the pressure drop in solid desiccants, the carry over in liquid desiccants by air stream, the low moisture adsorption capacity (heat pump drying can also be used for moisture removal from a drying medium stream) and especially the regeneration process, which requires the use of hot air of $\sim 300^{\circ}\text{C}$. This hot air is necessary for the reuse of the saturated material as the use of heat to regenerate desiccant materials has limitations in energy saving. The use of solar energy or waste heat from industrial processes (e.g., flue gases of steam generators) for regeneration as well as the ability for further use of the air after regeneration for heat recovery is the most effective way to increase the efficiency of the dryer through heat integration with other unit operations, rendering the method attractive. Vapor compression systems (heat pumps),

electrical heaters, ultrasonic technology assisted by hot air, and electro-osmosis have been considered as novel methods for regenerating desiccant materials, as they present low energy consumption. The use of adsorbents can reduce energy consumption up to 50%. Desiccants can be solids such as silica gel, alumina silicate, activated carbon, and zeolite, or liquids such as CaCl_2 , LiCl , LiBr , and KCOOH solution. Solid desiccants are used in the form of stationary or rotary wheel beds for packing the desiccant material and are more widely used in drying applications. Liquid desiccants are more complicated in handling and usage, although they are flexible and can be regenerated far away from the dryer, allowing localized dehumidification. Liquid desiccants also present relatively high moisture removal capacity, the ability to absorb organic and inorganic contaminants from the air, and regeneration at relatively lower temperatures compared to solid desiccants is possible. The method has been applied in the drying of herbs, cocoa, seeds, cereals, nuts, manure, and sludge, and the final products present good color, taste, and microbial stability. The efficiency of the regeneration step can be increased by using superheated steam at a temperature level of 350°C , which may result in a regenerated adsorbent with a moisture content of 2%.

Hybrid Drying

The presentation of a variety of drying methods and techniques in the previous sections reveals that there is no ideal method that prevails in engineering practice. Drying time, product quality, and operating cost are considered the most important factors and the recent trend in drying research is the application of combined or hybrid drying in order to exploit the best characteristics of each individual method. The selection of the most appropriate methods for each material, the sequence of their application, the operating parameters, and the duration of each method have to be established through experimental procedures and theoretical analyses. The utilization of hybrid methods may include their sequential or simultaneous application. Some of the most recent examples of hybrid drying are presented in this section.

The dehydration of the blackcurrant berry, a fruit with very high vitamin C content, using microwave-assisted foam mat drying (MW-FMD). They used a

household MW oven and heated air as the drying medium. The concept to combine the two methods was the volumetric heat generation and water vaporization inside the materials caused by microwave radiation, which can confine the poor heat transfer of air wrapped in the foamed materials. They described the beneficial effect of vapors, which strip up bubbles of the material, increasing the evaporation surface area and the instantaneous removal of water from the surface layer of the bubbles before their collapse. This hybrid method resulted in an increased drying rate combined with superior quality in terms of color and appearance. In general, the increase of microwave power and the decrease of pulp load accelerated the dehydration of the pulp. Pulp thickness is the most important factor for the retention of vitamin C followed by pulp load and drying time, while microwave power is the least important parameter. On the other hand, pulp thickness was the least important in regard to moisture content, which was affected mainly by microwave power, followed by drying time and pulp load. In the case of anthocyanin content, pulp thickness is again the most important factor, followed by pulp load and microwave power, while drying time is the least important. Microwave power and pulp load had a positive effect on both vitamin C and anthocyanin up to a certain level (420–490 W and 350–420 W and 57.5–65.0 gr and 35.0–42.5 gr, respectively), while the further increase of power resulted in degradation of these biomolecules. The optimum operating conditions for drying were microwave power of 560 W, pulp load of 65 g, drying time of 8 min, and pulp thickness of 4.46 mm. Under these conditions, vitamin C content was ~1.37 mg/g (compared to the maximum of ~1.40 mg/g when only vitamin C was the compound of interest), anthocyanin content was ~27.7 (color value) (compared to the maximum of ~33.57 when only anthocyanin was the compound of interest) and moisture content was ~0.197 kg moisture/kg db.

Effect of Drying Process in Bioactive Compounds of Foods

The selection of a drying method has direct impact on the deterioration of bioactive molecules present in the foodstuff. Different drying methods and conditions may have a great effect on the degree of preservation of individual valuable bioactive compounds. There are key components that are associated with the quality and the preservation of bioactive compounds that include ascorbic acid, β -carotene, chlorophylls, lysine, and others. In the following, some

recent research efforts concerning the preservation of bioactive compounds are presented. They clearly denote that the selection of the drying method and its operating conditions is essential for presenting the best possible quality and nutritional value in the production of foods.

The change in organic acids, phenolic compounds, and antioxidant activity of dried apricots when hot air drying combined or not when microwave (MW) energy was used. They concluded that the industrial processing of dried apricots may be improved by using microwave energy, as the fruit presented a higher phenolic content, particularly of chlorogenic acid, catequin, and epicatequin while drying time was considerably reduced and the antioxidant capacity was maintained. Drying led to a significant decrease in malic, caffeic, and tartaric acid and although hot air drying did not affect the citric acid content, the application of microwaves caused a significant decrease in the citric acid. Also, hot air drying, with or without MW assistance, significantly decreased the amount of gallic acid to a greater extent than when only MWD was employed. MWD significantly increased the epicatequin and catequin content. The combination of hot air drying–MWD increased catequin to a greater extent than MWD alone, while epicatequin decreased to the same degree as when hot air drying was used. All the drying methods led to a total loss of kaempferol. Higher temperatures contributed to a greater total phenolic content, while the application of MW heated the material even more extensively. This might be due to the more complete extraction of phenols after extensive heating or due to the sulfite pretreatment. DPPH scavenging activity (antioxidant capacity was assessed using the free radical-scavenging activity of the samples evaluated with the stable radical DPPH*) was increased to 3.5–3.8% for dried product compared to 2.4% for a frozen one.

The air drying of Atlantic salmon fillets at 40°C, 50°C, and 60°C and the influence of temperature on biochemical characteristics. The content of palmitic acid, eicosapentaenoic acid (EPA—an omega-3 fatty acid), and docosahexaenoic acid (DHA—an omega-3 fatty acid) were significantly lower in the dried fish fillets compared to the fresh fish. Palmitic acid decreased by 20% compared to fresh fish while a temperature increase caused a decrease of its content. Concerning the content of the typical fish fatty acids, EPA remained practically unchanged and DHA decreased slightly with increased temperature. The tocopherol content

decreased during drying by 40%. α -Tocopherol decreased significantly after drying at all three temperatures and especially at 40°C, although at 50°C, the highest content was observed, possibly due to the restricted flow out of melted fat from the fish muscle to the surface. This led to less loss of the liposoluble α -tocopherol due to the viscosity decrease of the lipid phase with increasing temperature. γ -Tocopherol decreased significantly only during drying at 40°C, maybe due to the longer drying time at that temperature. Astaxanthin content, which is a dietary carotenoid and the main pigment responsible for the pink color of the fillets, was practically the same as that of fresh fish after drying at 40°C, while it was significantly increased in the dried products processed at 50°C and 60°C. This indicates the concentrating effect of the process in regard to this compound as well as the stability of astaxanthin in the applied conditions. They also detected secondary lipid oxidation compounds formed during drying, which were measured by the thiobarbituric acid index (TBA-i). This index can be used for the evaluation of the effect of drying. An increase of TBA-i was recorded after drying at all temperatures, while the index increase was lower at higher drying temperatures, resulting in shorter drying time. Anisidine value was also used for the measurement of secondary oxidation products. Drying significantly increased the anisidine values of the products, confirming the rapid decomposition of hydroperoxides into secondary oxidation products (alcohols, aldehydes, ketones, acids, dimers, trimers, polymers, cyclic compounds, and free radicals) due to hydrolytic and oxidative degradation at high temperatures. The anisidine value of the dried products increased less with increasing drying temperature, leading to the conclusion that fish degradation is more relevant to longer drying times than higher drying temperatures.

Assignment for FTech-303 Food Processing Technology

Food safety, good manufacturing practice and quality assurance

Quality control systems were based on the inspection of a product at various points within a process, and rejection of any product that did not meet agreed standards. This reactive approach to food quality focused mainly on end-product testing, which is now recognised to be a waste of resources. A more proactive preventative approach to food safety and quality management, termed 'Quality Assurance' based on the principles of Good Manufacturing Practice (GMP). It aimed to ensure that quality and safety are maintained throughout a process and prevent product rejection and financial losses.

The pressures for this development came from two sources: first, commercial pressures including:

- increasing competition between companies
- the need to access expanding national and international food markets
- product quality management systems required by major retailers.

These all required an effective food monitoring and control system to control resources and ensure that safe, high quality products were manufactured, and led to the concept of Total Quality Management (TQM). Second, new legislation demanded systems that would both maintain quality and safety, and prove that a business is in control of these. The initial quality assurance legislation has been expanded to take all business operations into account. The aim of TQM is for companies to define and understand all of their processes, to implement controls, monitor performance and measure improvements. This concept takes into account separate standards for production operations and new product development production facilities, environmental and waste management, employment rights, health and safety, laboratory management as well as food quality and safety.

As part of a TQM programme, food manufacturers must take into account the requirements of a food safety management system termed 'HACCP' (Hazard Analysis Critical Control Point). This provides the key control measures needed to understand the mechanisms for producing safe food and the basis to create production control systems to ensure product quality. HACCP as the required standard for free international movement of food.

TQM is broader than quality control, and is a management philosophy that seeks to improve the effectiveness and competitiveness of the business as a whole. It is an integrated system which ensures that all areas of the business are controlled, to enable customers to consistently receive quality products that meet their needs and expectations.

TQM system covers the following areas:

- raw materials, purchasing and control (including agreed specifications, supplier auditing, raw material storage, stock control, traceability, inspection, investigation of non-conformity to specification)
- process control (including identification, verification and monitoring of critical control points in a HACCP scheme, hygienic design of plant and layouts to minimize crosscontamination, cleaning schedules, recording of critical production data, sampling procedures and contingency plans to cover safety issues)
- premises (including methods of construction to minimize contamination, maintenance, waste disposal)
- quality control (including product specifications and quality standards for non-safety quality issues, monitoring and verification of quality before distribution)
- personnel (including training, personal hygiene, clothing and medical screening)
- final product (including types and levels of inspection to determine conformity with quality specifications, isolating non-conforming products, packaging checks, inspection records, complaints monitoring systems)
- distribution (to maintain the product integrity throughout the chain, batch traceability and product recall systems).

TQM objectives and this requires the company to:

- have a defined organizational structure
- clearly allocate authority and division of responsibilities
- define procedures
- link the components of the system
- prepare key documentation
- allocate sufficient resources for implementation of the system.

The component procedures for introducing a quality management system include:

- development of audit methods
- procedures for corrective action
- procedures for management review and
- documentation of the system

HACCP

Hazard analysis is 'the identification of potentially hazardous ingredients, storage conditions, packaging, critical process points and relevant human factors which may affect product safety or quality'. HACCP enables potential hazards in a process to be identified, assessed, and controlled or eliminated. It sets tolerances for hazards and defines appropriate control measures, the frequency of their application, sampling procedures, specific tests to be used and the criteria for product acceptance. HACCP is used throughout each stage of a process, and includes raw materials, processing, storage and distribution. It can be used for all potential hazards, including inadequate quality as well as safety, and can identify areas of control where failure has not yet been experienced, making it useful for new operations. Implementation of a HACCP scheme involves the following stages:

1. Produce a detailed flow diagram of the process, including production methods and schedules, preparation and transport of raw materials, in-process stock etc., confirmed by a site visit.

2. Identify the essential characteristics of the product and its use and define the hazards or potential hazards that could threaten the consumer or the product. Included in this is the product formulation, handling procedures and storage conditions, packaging, expected customer handling and the target consumer groups.
3. Consider all stages in the process, including realistic process deviations, and identify critical stages (critical control points (CCPs)) which must be controlled to assure safety. The judgement of risk is made using one of three methods: probabilistic, comparative or pragmatic, and should be made by people who have a high degree of expertise and experience.
4. Devise target levels and critical limits for each CCP and produce effective procedures to monitor them, to verify them and to implement corrective action. Monitoring may be by physical, microbiological or chemical tests, or by visual or sensory observations. All monitoring procedures should be recorded and they should also include the location of the CCP, the frequency of monitoring and satisfactory compliance criteria. Examples include cleaning procedures (what is cleaned, how and when it is cleaned, who cleans it and what with), temperatures of foods, processing conditions, recipe formulations, hygienic practices, opportunities for cross-contamination and workers' illness or infections.
5. Establish documentation to record the HACCP system and the procedures needed to review it.

Hurdle technology

In traditionally preserved foods, such as smoked fish or meat, jams and other preserves, there are a combination of factors that ensure microbiological safety and stability of the food, and enable it to be preserved. In smoked products for example, this combination includes heat, reduced moisture content and anti-microbial chemicals deposited from the smoke onto the surface of the food. Some smoked foods may also be dipped or soaked in brine or rubbed with salt before smoking, to impregnate the flesh with salt and add a further preservative mechanism. Smoked products may also be chilled or packed in modified atmospheres to extend the shelf life. In jams and other fruit preserves, the

combined factors are heat, a high solids content and high acidity. These preservative factors also strongly influence the sensory characteristics of the product and contribute to important differences in flavour, texture or colour between different products. In vegetable fermentation, the desired product quality and microbial stability are achieved by a sequence of factors that arise at different stages in the fermentation process: the addition of salt selects the initial microbial population which uses up the available oxygen in the brine. This reduces the redox potential and inhibits the growth of aerobic spoilage micro-organisms and favours the selection of lactic acid bacteria. These acidify the product and stabilise it. Further treatments may include pasteurisation and packaging to extend the shelf life and facilitate distribution. The demand by consumers for high quality foods having 'fresh' or 'natural' characteristics, that require a minimum amount of preparation has led to the development of ready-to-eat and convenience foods that are preserved using mild technologies. The main preservation technique is refrigeration, but because of the difficulty in maintaining sufficiently low temperatures throughout the production, distribution and storage chain, additional barriers are required to control the growth of spoilage or pathogenic micro-organisms. The application of Hurdle Technology, where an understanding of the complex interactions of temperature, water activity, pH, chemical preservatives, etc. It is used to design a series of hurdles that ensure microbiological safety of processed foods. The hurdles are also used to improve the quality of foods and the economic properties (for example, the weight of water that can be added to a food, consistent with its microbial stability). The hurdles that are selected should be 'high enough' so that the anticipated numbers of these microorganisms cannot overcome them. The same hurdles that satisfactorily preserve a food when it is properly prepared are overcome by a larger initial population of micro-organisms, when for example raw materials are not adequately cleaned. In this example, the main hurdles are low water activity and chemical preservatives in the product, with storage temperature, pH and redox potential having a smaller effect. Blanching vegetables or fruits has a similar effect in reducing initial numbers of micro-organisms before freezing or drying. The same hurdles are used with a different product that is richer in nutrients that can support microbial growth, again the hurdles may be inadequate to preserve it and a different combination may be needed or the height of the hurdles increased. By combining hurdles, the intensity of individual preservation

techniques can be kept comparatively low to minimize loss of product quality, while overall there is a high impact on controlling microbial growth.

Automatic control

Automation means that every action that is needed to control a process at optimum efficiency is controlled by a system that operates using instructions that have been programmed into it. The advantages of automatic process control can be summarised as:

- more consistent product quality (minor variations in processing that would cause changes to product quality are avoided)
- greater product stability and safety
 - greater compliance with legal and customer specifications
- more efficient operation
- verification of correct inputs by operators (e.g. checking that operators specify the correct weight and types of ingredients)
- better use of resources (raw materials, energy, labour, etc.)
- reduced effluents or more uniform effluent loads
- increased production rates (e.g. through optimization of equipment utilization)
- improved safety (automatic and rapid fail-safe procedures with operator warnings in case of, for example, a valve failure or excessive temperature rise).

The main disadvantages relate to the social effects of reduced employment when the number of operators required to process a food is reduced. Other disadvantages include:

- not suitable for processes in which manual skill is necessary or economically more attractive
- higher set-up and maintenance costs
- increased risk, delays and cost if the automatic system fails

- the need for a precise understanding of the process for programming to achieve the required product quality
- reliance on accurate sensors to precisely measure process conditions.

The components of an automatic control system are as follows:

- sensors to detect process conditions and transmitters to send this information to the controller
- a controller to monitor and control a process
- actuators (for example a motor, solenoid or valve) to make changes to the process conditions
- a system of communication between a controller and actuators and transmitters
- an 'interface' for operators to communicate with the control system.

Sensors

The pre-requisites for control of a process are sensors and instruments which measure specified process variables and transmit the information to a process controller. Parameters commonly measured by sensors are classified into:

- primary measurements (for example temperature, weight, flowrate and pressure)
- comparative measurements, obtained from comparison of primary measurements (for example specific gravity)
- inferred measurements, where the value of an easily measured variable is assumed to be proportional to a phenomenon that is difficult to measure (for example hardness as a measure of texture)
- calculated measurements, found using qualitative and quantitative data from analytical instruments or mathematical models (for example biomass in a fermenter).

It is important to recognize that process variables that are measured and controlled are often only used indirectly as indicators of complex biochemical reactions that take place during processing. Examples include the combination of

time and temperature needed to destroy micro-organisms, temperature and pressure as measures of the changes that take place during extrusion or the time required to remove a specified amount of moisture by dehydration. Solid-state electronic sensors have largely replaced older mechanical or chemical types, due to their greater reliability, greater accuracy and precision, and faster response times.

The positioning of sensors in a process may be summarized as 'in-line,' 'on-line,' 'at-line' and 'off-line'. On-line and in-line sensors are widely used because of their rapid response time and accurate positioning. Their main requirements are as follows:

- a hygienic sensing head
- contaminant free (contains no reagents or micro-organisms that could contaminate foods)
- no potential hazard from foreign bodies (e.g. no glass components)
- robust to withstand processing temperatures or pressures (for example 200°C and 10 MPa in cooker-extruders)
- able to withstand chemicals in food components or effluents
- tolerant to cleaning-in-place or having cheap, easily replaced, disposable sensing heads
- reliable with good reproducibility, even when exposed to moisture, steam, dust, food volatiles or fouling by fats, proteins or starches
- resistance to electromagnetic interference in some applications (e.g. microwaves, ohmic heaters)
- resistant to damage from mechanical vibration
- low maintenance requirement
- total cost (capital, operating and maintenance costs) in proportion to benefits gained.

Controllers

The information from sensors on process and product variables is used by controllers to make changes to process conditions. Automatic controllers operate using logic in a similar way to the decision-making logic demonstrated by human thought. In automatic control, the same sequence of questions is 'asked' by the controller. Information is provided by sensors indicating the approach to a set limit for empty in the current silo and the level status in other silos. This, together with information from a sugar flowrate transmitter and an on-line engineering report of ongoing maintenance work, is used to select the next silo and calculate the delay before initiating a preprogrammed sequence of signals to change the motorized valves. Each part of a process can be analyzed in this way and automatic controllers can be programmed with the control logic needed to produce the optimum level of control. There are two basic operational requirements of an automatic controller: a method of holding a specified process variable at a predetermined set-point, and a method to control the sequence of actions in an operation. These are supplemented in more advanced controllers with facilities for monitoring a process and providing management information. The first requirement, sensors measure a process variable and a transmitter sends a signal to the controller, where it is compared with a set-point. If the input deviates from the set-point (termed the error), the controller alters an actuator to correct the deviation and hold the variable constant at the set-point. The type of signals that are sent can be either digital (on or off) signals or analog (continuously variable) signals. For example, a digital signal could be sent to the controller from a motor, indicating whether it is switched on or off, or from a valve indicating whether it is in one of two possible positions (open or closed). Examples of analog control are varying signals to alter the degree to which for example, a steam valve is open in order to control the rate of heating, or the signal sent from a temperature transmitter to record the product temperature. The second requirement of process controllers is the proper sequencing of the control loops in a system, using sequence control, in which the completion of one operation signals the controller to start the next operation, with or without a time delay. This has been achieved using hard-wired relay circuits (relays are a type of electrical switch), controlled by timers and counters, which automatically turn different circuits on or off at predetermined times or in a specified sequence. These are now replaced by computer systems in which the logic is stored in the

computer memory, rather than in the physical arrangement of the wiring. Two additional functions of controllers are to monitor process conditions and to provide management information. Examples include identification of faults and electronic interlocks to prevent a process continuing if a fault is detected or a required condition is not met (for example automatic cleaning schedules are prevented until a tank level signal indicates that it is empty). An important benefit of controllers is their ability to monitor a process for faults (self-diagnosis) and to automatically restart a process when a fault has been corrected. Other benefits of monitoring include the collation and analysis of management information at pre-set intervals (e.g. each shift, each day or month) and the use of this information to prepare cost analyses or maintenance programmes.

Computer-based systems

Computers cannot only be programmed to read data from sensors and send signals to process control devices, but they can also store and analyse data and be connected to printers, communications devices, other computers and controllers throughout a plant. They can also be easily reprogrammed by operators to accommodate new products or process changes.

Programmable logic controllers (PLCs)

The introduction of PLCs are based on microcomputers, and have the same functions as relays, but with vastly greater flexibility. They were first used to replace relays in simple repetitive applications, but the greater power was quickly used to develop other functions, including recipe storage, data transfer and communications with higher level computers. PLCs have a fixed program stored in two modes in the computer memory using similar logic to relay circuits. The first (teach) mode allows instructions to be programmed into the memory via a keyboard by an operator. In the second (run) mode the program is executed automatically in response to data received from sensors. If a process parameter exceeds a pre-set limit, a warning is activated to attract the attention of the operator. The program may automatically correct any deviation from the specified limits. PLC can be programmed to monitor constantly the status of valves or other

equipment and inform an operator of any malfunction, which greatly speeds up fault tracing and repairs. PLCs are highly reliable, relatively low cost and easy to install and use. An important advantage is the ease and speed with which they can be reprogrammed by factory staff who do not have sophisticated computing knowledge. This allows great flexibility in being able to modify process conditions or change product formulations.

Batching and blending

The increased range of products demanded by consumers has required manufacturers to produce smaller batches, with more frequent changes to product formulations and processing conditions during routine production. This is complex and time consuming if performed manually, but is well suited to automatic control by PLCs. Each formulation is assigned a number and, when a number is entered by the operator, the PLC automatically controls the flow of ingredients from storage silos, through automatic weighers, to mixing vessels. This type of control is widely used in the production of baked goods, snackfoods, confectionery and ice cream. A similar system is used for the automatic control of raw materials that have a variable composition but are used to produce a final product in which the composition is subject to legislation or trade standards. In another application, a computer is used to determine the least-cost formulation needed to produce a particular product specification from different combinations of raw materials. For example, the quality of meat products such as burgers and sausages, and the profitability of their production, are determined by both the fat content of the meat and accurate proportioning of meat and non-meat ingredients. Data on the composition of the raw materials is fed into the PLC, which simulates possible formulations and selects the one that has the lowest cost. Automatic control of the formulation also produces the exact lean-to-fat ratio and meat-to-non-meat ratio required in the product.

Types of control systems

The different combinations in which PLCs and larger computers can be linked together in an integrated control system can be described in three categories:

1. dedicated systems
2. centralised systems
3. distributed systems.

Dedicated control systems: These use local equipment controllers (PLCs) which are an integral part of the process plant, dedicated to the control of a single unit operation. They do not communicate information to other computers but simply receive on/off instructions from a central control panel. They are relatively unsophisticated computers that are able to receive data from sensors and send signals to actuators. They may also have the capability for data-logging, report generation and automatic set-point adjustment. They have remained popular because they are easy to fit to existing processes without requiring significant changes to the control system, they are easy to use and low cost.

Centralised control systems: In these systems, a mainframe computer or large mini-computer, located in a centralised control room, monitors and controls different on-line controllers that in turn control the process in specified zones. Each on-line controller may have a printer, data logger and graphics display to inform operators of the status of the process. They can be reprogrammed relatively easily to accommodate process changes and can have facilities for report generation and communication with other computers. Each process area has a mimic panel to indicate continuously the status of the process variables. Closed-circuit television cameras view the plant and relay the information to monitors located in the central control room. The central computer checks the positions of valves, fluid levels, pressures, flow rates, densities and temperatures in the processing equipment, at a rate of 998 inputs every 7 s. Centralised computer control systems have been used in large companies for several years, their major disadvantage is that any failure in the central computer could cause a total plant shutdown, unless an expensive standby computer of equal capacity is

available to take over. For this reason, distributed control systems which do not have this disadvantage, are now more commonly installed.

Distributed control systems (DCS): These are an integrated system of control in which each area of a process is independently controlled by a PLC, and the PLCs are both linked together (process interlocking), and linked to a central computer via a communications network. Each PLC controller is located close to the equipment that it controls to reduce the cost of wiring, and each has an operator's console with a graphics display and control inputs. Although the capital cost and programming costs are higher than the other systems, distributed control systems are highly flexible in being able to change processing conditions and do not have the vulnerability to total plant shutdown if one component fails.

Integrated control systems: When distributed control systems are used in different sections of a factory, they can be integrated into a larger management information system, known as an Integrated Control System. A central computer is used for mass data storage, sophisticated data manipulation, control of printers, plotters and communications with other management computers. This allows it to be used for other functions, including administration, marketing, quality assurance and plant maintenance, in addition to process control.

Process control systems: More recent developments involve using computers to operate a control programme that does not require specialist hardware (often referred to as 'soft-logic' or 'PC-based control'). These are hybrids of PLC and distributed control systems which are now being termed Process Control Systems (PCS). They enable complex combinations of continuous control, batch sequencing and processing to give complete automation using a single highly flexible program. This enables considerable time savings in system design, commissioning and engineering. These systems are able to collect and process data to show the performance of the process plant. Factory engineers can use the data to design more effective maintenance programmes and locate faults more quickly. Summaries of processing costs and production line efficiencies are used by production staff to improve materials handling and scheduling procedures and hence to improve the efficiency of production.

Software developments

One of the most important software developments was the Supervisory Control and Data Acquisition (SCADA) software. This collects data from a PLC that is controlling a process and displays it to plant operators in real-time as animated graphics. An operator can see a tank filling or a valve change colour as it opens or closes. The graphics are interactive to allow the operator to start a motor, adjust a process variable or control equipment. Alarm messages are displayed on the screen when a pre-set processing condition is exceeded. A major limitation of SCADA systems was their inability to analyse trends or recall historical data. This was corrected by new software, based on Microsoft's 'Windows' operating system, which allows data to be transferred between different programs and applications, using a Dynamic Data Exchange (DDE). This enables analysis and reporting of simple trends and historical data using spreadsheets and is linked in real-time to office automation systems. With this software, the office software can be used for real-time process control to adjust recipes, schedule batches, produce historical information or management reports. A system is used in a large ice cream factory to reduce costs by closer monitoring and control of the refrigerator's compressors, to display real-time running costs and to produce records of refrigeration plant performance. Two new types of software. The first monitors machine performance in applications such as packaging, where stoppages due to material jamming are common. The second type of software is used to monitor details of the processing received by an individual batch of food (for example time and temperature of heating or cooling) and store this together with the batch number and data on the final product. It has been difficult to make different software systems communicate with each other, but more recent developments in software, including the open data base connectivity (ODBC) standard have enabled different information databases to be linked together and accessed by anyone who is connected to a network. Information such as master recipes, production schedules and plant status can be incorporated into company business systems. The development of object linking and embedding (OLE) for process control, known as OPC, greatly simplifies the linking together of different software. The system is compatible with other management programs and is used to share production information with other departments within a company, such as sales and marketing.

Neural networks

Where complex relationships exist between a measured variable and the process or product, it has not yet been possible to automate the process. Recent developments of 'expert systems' or 'neural networks' may have the potential to solve such problems. The use of neural networks for a number of applications including automatic control of highly complex extrusion cookers by 'intelligent' interpretation of the range of variables in raw materials, processing conditions and final product quality. They are also being developed for applications in fermentation processes, production line robotics, analysis of leanness of meat and inspection of fruits and vegetables. These systems are reported to offer reductions in labour costs and wastage, higher production rates and generation of improved information for more accurate production scheduling and sales forecasting. Advances in neural systems, together with vision systems, pressure sensitive grippers and laser guidance systems have also been applied to robotics. Production line robots have so far found applications in meat deboning, cake decoration, mushroom picking, packaging assorted chocolates, carton erection and palletising cases.

Raw material preparation

At the time of harvest or slaughter, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour). It is necessary to perform one or more of the unit operations of **cleaning** (wet cleaning, dry cleaning and removing contaminants and foreign bodies), **sorting** (shape and size sorting, colour sorting and weight sorting), **grading or peeling** (flash steam peeling, knife peeling, abrasion peeling, caustic peeling and flame peeling) to ensure that foods with a uniformly high quality are prepared for subsequent processing. It is not possible to produce high quality processed foods from substandard raw materials and these mechanical separation procedures, which are applied near the beginning of a process, are a highly cost-effective method of improving the quality of the raw material.

Size reduction

Size reduction or 'comminution' is the unit operation in which the average size of solid pieces of food is reduced by the application of grinding, compression or impact forces. When applied to the reduction in size of globules of immiscible liquids (for example oil globules in water) size reduction is more frequently referred to as homogenisation or emulsification.

Size reduction has the following benefits in food processing:

- There is an increase in the surface-area-to-volume ratio of the food which increases the rate of drying, heating or cooling and improves the efficiency and rate of extraction of liquid components.
- When combined with screening, a predetermined range of particle sizes is produced which is important for the correct functional or processing properties of some products (for example icing sugar, spices and cornstarch).
- A similar range of particle sizes allows more complete mixing of ingredients.

Size reduction and emulsification have little or no preservative effect. They are used to improve the eating quality or suitability of foods for further processing and to increase the range of products available. In some foods they may promote degradation by the release of naturally occurring enzymes from damaged tissues, or by microbial activity and oxidation at the increased area of exposed surfaces, unless other preservative treatments are employed.

Different methods of size reduction are classified according to the size range of particles produced:

1. Chopping, cutting, slicing and dicing:

- (a) large to medium (stewing steak, cheese and sliced fruit for canning)
- (b) medium to small (bacon, sliced green beans and diced carrot)
- (c) small to granular (minced or shredded meat, flaked fish or nuts and shredded vegetables).

2. Milling to powders or pastes of increasing fineness (grated products > spices > flours > fruit nectars > powdered sugar > starches > smooth pastes)

3. Emulsification and homogenisation (mayonnaise, milk, essential oils, butter, ice cream and margarine).

Irradiation

Ionising radiation takes the form of γ -rays from isotopes or, commercially to a lesser extent, from X-rays and electrons. It is permitted in 38 countries to preserve foods by destruction of micro-organisms or inhibition of biochemical changes.

The main advantages of irradiation are as follows:

- there is little or no heating of the food and therefore negligible change to sensory characteristics
- packaged and frozen foods may be treated
- fresh foods may be preserved in a single operation, and without the use of chemical preservatives
- energy requirements are very low
- changes in nutritional value of foods are comparable with other methods of food preservation
- processing is automatically controlled and has low operating costs.

A major disadvantage is the high capital cost of irradiation plant. The main problems as:

- the process could be used to eliminate high bacterial loads to make otherwise unacceptable foods saleable
- if spoilage micro-organisms are destroyed but pathogenic bacteria are not, consumers will have no indication of the unwholesomeness of a food
- there will be a health hazard if toxin-producing bacteria are destroyed after they have contaminated the food with toxins

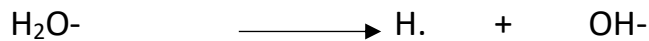
- the possible development of resistance to radiation in micro-organisms
- loss of nutritional value
- until recently, inadequate analytical procedures for detecting whether foods have been irradiated
- public resistance due to fears of induced radioactivity or other reasons connected to concerns over the nuclear industry.

Theory

Details of the physical and chemical processes involved in the decay of radioactive materials to produce α -, β - and γ radiation, X-rays and free electrons. γ -rays and electrons are distinguished from other forms of radiation by their ionising ability (that is they are able to break chemical bonds when absorbed by materials). The products of ionisation may be electrically charged (ions) or neutral (free radicals). These then further react to cause changes in an irradiated material known as radiolysis. It is these reactions that cause the destruction of micro-organisms, insects and parasites during food irradiation. In foods that have a high moisture content, water is ionised by radiation. Electrons are expelled from water molecules and break the chemical bonds. The products then recombine to form hydrogen, hydrogen peroxide, hydrogen radicals (H.), hydroxyl radicals (OH.) and hydroperoxyl radicals (HO₂.). The radicals are extremely short lived but are sufficient to destroy bacterial cells. Similar radicals are also present in non-irradiated foods owing to:

- the action of enzymes (for example lipoxygenases and peroxidases)
- the oxidation of fats and fatty acids
- the degradation of fat soluble vitamins and pigments.

In addition, reactive oxygen and its derivatives are produced in foods by peroxidases, xanthine oxidase and amino acid oxidase. Fat-soluble components and essential fatty acids are therefore lost during irradiation and some foods (for example dairy products) are unsuitable for irradiation owing to the development of rancid off-flavours. The presence of oxygen accelerates this process and meat is therefore irradiated in vacuum packs.



Equipment

Irradiation equipment consists of a high-energy isotope source to produce γ -rays or, less commonly, a machine source to produce a high-energy electron beam. γ -radiation from cobalt-60 (^{60}Co) or caesium-137 (^{137}Cs) is used in most commercial plants. ^{60}Co emits γ -rays at two wavelengths which have energies of 1.17 MeV and 1.33 MeV respectively. The activity of the ^{60}Co or ^{137}Cs sources is rated at $(222\text{--}370) \times 10^{10} \text{ Bq g}^{-1}$ (or $10^{13} \text{ Bq kg}^{-1}$). This generates 15 kW/M Ci (15 kW per $3.7 \times 10^{16} \text{ Bq}$). The residence time of the food is determined by the dose required and the power output of the source. An isotope source cannot be switched off and so is shielded within a pool of water below the process area, to allow personnel to enter. In operation the source is raised, and packaged food is loaded onto automatic conveyors and transported through the radiation field in a circular path. This makes maximum use of the emitted radiation and ensures a uniform dose. Isotope sources require a more complex materials-handling system than that used with machine sources. Machine sources are electron accelerators which consist of a heated cathode to supply electrons and an evacuated tube in which electrons are accelerated by a high-voltage electrostatic field. Either the electrons are used directly on the food, or a suitable target material is bombarded to produce X-rays. The main advantages of machine sources are:

- they can be switched off
- the electron beams can be directed over the packaged food to ensure an even dose distribution.

Handling equipment is therefore relatively simple. However, machine sources are expensive and relatively inefficient in producing radiation. Radiation is contained within the processing area by the use of thick concrete walls and lead shielding. Openings in the shielding, for entry of products or personnel, must be carefully constructed to prevent leakage of radiation. A dose of 5 Gy is sufficient to kill an operator and it is essential that even at the lowest commercial doses (0.1 kGy), stringent safety procedures are in place to prevent the source from being raised when personnel are present and to prevent entry to the building during processing.

Measurement of radiation dose

Dosimeters are made from a number of materials, including photographic film, Perspex and cobalt glass. Polyvinylchloride (PVC) dosimeters are impregnated with a dye. Hydrogen chloride is released from the PVC by irradiation and it produces a qualitative or quantitative change in the colour of the dye to indicate the dose received.

Dose distribution

Penetration of γ -radiation depends on the density of the food as well as the energy of the rays. Because radiation is absorbed as it passes through the food, the outer parts receive a higher dose than do inner parts. At a density of 1000 kg m^{-3} , half of the rays are absorbed in 11 cm. Halving the density approximately doubles the depth of penetration. The uniformity of dose distribution can be expressed as a ratio of $D_{\text{max}} : D_{\text{min}}$. For foods that are sensitive to radiation, such as chicken, this ratio should be as low as possible and not more than about 1.5. The distribution of dose can be controlled by adjusting the thickness of the packed product and irradiating from both sides. Dosimeters are placed at points throughout the package to determine the dose received and to ensure that the $D_{\text{max}} : D_{\text{min}}$ ratio is achieved. High energy electrons have a lower penetration than γ -rays and are not suitable for bulk foods. They are used for thin packages or for surface treatments. The selection of a radiation source therefore depends on

the type of product and its density, the dimensions of the package and the reason for the treatment.

Pulsed electric field processing

The origin of High Intensity Pulsed Electric Field (HIPEF) processing is the 'ElectroPure' process, a forerunner of ohmic heating, which was developed and used to pasteurise milk. This process produced only thermal destruction of micro-organisms because only low electricity voltages were used. The use of higher voltages (3000–4000 V) demonstrated that, in addition to thermal effects, there was enhanced microbial destruction caused by the electricity itself. Non-thermal destruction of micro-organisms and enzymes using electric discharges was then demonstrated in model food systems. HIPEF is not yet used on a commercial scale but its relatively low energy consumption, and the low processing temperatures which result in high retention of sensory characteristics and nutritional properties, indicate a good potential for producing high quality foods.

Theory

When an electric field with a strength in the range of 12–35 kV cm⁻¹ is applied to a liquid food in a short pulse (1–100 μs), there is a pronounced lethal effect on micro-organisms. The precise mechanisms by which micro-organisms are destroyed by electric fields are not well understood, but are likely to include:

- formation of pores in cell membranes when the applied electric field causes the electrical potential of the membrane to exceed the natural level of 1 V– the pores then cause swelling and rupturing of the cells
- electrolysis products or highly reactive free radicals produced from components of the food by the electric arc, depending on the type of electrode material used and the chemical composition of the food
- induced oxidation and reduction reactions within the cell structure that disrupt metabolic processes

- heat produced by transformation of induced electric energy.

The degree of inactivation of micro-organisms by HIPEF is greater at higher electric field intensities and/or with an increase in the number and duration of the pulses. Other factors that influence the degree of inactivation include the temperature of the food, its pH, ionic strength and electrical conductivity.

In addition to microbial destruction, reported a reduction in lipase activity in milk and a reduction in the ascorbic acid content after HIPEF treatment, but vitamins and enzymes are not inactivated to any appreciable extent by HIPEF processing. The flavour and colour of fruit juices was unaltered by processing.

Equipment

Typical HIPEF equipment consists of a high-voltage power supply, capacitors to store the charge, a discharge switch to release the charge to electrodes which pass an electric field through the product contained in a treatment chamber. Inductors are used to modify the shape and width of the electric field pulse. Although the process is intended to operate at ambient temperatures, the HIPEF treatment may cause a rise in the product temperature, depending on the field strength, pulse frequency (Hz) and number of pulses, and equipment is fitted with refrigeration coils to control the temperature. The entire apparatus is contained within a restricted-access area due to the risk to operators from the high voltages and all connections to the chamber including product pipework and refrigeration units must be isolated and earthed to prevent leakage of energy.

High pressure processing

The use of high pressures as a method of food processing was conducted using high hydrostatic pressures to preserve milk, fruit juice, meat and a variety of fruits. They demonstrated that micro-organisms in these products could be destroyed by pressures of 658 MPa (6500 atm) for 10 minutes. Protein structure in egg-white could be altered by high pressures. The potential was limited because enzymes were largely unaffected, particularly in milk. They were also constrained by both difficulties in manufacturing high pressure units and inadequate

packaging materials to contain the foods during processing. The commercial products produced by high pressure processing. A range of pressure-processed jams, including apple, kiwi, strawberry and raspberry in flexible sealed plastic packs, and started production of bulk orange juice and grapefruit juice. The jams had a shelf life of two months under chilled storage, which is required to prevent enzyme activity. Other products included fruit jellies, sauces, fruit yoghurts and salad dressings. The products currently sell at three to four times the cost of conventional products, but the higher quality, particularly flavour and texture of the fruit, has so far ensured sufficient demand for commercial viability.

Theory

When high pressures, up to 1000 MPa (10 000 bar), are applied to packages of food that are submerged in a liquid, the pressure is distributed instantly and uniformly throughout the food (i.e. it is 'isostatic'). The high pressure causes destruction of micro-organisms. Bacteria in the log phase of growth are more barosensitive (sensitive to high pressures) than cells in the stationary, dormant or death phases. Moderately high pressures (300–600 MPa) cause vegetative microbial cells to be killed or inactivated. Typically, a pressure of 350 MPa applied for 30 min or 400 MPa applied for 5 min will cause a ten-fold reduction in vegetative cells of bacteria, yeasts or moulds. Pulsed pressure treatments have been found to be more effective than static pressure for pasteurisation of pineapple juice. Higher pressures are required to cause bacterial spores to germinate, followed by inactivation of the germinated cells. However, when combined with moderate heating (e.g. to 60°C), spores are destroyed at pressures of 400 MPa to different extents, depending on the strains that are present.

Enzymes that are related to food quality vary in their barosensitivity: some can be inactivated at room temperature by pressures of a few hundred MPa whereas others can withstand 1000 MPa and for example peroxidase in peas and pectin methyl esterase in strawberries can withstand 1200 MPa. Pressure activation or inactivation is also strongly dependent on pH, substrate composition and temperature. The situation is further complicated by effects of high pressures on cellular membranes, which when ruptured, may permit reactions between released intracellular enzymes and their substrates. This permits destruction of

microbial activity without significantly affecting food molecules that contribute to the texture or flavour of the food. As the process can be operated at ambient or even chill temperatures, there is little heat damage to nutrients or natural flavours and colours, which results in high quality products. Additionally, the process does not require the use of chemical preservatives to achieve an adequate shelf life of processed products. High pressure processing has no 'heating' or 'cooling' periods, and there are rapid pressurisation/de-pressurisation cycles, reducing processing times compared to thermal processing. High pressure processing will be capable of being used in combination with other types of processing and thus expand the unit operations available to food processors, leading to the development of new products and processes.

Processing and equipment

The construction of high pressure machinery is a specialised and expensive operation. This is being adapted for use in the food industry and batch presses are available, having vessels of up to 9400 l capacity, which can operate at pressures of 200–500 MPa with operating cycles of as little as two to three minutes.

The main components of a high pressure system are:

- a pressure vessel and its closure
- a pressure generation system
- a temperature control device
- a materials handling system

Most pressure vessels are made from a high tensile steel alloy 'monoblocs' (forged from a single piece of material), which can withstand pressures of 400–600 MPa. For higher pressures, pre-stressed multi-layer or wire-wound vessels are used. Vessels are sealed by a threaded steel closure, a closure having an interrupted thread, which can be removed more quickly, or by a sealed frame that is positioned over the vessel. In operation, after all air has been removed, a pressure transmitting medium (either water or oil) is pumped from a reservoir into the pressure vessel using a pressure intensifier until the desired pressure is reached. This is termed 'indirect compression' and requires static pressure seals.

Another method, termed 'direct compression' uses a piston to compress the vessel, but this requires dynamic pressure seals between the piston and internal vessel surface, which are subject to wear and are not used in commercial applications.

Temperature control in commercial operations can be achieved by pumping a heating/ cooling medium through a jacket that surrounds the pressure vessel. This is satisfactory in most applications as a constant temperature is required, but if it is necessary to regularly change the temperature, the large thermal inertia of the vessel and relatively small heat transfer area make this type of temperature control very slow to respond to changes. In such situations, an internal heat exchanger is fitted.

There are two methods of processing foods in high pressure vessels: in-container processing and bulk processing. Because foods reduce in volume at the very high pressures used in processing (for example, water reduces in volume by approximately 15% at 600 MPa), there is considerable stress and distortion to the package and the seal when in-container processing is used. It is likely that conventional plastic and foil pouches will prove suitable and research is continuing on the optimum design of the package, seal integrity and other suitable packaging materials. Materials handling for in-container processing is achieved using automatic equipment, similar to that used to load/unload batch retorts. Bulk handling is simpler, requiring only pumps, pipes and valves.

Semi-continuous processing of fruit juices at 4000–6000 l h⁻¹ using pressures of 400–500 MPa for 1–5 min at ambient temperature is used whereas another uses a similar process operating at 120–400 MPa followed by a short heat treatment before the juice is packaged. The process is highly energy efficient although at present the capital costs of equipment remain high. It is possible that such liquid foods could also be used as the pressurising fluid by direct pumping with high pressure pumps. Such systems would reduce the capital cost of a pressure vessel and simplify materials handling. If liquids were also rapidly decompressed through a small orifice, the high velocity and turbulent flow would increase the shearing forces on micro-organisms and increase their rate of destruction. Developments in high pressure processing include combined freeze concentration, pressure freezing and high pressure blanching. Initial results

suggest that pressure blanched fruits are dried more rapidly than those treated by conventional hot water blanching.

Effect on micro-organisms, enzymes and food components

Germination of spores under high pressures is temperature dependent: near 0°C spores resist germination even at pressures of 1000 MPa, whereas at moderate temperatures, pressure induced germination can be achieved at 100 MPa. Germinated spores can be destroyed at a pressure of 600 MPa and a temperature of 50–70°C. These effects are not consistent and a combination of high pressure and moderate heating can have either synergistic or antagonistic effects on microbial growth, enzyme activity and chemical reactivity. For example high pressure can either make micro-organisms more sensitive to heat or it can prevent their destruction at higher temperatures, depending on the type of micro-organism.

As fruit processing has so far been the main application of high pressure technology, many studies of enzyme inactivation are concerned with those enzymes that affect the quality of fruit products. For example polyphenoloxidase has been shown to resist pressures of up to 1200 MPa for 10 minutes before inactivation, although it is more sensitive at higher pH levels. Pectinesterase is responsible for cloud destabilisation in juices, gelation of fruit concentrates and loss of consistency in tomato products. It is less resistant than polyphenoloxidase; its activity decreases above 300 MPa and it can be inactivated at pressures above 700 MPa at 45°C for 10 minutes. Orange pectin esterase is partially (90%) inactivated at 600 MPa at room temperature and does not reactivate during storage. The effects on microbial and enzyme activity of combined high pressures with low water activity, compressed or supercritical CO₂, pre-treatments with biopolymers (e.g. chitosan) or enzymes (e.g. lysozyme, glucose oxidase), ethanol, sodium sulphite, ultrasonic waves and high electric field pulses. High pressure processing causes complex changes to the structure and reactivity of biopolymers such as starches and proteins. In proteins, the pressure causes unfolding of the molecular structure and then aggregation with either different proteins in a food or into a different form, resulting in changes to the texture of the food. Gel formation is observed in some proteins, such as soya, meat, fish and egg albumin.

Compared to heat treated gels, pressure induced gels maintain their natural colour and flavour and are described as smooth, glossy and soft, and having greater elasticity. These results are being evaluated in relation to surimi products on an experimental scale. A further potential application of high pressure processing is the tenderisation of meat. Processing at 103 MPa and 40–60°C for 2.5 min improves the eating quality of meat and reduces cooking losses. The extent of tenderisation depends on all three factors involved: pressure, temperature and holding time. Commercially produced products include pressure-processed salted raw squid and fish sausages.

Starch molecules are similarly opened and partially degraded, to produce increased sweetness and susceptibility to amylase activity. Fruit products are reported to retain the flavour, texture and colour of the fresh fruit. Other applications include tempering chocolate, where the high pressures transform cocoa butter into the stable crystal form, preservation of honey and other viscous liquids, seafoods, dairy products such as unpasteurised milk and mould ripened cheese.

Equipment

Chilling equipment is classified by the method used to remove heat, into:

- mechanical refrigerators
- cryogenic systems.

Batch or continuous operation is possible with both types of equipment, but all should lower the temperature of the product as quickly as possible through the critical warm zone (50–10°C) where maximum growth of micro-organisms occurs.

Mechanical refrigerators

Mechanical refrigerators have four basic elements: an evaporator, a compressor, a condenser and an expansion valve. Components of refrigerators are frequently constructed from copper as the low thermal conductivity allows high rates of heat transfer and high thermal efficiencies. A refrigerant circulates

between the four elements of the refrigerator, changing state from liquid to gas, and back to liquid as follows:

- In the evaporator the liquid refrigerant evaporates under reduced pressure, and in doing so absorbs latent heat of vaporisation and cools the freezing medium. This is the most important part of the refrigerator; the remaining equipment is used to recycle the refrigerant.
- Refrigerant vapour passes from the evaporator to the compressor where the pressure is increased.
- The vapour then passes to the condenser where the high pressure is maintained and the vapour is condensed.
- The liquid passes through the expansion valve where the pressure is reduced to restart the refrigeration cycle.

The important properties of refrigerants are as follows:

- a low boiling point and high latent heat of vaporisation
- a dense vapour to reduce the size of the compressor
- low toxicity and non-flammable
- low miscibility with oil in the compressor
- low cost.

Ammonia has excellent heat transfer properties and is not miscible with oil, but it is toxic and flammable, and causes corrosion of copper pipes. Carbon dioxide is non-flammable and non-toxic, making it safer for use for example on refrigerated ships, but it requires considerably higher operating pressures compared to ammonia. Halogen refrigerants (chlorofluoro-carbons or CFCs) are all non-toxic and non-flammable and have good heat transfer properties and lower costs than other refrigerants. However, their interaction with ozone in the earth's atmosphere, and consequent contribution to global warming as 'greenhouse gases', has resulted in an international ban on their use as refrigerants under the Montreal Protocol. Partially halogenated CFCs (or HCFCs) are less environmentally harmful and existing HCFCs are being temporarily substituted for CFCs, but these too are to be phased out before the first decades of the new century. Newer,

ozone-friendly HCFCs are being developed and are likely to become important refrigerants. The main refrigerants that are now used are Freon-22 and ammonia, with the possibility of future use of propane. However, the latter two in particular are more expensive and could cause localised hazards.

The chilling medium in mechanically cooled chillers may be air, water or metal surfaces. Air chillers (for example blast chillers) use forced convection to circulate air at around -4°C at high speed (4 m s^{-1}), and reduce the thickness of boundary films to increase the rate of heat transfer. Air-blast chillers are also used in refrigerated vehicles, but food should be adequately chilled when loaded onto the vehicle, as the refrigeration plant is only designed to hold food at the required temperature and cannot provide additional cooling of incompletely chilled food. Eutectic plate systems are another type of cooling that is used in refrigerated vehicles, especially for local distribution. Salt solutions (e.g. potassium chloride, sodium chloride or ammonium chloride) are frozen to their eutectic temperature (from -3 to -21°C) and air is circulated across the plates, to absorb heat from the vehicle trailer. The plates are regenerated by re-freezing in an external freezer. Retail chill cabinets use chilled air which circulates by natural convection. The cost of chill storage is high and to reduce costs, large stores may have a centralised plant to circulate refrigerant to all cabinets. The heat generated by the condenser can be used for in-store heating. Computer control of multiple cabinets detects excessive rises in temperature and warns of any requirement for emergency repairs or planned maintenance. Other energy-saving devices include night blinds or glass doors on the front of cabinets to trap cold air.

Other methods of cooling

Foods with a large surface area (for example lettuce) are washed and vacuum cooled. The food is placed in a large vacuum chamber and the pressure is reduced to approximately 0.5 kPa . Cooling takes place as moisture evaporates from the surface (a reduction of approximately 5°C for each reduction of 1% in moisture content). Direct immersion in chilled water (hydrocooling) is used to remove field heat from fruit and vegetables, and cheese is often cooled by direct immersion in refrigerated brine. Recirculated chilled water is also used in plate heat exchangers to cool liquid foods after pasteurisation. Liquid and semi-solid foods are cooled by contact with refrigerated, or water-chilled metal surfaces in scraped-surface heat exchangers.

Cryogenic chilling

A cryogen is a refrigerant that changes phase by absorbing latent heat to cool the food. Cryogenic chillers use solid carbon dioxide, liquid carbon dioxide or liquid nitrogen. Solid carbon dioxide removes latent heat of sublimation (352 kJ kg⁻¹ at -78°C), and liquid cryogens remove latent heat of vaporisation (358 kJ kg⁻¹ at -196°C for liquid nitrogen; liquid carbon dioxide has a similar latent heat to the solid). The gas also absorbs sensible heat as it warms from -78°C (CO₂) or from -196°C (liquid nitrogen) to give a total refrigerant effect of 565 kJ kg⁻¹ and 690 kJ kg⁻¹ respectively. The advantages of carbon dioxide include:

- a higher boiling and sublimation point than nitrogen, and therefore a less severe effect on the food
- most of enthalpy (heat capacity) arises from the conversion of solid or liquid to gas.

Only 13% of the enthalpy from liquid carbon dioxide and 15% from the solid is contained in the gas itself. This compares with 52% in nitrogen gas. Carbon dioxide does not therefore require gas handling equipment to extract most of the heat capacity, whereas liquid nitrogen does. The main limitation of carbon dioxide, and to a lesser extent nitrogen, is its ability to cause asphyxia. There is therefore a maximum safe limit for operators of 0.5% CO₂ by volume and excess carbon dioxide is removed from the processing area by an exhaust system to ensure operator safety, which incurs additional setup costs. Other hazards associated with liquefied gases include cold burns, frostbite and hypothermia after exposure to intense cold. Solid carbon dioxide can be used in the form of 'dry-ice' pellets, or liquid carbon dioxide can be injected into air to produce fine particles of solid carbon dioxide 'snow', which rapidly sublime to gas. Both types are deposited onto, or mixed with, food in combo bins, trays, cartons or on conveyors. A small excess of snow or pellets continues the cooling during transportation or storage prior to further processing. If products are despatched immediately in insulated containers or vehicles, this type of chilling is able to replace on-site cold stores and thus saves space and labour costs. Snow is replacing dry-ice pellets because it is cheaper and does not have the problems of handling, storage and operator safety associated with dry ice. However, lack of uniformity in distribution of pellets resulted in some meat becoming frozen and

some remaining above 5°C, which permitted bacterial growth and resulted in variable product temperatures for subsequent processing. The use of snow horns to distribute a fine layer of snow over minced meat as it is loaded into combo bins has eliminated these problems and resulted in rapid uniform cooling to 3–4°C. A recent advance in the use of carbon dioxide snow for chilled and frozen distribution of foods.

Liquid nitrogen is used in both freezing and chilling operations. For batch chilling, typically 90–200 kg of food is loaded into an insulated stainless steel cabinet, containing centrifugal fans and a liquid nitrogen injector. The liquid nitrogen vaporizes immediately and the fans distribute the cold gas around the cabinet to achieve a uniform reduction in product temperature. The chiller has a number of pre-programmed time/temperature cycles which are microprocessor controlled. A food probe monitors the temperature of the product and the control system changes the temperature inside the cabinet as the food cools, thus allowing the same pre-programmed cycle to be used irrespective of the temperature of the incoming food.

For continuous chilling, food is passed on a variable speed conveyor to an inclined, insulated, cylindrical barrel having a diameter of 80–120 cm and length 4–10 m depending on the capacity. The barrel rotates slowly and internal flights lift the food and tumble it through the cold nitrogen gas. The temperature and gas flow rate are controlled by a microprocessor and the tumbling action prevents food pieces sticking together, to produce a free-flowing product. Controlled temperature liquid nitrogen tumblers are used to improve the texture and binding capacity of mechanically formed meat products. The gentle tumbling action in a partial vacuum, cooled by nitrogen gas to -2°C, solubilizes proteins in poultry meat, which increases their binding capacity and water holding capacity, improving later forming and coating operations. An alternative design is a screw conveyor inside a 2.5 m long stainless steel housing, fitted with liquid carbon dioxide injection nozzles. Foods such as minced beef, sauce mixes, mashed potato and diced vegetables are chilled rapidly as they are conveyed through the chiller at up to 1 t h⁻¹. It is used to firm foods before portioning or forming operations or to remove heat from previous processing stages.

Cryogenic cooling include sausage manufacture, where carbon dioxide snow removes the heat generated during size reduction and mixing and cryogenic

grinding where the cryogen reduces dust levels, prevents dust explosions and improves the throughput of mills. In spice milling, cryogens also prevent the loss of aromatic compounds. In the production of multi-layer chilled foods the first layer of product is filled and the surface is hardened with carbon dioxide. The next layer can then be added immediately, without waiting for the first layer to set, and thus permit continuous and more rapid processing.

Packaging

Packaging may be defined in terms of its protective role as in 'packaging is a means of achieving safe delivery of products in sound condition to the final user at a minimum cost' or it can be defined in business terms as 'a techno-economic function for optimising the costs of delivering goods whilst maximising sales and profits'. The functions of packaging are:

- containment – to hold the contents and keep them secure until they are used
- protection – against mechanical and environmental hazards encountered during distribution and use
- communication – to identify the contents and assist in selling the product. Shipping containers should also inform the carrier about the destination and any special handling or storage instructions. Some packages inform the user about method of opening and/or using the contents
- machinability – to have good performance on production lines for high speed filling, closing and collating (1000 packs per min or more), without too many stoppages
- convenience – throughout the production, storage and distribution system, including easy opening, dispensing and/or after-use retail containers for consumers. The main marketing considerations for a package are:
 - the brand image and style of presentation required for the food
 - flexibility to change the size and design of the containers
 - compatibility with methods of handling and distribution, and with the requirements of retailers.

Packaging materials can be grouped into two main types:

1. Shipping containers which contain and protect the contents during transport and distribution, but have no marketing function. Corrugated fibreboard cases are the most widely used shipping container for 5–20 kg loads, although they are steadily being replaced by shrink wrapped or stretch wrapped corrugated trays. Other types of shipping containers include wooden or metal cases, crates, barrels, drums and sacks. More recently, intermediate bulk containers (IBCs), including combi-bins, large boxes made from metal, plastic or corrugated fibreboard, and large bags made from woven plastic fabric, have been introduced to increase handling efficiencies and have largely displaced wooden crates and cases. IBCs have a capacity between that of a bulk road tanker and 220 l drums (e.g. 1000 l containers with integral pallet and bottom discharge valve), and are used for powders and liquids. Many shipping containers are expensive and therefore made to be returnable (e.g. plastic crates for milk, beer and soft drink bottles). Others (for example expanded polystyrene shipping containers) provide insulation and mechanical protection for tomatoes and grapes or cured and wet fish and are used once.

The requirements of shipping containers are to:

- contain products efficiently throughout the journey
- protect against the climate and contamination
- be compatible with the product
- be easily and efficiently filled and sealed
- be easily handled
- remain securely closed in transit, open easily when required (e.g. customs inspection) and reclose securely
- carry information for carriers, wholesalers, and manufacturers about contents, destination, and how to handle and open the pack.
- have minimum cost
- be readily disposable, re-usable or have another use.

2. Retail containers (or consumer units) which protect and advertise the food in convenient quantities for retail sale and home storage (for example metal cans, glass bottles, jars, rigid and semi-rigid plastic tubs, collapsible tubes, paperboard cartons, and flexible plastic bags, sachets and overwraps).

Types of packaging materials

Textiles and wood

Textile containers have poor gas and moisture barrier properties, they are not suited to high-speed filling, have a poorer appearance than plastics and are a poor barrier to insects and micro-organisms. They are only used as shipping containers or in a few niche markets as over-wraps for other packaging. Wooden shipping containers have been used for a range of solid and liquid foods including fruits, vegetables, tea, wines, spirits and beers. They offer good mechanical protection, good stacking characteristics and a high vertical compression strength-to-weight ratio. However, polypropylene and polyethylene drums, crates and boxes have a lower cost and have largely replaced wood in many applications. The use of wood continues for some wines and spirits because the transfer of flavour compounds from the wooden barrels improves the quality of the product.

Metal

Hermetically sealed metal cans have advantages over other types of container in that they can withstand high temperature processing and low temperatures; they are impermeable to light, moisture, odours and micro-organisms to provide total protection of the contents; they are inherently tamperproof and the steel can be recycled by extraction from solid wastes. The high cost of metal and relatively high manufacturing costs make cans expensive. They are heavier than other materials, except glass, and therefore incur higher transport costs. Types of metals are as following:(1)Three-piece cans (2) Two-piece cans (3)Aerosol cans and (4) Other aluminium packaging.

Glass

Glass jars and bottles are made by heating a mixture of sand (73%), the main constituent being silica (99% SiO_2), broken glass or 'cullet' (15–30% of total weight), soda ash (Na_2CO_3) and limestone (CaCO_3 or $\text{CaCO}_3 \cdot \text{MgCO}_3$) to a temperature of 1350–1600°C. Alumina (Al_2O_3) improves the chemical durability of the glass, and refining agents reduce the temperature and time required for melting, and also help remove gas bubbles from the glass.

Glass containers have the following advantages:

- they are impervious to moisture, gases, odours and micro-organisms
- they are inert and do not react with or migrate into food products
- they have filling speeds comparable with those of cans
- they are suitable for heat processing when hermetically sealed
- they are transparent to microwaves
- they are re-useable and recyclable
- they are resealable
- they are transparent to display the contents and can be decorated
- they can be moulded into a wide variety of shapes and colours
- they are perceived by the customer to add value to the product
- they are rigid, having good vertical strength to allow stacking without damage to the container.

The main disadvantages of glass include:

- higher weight which incurs higher transport costs than other types of packaging
- lower resistance than other materials to fracturing and thermal shock
- more variable dimensions than other containers
- potentially serious hazards from glass splinters or fragments in foods.

Flexible films

Flexible packaging describes any type of material that is not rigid, but the term 'flexible film' is usually reserved for non-fibrous plastic polymers which are less than 0.25 mm thick. Flexible films have the following properties:

- they have relatively low cost
- they can be produced with a range of barrier properties against moisture and gases
- they are heat sealable to prevent leakage of contents, and can be laminated to paper, aluminium or other plastics
- they are suitable for high-speed filling
- they have wet and dry tensile and impact strength
- they are easy to handle and print and are convenient for the manufacturer, retailer and consumer
- they add little weight to the product and fit closely to the shape of the food, thereby wasting little space during storage and distribution.

Flexible films are single films, coated films, laminated films, coextruded films, edible and biodegradable films.

Rigid and semi-rigid plastic containers

Trays, cups, tubs, bottles and jars are made from single or coextruded polymers. The main advantages, compared with glass and metal, are as follows:

- they have a lower weight, resulting in savings of up to 40% in transport and distribution costs compared to glass or metal
- they are produced at a lower temperature than glass (300°C compared to 800°C) and therefore incur lower energy costs
- they are precisely moulded into a wider range of shapes than glass
- they are tough, unbreakable (impact and pressure resistance)

- they are easy to seal
- they can be easily coloured for aesthetic appeal and UV-light protection
- they are produced at relatively low cost
- they have a greater chemical resistance than metals.

Paper and board

Paper has a number of advantages as a food packaging material:

- it is produced in many grades and converted to many different forms, especially boxes or cartons
- it is recyclable and biodegradable
- it is easily combined with other materials to make coated or laminated packs
- it can be produced with different degrees of opacity.

Boards are made in a similar way to paper but are thicker to protect foods from mechanical damage. The main characteristics of board are:

- thickness
- stiffness
- the ability to crease without cracking
- the degree of whiteness
- surface properties
- suitability for printing

Combined packaging systems

A common combined packaging system is the use of cartons to contain multiple packs of food in flexible film. These in turn are shrink-wrapped or placed in corrugated board shipping containers. The bag collapses evenly as liquid is withdrawn which prevents the product from becoming trapped in the folds of the

bag and prevents oxidation of the product by air. It is a convenient lightweight secure container for liquid foods (for example wine, fruit juice, edible oils, syrups and milk).

Active packaging technologies

The rapid growth of chilled, MAP/CAP, and minimally processed foods has been accompanied by a number of developments in packaging technologies, which may be grouped under the term 'active' packaging. Active packaging has been included:

- oxygen scavenging
- CO₂ production
- preservative release (e.g. ethanol production)
- antimicrobial action
- aroma release
- moisture removal
- removal of odours, off-flavours or ethylene
- time–temperature indicators
- gas indicators
- edible coatings and films
- films to slow moisture transfer between ingredients that have different water activities
- microwave 'susceptor' films that create high temperature treatments.

Printing

Printing inks for films and papers consist of a dye which is dispersed in a blend of solvents, and a resin which forms a varnish. Solvents must be carefully removed after application of the ink to prevent odour contaminating the product

and blocking the film during use. Other considerations include the cost of the ink, and compatibility with the film which is needed to achieve a high bond strength. There are five processes used to print films and papers:

1. Flexographic printing (or relief or letterpress) in up to six colours, is high speed and suitable for lines or blocks of colour. A fast-drying ink is applied to the film by a flexible rubber plate with raised characters. The plate is pressed against an inked roller to cover the raised portions with ink and then against the film or paper. It is used, for example, for cartons that do not require high print quality.
2. Photogravure printing (or intaglio) is able to produce high-quality detail and realistic pictures and has been more expensive than flexographic printing, although new methods of making gravure cylinders have reduced the cost. It uses an engraved chromium-plated roller with the printing surfaces recessed in the metal. Ink is applied to the roller and the excess is wiped from all but the recesses. The remaining ink is transferred to the packaging material.
3. Offset lithography (or planographic) is based on the incompatibility of grease and water. A greasy ink is repelled by moistened parts of a printing plate but remains on compatible parts which carry the design. This method produces a print of similar quality to that of rotogravure and is suitable for papers and boards that are too rough for rotogravure printing.
4. Screen printing in which ink passes through a porous surface of a printing screen.
5. Ink-jet printing in which electrically charged droplets of ink are deflected by charged deflector plates to create the image.

Bar codes and other markings

The bar code information is fed to a computer which deducts the item from the store inventory and enables faster stock-taking, detection of pilferage and automatic re-ordering. The information is also collated into product sales reports, which can be used by store managers to adjust the shelf space allotment to specific items, or produce data on competitors' sales or the results of promotion and marketing strategies. Corrugated board shipping containers are also bar coded to inform the carrier about the destination, but this is not yet possible directly onto shrink-wrapping. Markings are also required on containers to show

the 'sell-by' or 'use by' date in many countries. A manufacturer's code is printed onto containers to identify the factory, the production line and the shift during which the product was made. Coding lasers are non-contact and produce permanent marks without the use of inks and solvents. They are fully programmable to easily change the characters, and are capable of producing 400–2000 characters per second on paperboard, metal, glass, plastics and foil. Future developments in labelling may include an information micro-dot on the pack that contains all required label information in a number of languages, leaving the main area of the pack for graphic design and branding.

Interactions between packaging and foods

Toxicological effects of interactions between food and packaging materials and also the effect of such interactions on the shelf life and sensory quality of the food are extremely complex. The main aspects that are being intensively studied are:

- lacquers and coatings for metal containers to prevent interaction of food acids, anthocyanins, sulphur compounds and other components with steel, tin or aluminium
- the migration of plasticisers, pigments, metal ions and other components of plastic packaging into foods
- the migration of oils from foods into plastics
- the interaction of the package and food under different processing conditions.

Environmental considerations

The value of packaging materials to protect foods against losses is illustrated by levels of food wastage of 2–3% in developed countries, compared to 30–50% in developing countries where sophisticated packaging, storage and distribution are not found. There have been a number of developments in both the types of materials used for packaging and the methods of handling and

distribution of packaged foods that have affected the environmental impact of food packaging.

Packaging costs

It is difficult to compare packaging costs without also including, the costs of shipping containers, depreciation costs of packaging machinery, labour requirements, etc. It is also important to consider the cost of the package in relation to the value of the product.

Manufacture of packaging materials

The main function of packaging is to enable consumers to receive foods in good condition at the lowest reasonable price. Manufacturers have the responsibility to review the economies of the total production and distribution chain, re-use and disposal options, and marketing and commercial considerations should be reconciled with economy in the use of materials and energy, and the environment. A code of packaging described as follows:

- packaging must comply with all legal requirements
- the pack must be designed to use materials as economically as possible while having regard to protection, preservation and presentation of the product
- packaging must adequately protect foods under normal conditions of distribution, retailing and home storage
- the packaging materials should have no adverse effects on the contents
- the pack must not contain any unnecessary void volume, nor mislead as to the amount, character or nature of the product it contains
- the package should be convenient for the consumer to handle and use for opening and reclosing when required and be appropriate to the product and its use
- all relevant information about the product should be presented concisely and clearly on the pack

- the pack should be designed with regard to its possible effect on the environment, its ultimate disposal and to possible recycling and re-use.

A proportion of the cost of packaging is the energy required for their manufacture and the energy needed to make 1 kg of different packaging materials from their raw materials. Other factors that should be taken into account are the energy needed to procure raw materials, manufacture the packaging material, convert the material into packages, handle and use the packs, types of energy sources used and their conversion efficiency, the distance that packaging raw materials are transported and the energy efficiency of the transport methods.

The total environmental impact of production of packaging takes into account the types and sources of raw materials, the cost of transporting them, the energy used to produce the packaging and the amount of wastage during production. The amount of energy needed to produce a range of packaging materials, including paper, board, aluminium, steel, glass and a variety of plastic films. A further area of environmental concern is the level of emissions and water pollution during the production of packaging materials. Controlled and uncontrolled airborne emissions of polluting gases and lead, and waterborne emissions of suspended solids, acids, a range of organic chemicals their biological oxidation demand (BOD), and heavy metals for a range of packaging materials, including steel, aluminium, plastic films, paper, board and glass.

Distribution of packaging materials and ingredients for food production

Ingredients and packaging materials were delivered in small unit loads to food manufacturers, which not only increased fuel consumption for transportation, but also increased the number of packages that were required to protect both ingredients and packaging materials. The energy needed to transport goods or packs depends in part on the types of packaging used. Developments in packaging technologies and design of materials, including rolls of material for form-fill-seal machines to replace pre-formed packs, and stackable pots to replace cans and jars, have substantially reduced the volume of packaging materials to be transported and hence the fuel and packaging consumed to deliver them to food manufacturers. The materials used to transport packaging

have also been made lighter, especially with the introduction of shrink wrapping and the area of packaging material has increased, the weight of materials used has decreased.

Distribution to retailers and consumers

The development of improved barrier packaging materials has reduced the weight and cost of retail packaging. PET has replaced glass bottles, aluminium has replaced tinplate cans for carbonated beverages and printed co-extruded polymers have replaced glass jars with metal lids and printed paper labels, are each good examples of such savings. Changes in handling and distribution methods mean that few foods are now packaged in one material, and an additional one or more shipping containers are also now used.

Consumer recycling

In contrast to most purchased goods, which begin their useful life upon purchase, most packaging materials cease their usefulness at this stage and apart from home storage, the consumer most often disposes of the package without further consideration. Progress has been made in many countries to encourage consumers to separate glass, metal and paper packaging for recycling. For example, cans from household waste are separated magnetically, cleaned to remove dirt and treated in a de-tinning plant to extract and re-use the tin. There are considerable difficulties in separating out the wide variety of different plastic packaging materials for recycling or re-use and even where this occurs, the materials are not suitable for food grade applications. A balance must therefore be made between the lower costs of production of plastic packaging versus the limited capacity for recycling and consequent disposal and pollution problems, compared with glass, metal and paper packaging.

Materials handling

Efficient materials handling is 'the organised movement of materials in the correct quantities, to and from the correct place, accomplished with a minimum of time, labour, wastage and expenditure, and with maximum safety'. The important techniques identified are:

- a systems approach to planning a handling scheme
- the use of unit loads and bulk handling
- continuous methods of handling
- automation

When establishing methods for materials handling, a systems approach that covers raw materials and ingredients, in-process stock and distribution of finished products to consumers is needed. This creates optimum flows of materials, in the correct sequence throughout the production process, and avoids bottlenecks or shortages. This area is known as production planning. In summary, correct production planning should ensure that:

- raw materials, ingredients and packaging materials are scheduled to arrive at the factory at the correct time, in the correct quantities and in the required condition
- storage facilities are sufficient for the anticipated stocks of materials and are suitable to maintain the quality of materials for the required time
- handling equipment has sufficient capacity to move materials in the required amounts
- staff levels are adequate to handle the required amounts of materials
- processing and packaging equipment is selected to provide the required production throughput
- finished product warehousing is sufficient to accommodate stock levels, taking into account both production and sales volumes

- distribution vehicles are sufficient in number and capacity, and journeys are scheduled to optimise fuel consumption and drivers' time, particularly minimising journeys with empty vehicles.

Handling equipment for raw materials and ingredients

The bulk movement of particulate, powdered and liquid food ingredients by road or rail tanker, and storage in large silos, has been common practice in large plants for many years. More recent advances in microelectronics are now applied to monitoring and control of storage silos (fill-level, humidity and temperature) and multi-ingredient batch weighing and metering systems, using PLC based logic controllers. Mechanised handling systems for fresh crops and other raw materials for processing have developed from, for example, the pea viners and combine harvesters that have been in common use for several decades. Mobile crop washing, destoning and grading equipment, gentle-flow box tippers that transport and unload crops with minimal damage, and automatic cascade fillers for large boxes and 'jumbo' bags are now routinely used to produce washed and graded crops for processors and retailers. Batch weighing and metering systems are an integral part of ingredient or raw materials handling and there are a number of different systems: for example, sensors can be used to detect the loss in weight from a storage tank or silo as it is emptied and calculate the weight of ingredient used. Sensors on a mixing vessel can detect the increase in weight as different ingredients are added. The information from sensors is used by PLCs to control pumps, create pre-programmed recipe formulations and record data for production costing and stock control.

Handling equipment for processing

The pattern of movement of materials during processing should be as simple as possible to avoid the risk of contamination of processed foods by raw foods and to attain the other benefits. Cross-contamination is a major concern for all food processors, but especially for those that produce 'high-risk' foods. Five patterns are commonly used:

1. straight line – for relatively simple processes containing few pieces of equipment

2. serpentine (or 'zig-zag') – where the production line is increased for a given floor area by 'bending back' on itself
3. U-shaped – used when a process is required to place the finished product in the same general area as the starting point
4. circular – used when a part-processed or finished product is required in exactly the same place where it started
5. odd-angle – where there is no recognizable pattern, but where short flow lines are needed between a group of related operations, where handling is mechanised or where space limitations will not permit another layout.

It is important that all equipment which is used to handle foods is designed to be easily cleaned, to reduce the risk of product contamination. The principles of sanitary equipment design are incorporated into good practice guides. These can be summarised as follows:

- equipment surfaces that are in contact with food should be inert to the food being processed and must not migrate to, or be absorbed by, the food
- surfaces should be smooth and non-porous to prevent accumulations of food and bacteria
- surfaces should either be accessible for cleaning and inspection, or able to be easily disassembled for manual cleaning and inspection. If cleaned without disassembly, it should be demonstrated that results are similar to manual cleaning
- equipment should be self-draining and have a minimum number of internal crevices or 'dead spaces' where food or micro-organisms could collect
- equipment should protect food from external contamination.

Continuous handling equipment is an essential component of continuous processes and it also improves the efficiency of batch processing. The most important types of materials handling equipment used in food processing are

- conveyors and elevators
- pumps.

Conveyors and elevators

Conveyors are widely used in all food processing industries for the movement of solid materials, both within unit operations, between operations and for inspection of foods. There are a large number of conveyor designs, produced to meet specific applications, but all types can only cover a fixed path of operation. There are many designs of elevator, but two common types are bucket and magnetic elevators: bucket elevators consist of metal or plastic buckets fixed between two endless chains. They have a high capacity for moving free-flowing powders and particulate foods. The shape and spacing of the buckets and the speed of the conveyor ($15\text{--}100\text{ m min}^{-1}$) control the flow rate of materials. Magnetic elevators are used for conveying cans within canneries. They have a positive action to hold the cans in place, and are able to invert empty cans for washing, and they produce minimal noise. Conveyors and elevators are best suited to high-volume movement, where the direction of flow of materials is fixed and relatively constant. They can be used as a reservoir of work-in-progress.

Pumps and valves

Pumps, valves and associated pipework are the usual method of handling liquid foods, cleaning fluids, etc., and there is a very wide range of designs that are available, often for specific applications.

Waste management and disposal

With the exception of a few processes (for example baking or grain milling), solid wastes and liquid effluents are produced in large quantities by food processing. They arise due to cleaning and preparation of raw materials, spillages and cleaning of equipment and floors, and change-overs to different products. Adequate cleaning routines in food plants are part of good manufacturing practice (GMP) and form an integral part of management systems needed to implement quality assurance and HACCP programmes. The nature of wastes varies according to the type of food being processed: fruit and vegetable processing, for example, produces effluents that have high concentrations of sugars, starch and solid matter such as peelings, whereas meat and dairy processing effluents contain a

higher proportion of fats and proteins. Nearly all processors also produce dilute waste water from washing equipment, and solid wastes from discarded packaging materials, office paper, etc.

In large processing plants or those located in unpopulated areas, effluent treatment can be carried out on-site in purpose-built facilities, but the effluent from most food factories is treated by municipal authorities or private water utilities. The cost of effluent treatment is based on a combination of the volume of effluent and its polluting potential, as measured by both chemical oxidation demand (COD)¹ and the amount of suspended solids (in mg l⁻¹). High concentrations of sugars, starches and oils have very high polluting potential (CODs from 500–4000 mg l⁻¹ compared to domestic sewage at 200– 500 mg l⁻¹) because as micro-organisms utilize these materials, they remove dissolved oxygen from water, which may kill fish and aquatic plants.

In many processes it is possible to reduce treatment costs by separating concentrated waste streams from more dilute ones (for example, washings from boiling pans in confectionery or jam production can be isolated from general factory washwater). Effluents that contain a relatively high percentage of sugars, starch or pectic materials have been used in some instances as growth media for yeasts or moulds to produce saleable animal feeds and thus reduce the costs of treatment. Other means of reducing both polluting potential and waste treatment charges include:

- recycling water
- recovering fats and oils by aeration flotation for sale as by-products
- storing concentrated effluents and blending them over a period of time with dilute wastes to produce a consistent moderately dilute effluent
- removing solids using screens and discharging them as solid waste to commercial waste disposal companies or for composting
- flocculating suspended solids using a chemical coagulant (for example lime or ferrous sulphate) or removing suspended solids directly by sedimentation, filtration or centrifugation and disposing of them as solid waste

- treating effluents using a biological method such as a trickling filter, activated sludge processes, lagoons, pond, oxidation ditches, spray irrigation or anaerobic digesters
- fermenting waste materials to produce more valuable products (e.g. organic acids, vitamins, etc.).

Storage

Storage of raw materials, ingredients and products can take place under ambient conditions or under controlled conditions of temperature, humidity or atmospheric composition. Manufacturers reduce the amount of stored ingredients and products to a minimum for the following reasons:

- financial – money is tied up in materials that have been paid for, or in final products that have incurred the costs of production. Large amounts of stored materials may adversely affect the cashflow of a company.
- loss of quality – chemical or biochemical changes to foods and deterioration of some types of packaging materials may occur during storage which reduce their quality and value, or render them unusable.
- risk of pilferage for some high value products
- high cost of warehousing and storage space.

The seasonality of supply for some raw materials and, for some products a seasonal demand, it is necessary for processors to maintain stocks of ingredients, packaging materials and final products. The 'just-in-time' methodologies of materials supply that are found in some other industries are less common in the food processing sector. Stored goods (or inventory) may be classified into raw materials, work-in-progress and finished goods. They can be categorised more usefully by their role in the production system as follows:

- buffer (or safety) inventory, to compensate for uncertainties in supply or demand
- cycle inventory – this occurs because a processor chooses to produce in batches that are greater than the immediate demand

- anticipation inventory – this is created where seasonal demand or supply fluctuations are significant but predictable. It is used especially for supply of seasonal fruits and vegetables, or for products that have a specific seasonal demand (for example Easter eggs and Christmas cakes)
- pipeline (or in-transit) inventory, for materials that are in the process of being moved from a point of supply to a point of demand.

Decisions on the size of stocks of different materials that are held in storage depend on the balance between two sets of costs: the cost of buying and the cost of storage.

The physical conditions of storage are an important aspect that may be given less attention than other areas of processing and as a result, causes problems of contamination and financial losses. It is important that there is a similar level of control over hygiene and storage conditions in warehouses and distribution vehicles to that given to processing operations. The main causes of spoilage of stored foods and ingredients are as follows:

- contamination by rodents, birds, insects and micro-organisms
- contamination by dust or foreign bodies
- respiratory activity of fresh foods, or enzyme activity leading to development of rancidity or browning
- losses from spillage, bursting of containers, etc.
- incorrect storage conditions such as exposure to sunlight, heat and moisture.

Correct storage and prevention of spoilage are important for finished products, because the expenditure that has already been made during processing makes losses at this stage very damaging financially. Storerooms, warehouses and distribution vehicles should therefore be constructed to prevent access by rodents, insects and birds, and carefully inspected on a regular basis to ensure that preventative measures are effective.

For ambient temperature storage, the store-room should be cool with good ventilation to maintain a flow of air. Fresh foods are only stored for short periods, but the storeroom temperature should be low and humidity sufficiently high to prevent wilting or drying out. Most foods are packaged for protection and

convenience of handling. Packages which are grouped into larger (or 'unitized') loads require less handling when they are moved through storage and distribution networks. Wooden pallets are commonly used to move unitized loads of cases or sacks by fork-lift or stacker trucks.

Working procedures in storerooms and warehouses ensure that sacks or cartons of food are stored on pallets or racks to keep them off the floor, with space to clean behind the stack. They should be carefully stacked to the recommended height to prevent crushing or collapse and injury to operators. Lighting should be as bright as possible and at a high level to reduce shadowing caused by stacked pallets. Warehouse management systems are increasingly computer controlled and are used to monitor material movements into and out of the stores, check stock levels, stock rotation, the use of materials in the process and the destinations for delivery of products. Daily cleaning routines are used as part of a HACCP plan to prevent dust or spilled food accumulating which would encourage insects or rodents.

Distribution

The link between harvesting and production of a processed food and purchase by the customer is known as the distribution chain and the different systems involved in distribution are termed 'logistics'. The main factors that are involved in an efficient distribution chain are:

- providing the consumer with products at the right place, at the right time and in the right amount
- reducing the cost to a minimum (distribution is an expense but does not add value to a product)
- maintaining the product quality throughout the distribution chain.

Consumers have demanded foods having better quality, freshness, availability, and a greater variety. This consumer pressure has resulted in a substantial increase in the volume and range of foods that are handled by the major food retailers, together with higher standards for temperature control of some foods. Products from a food manufacturer were transported to a relatively

large number of small distribution depots that each handled a single product. Delivery volumes were low and it was not economic to deliver every day. In addition, foods that required temperature-controlled transport had to be carried on separate vehicles, some of which were owned by contractors who operated their own distribution policies and delivery schedules. Each of these aspects increased the cost of distribution and reduced both quality and efficiency. These problems caused retailers to change their strategy for food distribution, and use mathematical models and simulations to improve the logistics of food supply to reduce costs and distribution times as a result of:

- combining distribution streams of various suppliers
- combining transport of fresh food, frozen food and dry foods
- changing the method and frequency of ordering
- redesigning and reorganizing warehouses

These developments resulted in a smaller number of large 'composite' distribution depots that can handle a wide range of products. Delivery vehicles use insulated trailers that are fitted with movable bulkheads and refrigeration units to create three different temperature zones. Short shelf life products are received into distribution depots during the afternoon and evening, and are delivered to retail stores before trading starts the next day (termed the 'first wave' delivery). Longer shelf life and ambient products are taken from stock and formed into orders for each retail store over a 24-hour period, and are delivered in a 'second wave' between 8 am and 8 pm at scheduled times that are agreed with each store. Many larger retailers now use electronic data interchange (EDI) to automatically order replacement products, directly in response to consumer purchases. These developments have caused a dramatic increase in distribution and handling costs for processors. Many smaller- and medium-scale processors now co-operate in logistics, to gain cost savings and more efficient distribution from the larger volumes that are handled. Managers in processing factories use forecasts of demand for foods and actual orders to inform computer-based systems, known as material requirement planning (MRPI) systems which co-ordinate decisions on ordering, stock levels, work-in-progress, storage and distribution of finished products. This enables them to calculate the amounts of materials that are needed at a particular time to manufacture products to meet

customer demand. The software is also used to generate customer orders and sales forecasts, the physical distribution routes for products, records of available stocks and inventory. The information can then be used to produce purchase orders for raw materials, work orders and material plans.

The concept of MRPI has expanded to integrate other parts of the business and has become Manufacturing Resource Planning (MRPII). This is a single integrated system, containing a database that can be accessed by all parts of the company, including engineering departments, sales and marketing departments, finance and accounting departments as well as production managers. Information from sales can be used directly in, for example, production scheduling, buying and plant maintenance. Details of computerised systems for management and process control.

Assignment for FTech-304 Food Microbiology

Mechanisms of principal food preservation procedures

Cooling, chill distribution and storage: Low temperature to retard growth

Freezing, frozen distribution and storage: Low temperature and reduction of water activity to prevent growth

Drying, curing and conserving: Reduction in water activity sufficient to delay or prevent growth

Vacuum and oxygen-free 'modified atmosphere' packaging: Low oxygen tension to inhibit strict aerobes and delay growth of facultative anaerobes

Carbon dioxide-enriched 'modified atmosphere' packaging: Specific inhibition of some micro-organisms by carbon dioxide

Addition of acids: Reduction of pH value and sometimes additional inhibition by the particular acid

Lactic fermentation: Reduction of pH value in situ by microbial action and sometimes additional inhibition by the lactic and acetic acids formed and by other microbial products, e.g. ethanol, bacteriocins

Emulsification: Compartmentalization and nutrient limitation within the aqueous droplets in water-in-oil emulsion foods

Addition of preservatives: Inhibition of specific groups of microorganisms

Pasteurization and appertization: Delivery of heat sufficient to inactivate target micro-organisms to the desired extent

Radurization, radication and radappertization: Delivery of ionizing radiation at a dose sufficient to inactivate target microorganisms to the desired extent

Application of high hydrostatic pressure Pascalization: Pressure-inactivation of vegetative bacteria, yeasts and moulds

Pasteurization and Appertization

Pasteurization, the term given to heat processes typically in the range 60–80 °C and applied for up to a few minutes, is used for two purposes. First is the elimination of a specific pathogen or pathogens associated with a product. This type of pasteurization is a legal requirement introduced as a public health measure when a product has been implicated as a vehicle of illness. Examples are milk, bulk liquid egg and ice cream mix, all of which have a much improved safety record as a result of pasteurization. The second reason for pasteurizing a product is to eliminate a large proportion of potential spoilage organisms, thus extending its shelf-life. This is the objective when acidic products such as beers, fruit juices, pickles, and sauces are pasteurized. Where pasteurization is introduced to improve safety, its effect can be doubly beneficial.

Appertization refers to processes where the only organisms that survive processing are non-pathogenic and incapable of developing within the product under normal conditions of storage. Appertized products have a long shelf-life even when stored at ambient temperatures. The term was coined as an alternative to the still widely used description commercially sterile which was objected to on the grounds that sterility is not a relative concept; a material is either sterile or it is not. An appertized or commercially sterile food is not necessarily sterile – completely free from viable organisms. It is free from organisms capable of growing in the product under normal storage conditions. Thus for a canned food in temperate climates, it is not a matter of concern if viable spores of a thermophile are present as the organism will not grow at the prevailing ambient temperature.

Quantifying the Thermal Death of Micro-organisms: D and z Values

The generally accepted view is that thermal death is a first order process, at a given lethal temperature, the rate of death depends upon the number of viable cells present. We can express this mathematically as:

$$dN/dt = -cN$$

where dN/dt is the rate of death, N is the number of viable cells present and c is a proportionality constant. The minus sign signifies that N is decreasing.

Heat Sensitivity of Micro-organisms

The heat sensitivity of various micro-organisms which shows their D values. Generally psychrotrophs are less heat resistant than mesophiles, which are less heat resistant than thermophiles; and Gram-positives are more heat resistant than Gram-negatives. Most vegetative cells are killed almost instantaneously at 100 °C and their D values are measured and expressed at temperatures appropriate to pasteurization.

Bacterial spores are far more heat resistant than vegetative cells; thermophiles produce the most heat resistant spores while those of psychrotrophs and psychrophiles are most heat sensitive. Since spore inactivation is the principal concern in producing appertized foods, much higher temperatures are used in appertization processes and in the measurement of spore D values. Yeast ascospores and the asexual spores of moulds are only slightly more heat resistant than the vegetative cells and will be killed by temperatures at or below 100 °C , e.g. in the baking of bread.

The heat resistance exhibited by the bacterial endospore is due to its ability to maintain a very low water content in the central DNA-containing protoplast; spores with a higher water content have a lower heat resistance. The relative dehydration of the protoplast is maintained by the spore cortex, a surrounding layer of electronegative peptidoglycan which is responsible for the spore's refractile nature.

Thermal sensitivity as measured by the D value can vary with factors other than the intrinsic heat sensitivity of the organism concerned. This is most pronounced with vegetative cells where the growth conditions and the stage of growth of the cells can have an important influence. For example, stationary phase cells are more heat resistant than log phase cells. Heat sensitivity is dependent on the composition of the heating menstruum; cells tend to show greater heat sensitivity as the pH is increased above 8 or decreased below 6.

Spoilage of Canned Foods

If a canned food contains viable micro-organisms capable of growing in the product at ambient temperatures, then it will spoil. Organisms may be present as a result of an inadequate heat process, underprocessing, or of post process contamination through container leakage. Spoilage by a single spore former is diagnostic of underprocessing since rarely would such a failure be so severe that vegetative organisms would survive.

Spoilage often manifests itself through microbial gas production which causes the ends to distend and a number of different terms. Cans may sometimes swell as a result of chemical action. Defects in the protective lacquer on the inside of the can may allow the contents to attack the metal releasing hydrogen. These hydrogen swells can be distinguished from microbiological spoilage since the appearance of swelling occurs after long periods of storage and the rate at which the can swells is very slow. In cases where microbial growth occurs without gas production, spoilage will only be apparent once the pack has been opened. *Bacillus* species, with the exceptions of *B. macerans* and *B. polymyxa*, usually break down carbohydrates to produce acid but no gas giving a type of spoilage known as a 'flat sour', which describes the characteristics of both the can and the food. The heat process a product receives is determined largely by its acidity: the more acidic a product is, the milder the heat process applied.

Leakage is the most common cause of microbiological spoilage in canned foods. Cans are the most common containers used for retorted products, although glass jars, rigid plastic containers and soft pouches are also sometimes used. Cans are made of two or three parts: the three-part can consists of a base, body and lid while in two part cans the body and base are made from a single piece of metal. The correct formation and integrity of this seam are crucial to preventing leakage and monitoring seam integrity is an important aspect of quality control procedures in canning.

Description of blown cans

Flat: No evidence of swelling.

Hard swell: Both ends of the can are permanently and firmly bulged and do not yield readily to thumb pressure.

Soft swell: Both ends bulged but not tightly; they yield to thumb pressure.

Springer: One end flat, the other bulged. When the bulged end is pressed in then the flat one springs out.

Flipper: A can with a normal appearance which when brought down sharply on a flat surface causes a flat end to flip out. The bulged end can be forced back by very slight pressure.

Aseptic Packaging

Aseptic packaging was confined to liquid products such as milk, fruit juices and some soups which would heat up very quickly due to convective heat transfer. If a food contained solid particles larger than about 5 mm diameter it was unsuited to the rapid processing times due to the slower conductive heating of the particulate phase. Scraped surface heat exchangers have been used to process products containing particles up to 25 mm in diameter but at the cost of overprocessing the liquid phase. To avoid this, one system processes the liquid and solid phase separately. A promising alternative is the use of ohmic heating in which a food stream is passed down a tube which contains a series of electrodes. An alternating voltage is applied across the electrodes and the food's resistance causes it to heat up rapidly. Most of the energy supplied is transformed into heat and the rate at which different components heat up is determined by their conductivities rather than heat transfer.

Packaging material is generally refractory to microbial growth and the level of contamination on it is very low. Nevertheless to obtain commercial sterility it is given a bactericidal treatment, usually with hydrogen peroxide, sometimes coupled with UV irradiation.

Microwave Radiation

The microwave region of the e.m. spectrum occupies frequencies and has a relatively low quantum energy. For the two frequencies used in food processing. Microwaves are generated using a magnetron. Magnetrons are used both commercially and domestically, but their biggest impact has been in the domestic microwave oven and in catering where their speed and convenience have enormous advantages. The principal problem associated with the domestic use of microwaves is non-uniform heating of foods, due to the presence of cold spots in the oven, and the non-uniform dielectric properties of the food.

Microwaves have been slow to find industrial applications in food processing, although they are used in a number of areas. Microwaves have been used to defrost frozen blocks of meat prior to their processing into products such as burgers and pies thus reducing wear and tear on machinery. There has been a limited application of microwaves in the blanching of fruits and vegetables and in the pasteurization of soft bakery goods and moist (30% H₂O) pasta to destroy yeasts and moulds. Microwaves have been used to pasteurize high-acid foods, such as fruits in syrup, intended for distribution at ambient temperature. These are packed before processing and have an indefinite microbiological shelf-life because of the heat process and their low pH. The modest oxygen barrier properties of the pack has meant that their biochemical shelf-life is limited to a few months.

UV Radiation

The quanta contain energy sufficient to excite electrons in molecules from their ground state into higher energy orbitals making the molecules more reactive. Chemical reactions induced in micro-organisms can cause the failure of critical metabolic processes leading to injury or death. Only quanta providing energy sufficient to induce these photochemical reactions will inhibit micro-organisms, so those wavelengths that are most effective give us an indication of the sensitive chemical targets within the cell. The resistance of micro-organisms to UV is largely determined by their ability to repair such damage, although some organisms such as micrococci also synthesize protective pigments.

Death of a population of UV-irradiated cells demonstrates log-linear kinetics similar to thermal death and, in an analogous way, D values can be determined. Determination of UV D values is not usually a straightforward affair since the incident radiation can be absorbed by other medium components and has very low penetration. This low penetrability limits application of UV radiation in the food industry to disinfection of air and surfaces. Low-pressure mercury vapour discharge lamps are used: 80% of their UV emission is at a wavelength of 254 nm which has 85% of the biological activity of 260 nm.

Air disinfection is only useful when the organisms suspended in air can make a significant contribution to the product's microflora and are likely to harm the product; for example, in the control of mould spores in bakeries.

Process water can be disinfected by UV; this avoids the risk of tainting sometimes associated with chlorination, although the treated water will not have the residual antimicrobial properties of chlorinated water. UV radiation is commonly used in the depuration of shellfish to disinfect the water recirculated through the depuration tanks. Chlorination would not be suitable in this situation since residual chlorine would cause the shellfish to stop feeding thus stopping the depuration process. Surfaces can be disinfected by UV, although protection of microorganisms by organic material such as fat can reduce its efficacy. Food containers are sometimes treated in this way and some meat chill store rooms have UV lamps to retard surface growth. UV can induce spoilage of products containing unsaturated fatty acids where it accelerates the development of rancidity. Process workers must be protected from UV since the wavelengths used can cause burning of the skin and eye disorders.

Ionizing Radiation

Ionizing radiation has sufficient energy to eject electrons from molecules it encounters. Ionizing radiation can affect micro-organisms directly by interacting with key molecules within the microbial cell, or indirectly through the inhibitory effects of free radicals produced by the radiolysis of water. These indirect effects play the more important role since in the absence of water, doses 2–3 times higher are required to obtain the same lethality. Removal of oxygen also increases microbial resistance 2–4 fold and it is thought that this may be due to the ability

of oxygen to participate in free radical reactions and prevent the repair of radiation induced lesions. As with UV irradiation, the main site of damage in cells is the chromosome. Hydroxyl radicals cause single- and double-strand breaks in the DNA molecule as a result of hydrogen abstraction from deoxyribose followed by β -elimination of phosphate which cleaves the molecule. They can hydroxylate purine and pyrimidine bases. Resistance to ionizing radiation depends on the ability of the organism to repair the damage caused.

Free radicals created by irradiation can be detected using electron spin resonance when they are trapped in solid matrices such as bone, seeds and shells. The energy stored in grains of silicate minerals as a result of irradiation can be measured in foods such as herbs and spices using thermoluminescence and long chain volatile hydrocarbons and 2-alkylcyclobutanones produced by irradiation of fatty foods can be detected using gas chromatography. One microbiological test for irradiated food is based on the ratio between an assessment of total microbial numbers using the DEFT technique and a plate count to determine the number of viable bacteria present. Morphological, biochemical and other changes which may impede isolation and identification and increased radiation resistance have been noted as a result of repeated cyclic irradiation. The levels of radiation proposed for foods are not sufficient to induce radioactivity in the product and there is no evidence that consumption of irradiated foods is harmful. Food irradiation facilities do require stringent safety standards to protect workers but that is already in place for the irradiation of other materials such as the sterilization of medical supplies and disposables.

High-Pressure Processing – Pascalization

High pressure processing is a batch process employing a pressure vessel, the pressure transmission fluid (usually water) and pumps to generate the pressure. Although the capital cost of equipment is quite high, hydrostatic processing has a number of appealing features for the food technologist. It acts instantly and uniformly throughout a food so that the processing time is not related to container size and there are none of the penetration problems associated with heat processing. Commercial application of high-pressure technology was limited mainly to acidic products. The yeasts and moulds normally

responsible for spoilage in these products are pressure sensitive and the bacterial spores that survive processing are unable to grow at the low pH. The range of products may be increased by coupling moderate pressure with a heat treatment equivalent to pasteurization. In one trial, shelf stable, low acid foods were produced by combining a pressure of just 0.14MPa with heating at temperatures of 82–103 °C. Other developments such as equipment capable of semi- or fully-continuous operation will considerably improve commercial feasibility, so that we may see and hear a lot more about pascalization.

Low-Temperature Storage – Chilling and Freezing

The rates of most chemical reactions are temperature dependent; as the temperature is lowered so the rate decreases. Since food spoilage is a result of chemical reactions mediated by microbial and endogenous enzymes, the useful life of many foods can be increased by storage at low temperatures. The use of chilling and freezing has extended to a much wider range of perishable foods and to such an extent that refrigeration is now arguably the technology of paramount importance to the food industry.

Chill Storage

Chilled foods are those foods stored at temperatures near, but above their freezing point, typically 0–5 °C. Chilled products such as fresh meat and fish and dairy products have been joined by a huge variety of new products including complete meals, prepared and delicatessen salads, dairy desserts and many others. Three main factors have contributed to this development:

- (1) the food manufacturers' objective of increasing added value to their products;
- (2) consumer demand for fresh foods and ease of preparation while at the same time requiring the convenience of only occasional shopping excursions; and
- (3) the availability of an efficient cold chain – the organization and infrastructure which allows low temperatures to be maintained throughout the food chain from manufacture/harvest to consumption.

Chill storage can change both the nature of spoilage and the rate at which it occurs. There may be qualitative changes in spoilage characteristics, as low temperatures exert a selective effect preventing the growth of mesophiles and leading to a microflora dominated by psychrotrophs. Low temperatures can cause physiological changes in micro-organisms that modify or exacerbate spoilage characteristics. Two such examples are the increased production of phenazine and carotenoid pigments in some organisms at low temperatures and the stimulation of extracellular polysaccharide production in *Leuconostoc* spp. and some other lactic acid bacteria. In most cases, such changes probably represent a disturbance of metabolism due to the differing thermal coefficients and activation energies of the numerous chemical reactions that comprise microbial metabolism. Chilling will produce a phenomenon known as cold shock which causes death and injury in a proportion of the population but its effects are not predictable in the same way as heat processing. The extent of cold shock depends on a number of factors such as the organism (Gram-negatives appear more susceptible than Gram-positives), its phase of growth (exponential-phase cells are more susceptible than stationary phase cells), the temperature differential and the rate of cooling (in both cases the larger it is, the greater the damage), and the growth medium (cells grown in complex media are more resistant). Chilling is not a bacteriocidal process, the use of good microbiological quality raw materials and hygienic handling are key requirements for the production of safe chill foods. The chilling will prevent an increase in the risk from mesophilic pathogens, but will not assure its elimination. There are pathogens that will continue to grow at some chill temperatures and the key role of chilling in the modern food industry. Some foods are not suitable for chill storage as they suffer from cold injury where the low temperature results in tissue breakdown which leads to visual defects and accelerated microbiological deterioration. Tropical fruits are particularly susceptible to this form of damage.

Freezing

Freezing is the most successful technique for long-term preservation of food since nutrient content is largely retained and the product resembles the fresh material more closely than in appertized foods. Foods begin to freeze somewhere in the range -0.5 to -3°C , the freezing point being lower than that of pure water due to the solutes present. As water is converted to ice during freezing, the

concentration of solutes in the unfrozen water increases, decreasing its freezing point still further so that even at very low temperatures, e.g. -60°C , some water will remain unfrozen. Micro-organisms are affected by each phase of the freezing process. At the freezing temperature, further death and injury occur as the cooling curve levels out as latent heat is removed and the product begins to freeze. Changes in the ionic strength and pH of the water phase as a result of freezing will disrupt the structure and function of numerous cell components and macromolecules which depend on these factors for their stability. Cooling down to the storage temperature will prevent any further microbial growth once the temperature has dropped below -10°C . The lower the storage temperature, the slower the death rate. As with chilling, freezing will not render an unsafe product safe – its microbial lethality is limited and preformed toxins will persist. Survival rates after freezing will depend on the precise conditions of freezing, the nature of the food material and the composition of its microflora, but have been variously recorded as between 5 and 70%. Food freezing processes are not designed to maximize microbial lethality but to minimize loss of product quality. The rate of freezing in domestic freezers is much slower so, although microbial lethality may be greater, so too is product quality loss. Freezing and defrosting may make some foods more susceptible to microbiological attack due to destruction of antimicrobial barriers in the product and condensation, but defrosted foods do not spoil more rapidly than those that have not been frozen. Injunctions against refreezing defrosted products are motivated by the loss of textural and other qualities rather than any microbiological risk that is posed.

Chemical Preservatives

Additives may be used to aid processing, to modify a food's texture, flavour, nutritional quality or colour but, which effect keeping quality: preservatives. Preservatives are defined as 'substances capable of inhibiting, retarding or arresting the growth of micro-organisms or of any deterioration resulting from their presence or of masking the evidence of any such deterioration'. They do not include substances which act by inhibiting a chemical reaction which can limit shelf-life, such as the control of rancidity or oxidative discolouration by

antioxidants. These include the antioxidants, butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), and the phosphates used as acidity regulators and emulsifiers in some products. Preservatives may be microbicidal and kill the target organisms or they may be microbistatic in which case they simply prevent them growing. This is very a dose-dependent feature; higher levels of an antimicrobial proving lethal while the lower concentrations that are permitted in foods tend to be microbistatic. For this reason chemical preservatives are useful only in controlling low levels of contamination and are not a substitute for good hygiene practices.

Organic Acids and Esters

The most important organic acids and esters that are used as food preservatives. The antimicrobial effect of organic acids such as acetic and lactic acids. Both are produced microbiologically, although food-grade acetic acid derived petrochemically is sometimes used as an alternative to vinegar. They differ from the other acids and esters described here in that they are present in amounts sufficient to exert an effect on flavour and on product pH, thus potentiating their own action by increasing the proportion of undissociated acid present. Benzoic acid occurs naturally in cherry bark, cranberries, greengage plums, tea and anise but is prepared synthetically for food use. Parabens (para-hydroxybenzoic acid esters) differ from the other organic acids described. They are phenols rather than carboxylic acids. Sorbic acid is an unsaturated fatty acid, 2,4-hexadienoic acid, found naturally in the berries of the mountain ash. Propionic acid (pKa 4.9) occurs in a number of plants and is produced by the activity of propionibacteria in certain cheeses. It is used as a mould inhibitor in cheese and baked products where it also inhibits rope-forming bacilli.

Nitrite

The antibacterial action of nitrite used in the production of cured meats where it is responsible for their characteristic colour and flavour. Curing processes nitrite was produced by the bacterial reduction of nitrate present as an impurity in the crude salt used, but now nitrate, or more commonly nitrite itself, is added as the sodium or potassium salt. Nitrite is inhibitory to a range of bacteria. The ability of nitrite to inhibit spore-forming bacteria such as *Clostridium botulinum* which will survive the heat process applied to many cured meats. The complexity of the interaction of several factors such as pH, salt content, presence of nitrate or nitrite and the heat process applied to the cured meat. Bacterial inhibition by nitrite increases with decreasing pH, suggesting that nitrous acid (HNO_2 , pK_a 3.4) is the active agent. In the case of spores, it appears that nitrite acts by inhibiting the germination and outgrowth of heated spores and by reacting with components in the product to form other inhibitory compounds. When nitrite was heated in certain bacteriological media, the resulting medium proved more inhibitory to clostridia than when filter-sterilized nitrite was added after heating. Clostridia are very sensitive to these 'Perigo factors' which differ from nitrite in displaying activity that is independent of pH. The presence of 'Perigo-type factors' has been reported in heated cured meats but these are produced by severe heating and have minor antibacterial activity.

Sulfur Dioxide

Sulfur dioxide (SO_2) has long enjoyed a reputation for its disinfecting properties and its earliest use in the food industry was when sulfur candles were burnt to disinfect the vessels used to produce and store wine. Nowadays, it is also used as an antioxidant to inhibit enzymic and non-enzymic browning reactions in some products. Sulfur dioxide is a colourless gas that readily dissolves in water to establish a pH-dependent equilibrium similar to CO_2 . SO_2 is a reactive molecule and can disrupt microbial metabolism in a number of ways. As a reducing agent, it can break disulfide linkages in proteins and interfere with redox processes. It can also form addition compounds with pyrimidine bases in nucleic acids, sugars and a host of key metabolic intermediates. One disadvantageous consequence of this reactivity is its ability to destroy the vitamin thiamine in foods and the once

widespread practice of using it in meat and meat products has been prohibited, with the exception of British fresh sausage. Sulfur dioxide is active against bacteria, yeasts and moulds, although some yeasts and moulds are more resistant. Seasonal surpluses of soft fruits are preserved by the addition of high levels of SO₂ to permit jam production.

Natamycin

Natamycin formerly known as pimaricin, is a polyene macrolide antibiotic produced by the bacterium *Streptomyces natalensis*. It is a very effective antifungal agent as it binds irreversibly to the fungal sterol, ergosterol, disrupting the fungal cell membrane leading to a loss of solutes from the cytoplasm and cell lysis. Natamycin is poorly soluble in water and is used as an aqueous suspension for the surface treatment of cheeses and sausages to control yeast and mould growth. The surface of the product, is not dependent on a low pH for its activity and has no effect on bacteria important in the fermentation and maturation of such products.

‘Natural’ Food Preservatives

Methods of preservation that can be described as ‘natural’. The whole area though is riddled with inconsistency and contradiction; it can be argued that any form of preservation which prevents or delays the recycling of the elements in plant and animal materials is unnatural. There is nothing more natural than strychnine or botulinum toxin. Smoking of foods might be viewed as a natural method of preservation. Its antimicrobial effect is a result of drying and the activity of woodsmoke components such as phenols and formaldehyde which would not be allowed were they to be proposed as chemical preservatives in their own right. The use of natural food components possessing antimicrobial activity such as essential oils and the lactoperoxidase system in milk.

Modification of Atmosphere

Modified atmospheres exert their effect principally through the inhibition of fast-growing aerobes that would quickly spoil perishable products. Obligate and facultative anaerobes such as clostridia and the Enterobacteriaceae are less affected. Thus keeping quality is improved but there is little effect on pathogens, if present, and the technique is invariably applied in conjunction with refrigerated storage. Three different procedures are used to modify the atmosphere surrounding a product: vacuum packing, modified-atmosphere packing or gas flushing, and controlled atmospheres. An essential feature of all three techniques is that the product is packed in a material which helps exclude atmospheric oxygen and retain moisture.

In vacuum packing: the product is placed in a bag from which the air is evacuated, causing the bag to collapse around the product before it is sealed. Residual oxygen in the pack is absorbed through chemical reactions with components in the product and any residual respiratory activity in the product and its microflora. To achieve the best results, it is important that the material to be packed has a shape that allows the packaging film to collapse on to the product surface entirely – without pockets and without the product puncturing the film. Vacuum packing has been used for some years for primal cuts of red meats. At chill temperatures, good quality meat in a vacuum pack will keep up to five times longer than aerobically stored meats. The aerobic microflora normally associated with the spoilage of conventionally stored meats is prevented from growing by the high levels of CO₂ which develop in the pack after sealing and the low oxygen tension. The microflora that develops is dominated by lactic acid bacteria which are metabolically less versatile than the Gram-negative aerobes, grow more slowly and reach a lower ultimate population.

In modified atmosphere packing, MAP: a bulk or retail pack is flushed through with a gas mixture usually containing some combination of carbon dioxide, oxygen and nitrogen. The composition of the gas atmosphere changes during storage as a result of product and microbial respiration, dissolution of CO₂ into the aqueous phase, and the different rates of gas exchange across the packing membrane. MAP gas mixtures used in different products. Carbon dioxide is included for its inhibitory effect, nitrogen is non-inhibitory but has low water solubility and can prevent pack collapse when high concentrations of CO₂ are used. By displacing

oxygen it can delay the development of oxidative rancidity. Oxygen is included in the gas flush mixtures for the retail display of red meats to maintain the bright red appearance of oxymyoglobin. This avoids the acceptability problem associated with vacuum packs of red meats, although the high oxygen concentration (typically 60–80%) helps offset the inhibitory effect of CO₂ (around 30%) so that the growth of aerobes is slowed rather than suppressed entirely.

In controlled-atmosphere storage, CAP: the product environment is maintained constant throughout storage. It is used mainly for bulk storage and transport of foods, particularly fruits and vegetables, such as the hard cabbages used for coleslaw manufacture. CAP is used for shipment of chilled lamb carcasses and primal cuts which are packed in an aluminium foil laminate bag under an atmosphere of 100% CO₂. It is more encountered though with fruits such as apples and pears which are stored at sub-ambient temperatures in atmospheres containing around 10% CO₂. This has the effect of retarding mould spoilage of the product through a combination of the inhibitory effect of CO₂ on moulds and its ability to act as an antagonist to ethylene, delaying fruit senescence and maintaining the fruit's own ability to resist fungal infection.

Control of Water Activity

The water activity of a product can be reduced by physical removal of liquid water either as vapour in drying, or as a solid during freezing. It is also lowered by the addition of solutes such as salt and sugar. Water activity reduction played some part in almost all the known procedures for food preservation. Solar drying, while perhaps easy and cheap, is subject to the vagaries of climate. Drying indoors over a fire was one way to avoid this problem and one which had the incidental effect of imparting a smoked flavour to the food as well as the preservative effect of chemical components of the smoke. Micro-organisms that were in the product before drying or were introduced during processing can survive for extended periods. This is most important with respect to pathogens if they were present in hazardous numbers before drying or if time and temperature allow them to resume growth in a product that is rehydrated before consumption. There have been a number of instances where the survival of pathogens or their toxins has caused problems in products such as chocolate, pasta, dried milk and eggs.

Traditional IMFs are made by a process of desorption whereby water is lost from the product during processing but a number of the new IMFs used an adsorption process in which the product is first dried and its moisture content readjusted to give the desired aw. The hysteresis effect in water sorption isotherms. Products made by desorption and having the higher water content were also more susceptible to microbial spoilage. Solar drying is still widely practised in hot climates for products such as fruits, fish, coffee and grain. The traditional technique of spreading the product out in the sun with occasional turning often gives only rudimentary or, sometimes, no protection from contamination by birds, rodents, insects and dust. Rapid drying is essential to halt incipient spoilage; this is usually achievable in hot dry climates, though in tropical countries with high humidity drying is usually slower so that products such as fish are pre-salted to inhibit microbial growth during drying. Mechanical drying which are quicker, more reliable, albeit more expensive than solar drying. During drying a proportion of the microbial population will be killed and sub-lethally injured to an extent which depends on the drying technique and the temperature regime used. It is no substitute for bactericidal treatments such as pasteurization. Although the air temperature employed in a drier may be very high, the temperature experienced by the organisms in the wet product is reduced due to evaporative cooling. As drying proceeds and the product temperature increases, the heat resistance of the organisms due to the low water content. Good quality raw materials and hygienic handling prior to drying are essential.

Compartmentalization

Butter is an interesting example of a rather special form of food preservation where microbial growth is limited by compartmentalization within the product. Essentially there are two types of butter: sweet cream butters, which are salted, and ripened cream butters. In ripened-cream butters, the cream has been fermented by lactic acid bacteria to produce inter alia diacetyl from the fermentation of citrate which gives a characteristically buttery flavour to the product. They have a stronger flavour than sweet cream butters but are subject to faster chemical deterioration. Butter is an emulsion of water droplets in a continuous fat phase in contrast to milk which is an emulsion of fat globules in a continuous water phase. It has a higher fat content than milk (80%) and uses

pasteurized cream as its starting point. Typically, the cream is pasteurized using an HTST process of 85 °C for 15 s and held at 4–5 °C for a period to allow the fat globules to harden and cluster together. In making a conventional ripened cream butter, the starter culture is added at this stage and the cream incubated at around 20 °C to allow flavour production to take place. Few micro-organisms survive pasteurization so the microbiological quality of butter depends on the hygienic conditions during subsequent processing, particularly the quality of the water used to wash the butter. Good microbiological quality starting materials are essential though, as preformed lipases can survive pasteurization and rapidly spoil the product during storage. Butter spoilage is most often due to the development of chemical rancidity but microbiological problems do occur in the form of cheesy, putrid or fruity odours or the rancid flavour of butyric acid produced by butterfat hydrolysis. Butter is a relatively safe commodity from a microbiological standpoint. Margarine relies on a similar compartmentalization for its microbiological stability, but uses vegetable fat as its continuous phase. Although skim milk is included in the formulation, it is possible to make the aqueous phase in margarine even more deficient nutritionally than in butter, increasing the microbiological stability further. A higher moisture content means that the preservative effect of salt or lactic acid, which is included, is diluted and that micro-organisms can grow to a greater extent in the larger aqueous droplets. The use of preservatives may be required to maintain stability.

Quality and Criteria

The microbiology of foods, quality comprises three aspects:

- (1) Safety: A food must not contain levels of a pathogen or its toxin likely to cause illness when the food is consumed.
- (2) Acceptability/shelf-life: A food must not contain levels of micro-organisms sufficient to render it organoleptically spoiled in an unacceptably short time.
- (3) Consistency: A food must be of consistent quality both with respect to safety and to shelf-life. The consumer will not accept products which display large batch-to-batch variations in shelf-life.

To distinguish food of acceptable quality from food of unacceptable quality requires the application of what are known as microbiological criteria. Three different types of microbiological criterion have been defined by The International Commission on Microbiological Specifications for Foods (ICMSF).

(1) A microbiological standard is a criterion specified in a law or regulation. It is a legal requirement that foods must meet and is enforceable by the appropriate regulatory agency.

(2) A microbiological specification is a criterion applied in commerce. It is a contractual condition of acceptance that is applied by a purchaser attempting to define the microbiological quality of a product or ingredient. Failure of the supplier to meet the specification will result in rejection of the batch or a lower price.

(3) A microbiological guideline is used to monitor the microbiological acceptability of a product or process. It differs from the standard and specification in that it is advisory rather than mandatory.

The ICMSF have specified what should be included in a microbiological criterion as set out below:

(1) A statement of the food to which the criterion applies. Clearly foods differ in their origin, composition, and processing; will present different microbial habitats; and will pose different spoilage and public health problems.

(2) A statement of the micro-organisms or toxins of concern. These may cover both spoilage and health aspects, but decisions on what to include must be realistic and based on a sound understanding of the microbial ecology of the food in question.

(3) Details of the analytical methods to be used to detect and quantify the micro-organisms/toxins. Preferred methods for standards or specifications would be those elaborated by international bodies, although less sensitive or less reproducible methods may be used for simplicity and speed in confirming compliance with guidelines.

(4) The number and size of samples to be taken from a batch of food or from a source of concern such as a point in a processing line.

(5) The microbiological limits appropriate to the product and the number of sample results which must conform with these limits for the product to be acceptable. In this regard, it should be remembered that for certain food-borne pathogens such as *Staphylococcus aureus* or *Clostridium perfringens*, their mere presence does not necessarily indicate a hazard and specification of some numerical limits is necessary.

Sampling Schemes

The sampling scheme most commonly applied in the microbiological testing of foods is that of sampling for attributes.

Two-class Attributes Plans

In an attributes sampling scheme analytical results are assigned into classes; in the simplest type, the two-class scheme, samples are classified as acceptable or defective depending on the test result. A sample is described as defective if it is shown to contain more than a specified number of organisms or, in cases where a presence or absence test is applied, the target organism is detected.

A two-class sampling scheme is defined by three numbers:

n – the number of sample units to be tested;

m – the count above which the sample is regarded as defective. This term would not appear in schemes employing a presence/absence test since a positive result is sufficient for the sample to be defective;

c – the maximum allowable number of sample units which may exceed m before the lot is rejected.

Three-class Attributes Plans

Three-class attributes sampling plans introduce a further category and divide samples into three classes: acceptable, marginally acceptable, and unacceptable. Use of this extra classification of marginally acceptable means that

they are not used with presence or absence tests but only with microbiological count data. A three-class plan is defined by four numbers:

n – the number of samples to be taken from a lot;

M – a count which if exceeded by any of the test samples would lead to rejection of the lot;

m – a count which separates good quality from marginal quality and which most test samples should not exceed;

c – the maximum number of test samples which may fall into the marginally acceptable category before the lot is rejected.

Choosing a Plan Stringency

Two important principles governing the choice of plan stringency. As the severity of the hazard being tested for increases, so too must the stringency of the sampling plan. For example, spoilage can be regarded as more of a risk to the product than to the consumer and so tests for indicators of shelf-life such as aerobic plate counts will have the most lenient sampling plans. Plans may quite frequently pass products which are defective, they can still be effective in the sense that regular rejection of say 1 in 5 batches of product would represent a significant economic loss to the producer and would be a strong incentive to improve quality. Plan stringency should also take account of whether the food is to be consumed by particularly vulnerable groups of the population such as infants, the very old, or the very sick.

Variables Acceptance Sampling

Micro-organisms are distributed log-normally, that is to say the logarithms of the counts from different samples conform to a normal distribution. For example, a survey of nearly 1300 batches of frozen and dried foods found that, on average, only 7.8% of batches did not conform to a log-normal distribution.

Quality Control Using Microbiological Criteria

Microbiological testing of milk is more likely to give an accurate reflection of microbiological quality in the batch as a whole since it is easier to obtain truly representative samples of a liquid. Also, much is known on how to produce raw milk hygienically so that bacterial contamination is minimized, farmers had simply not been assiduous in the application of these procedures until financial penalties acted as an incentive. These two cases indicate two important features of microbiological quality control. Namely the ineffectiveness of retrospective systems of quality control and the importance of control at source. A system of retrospective quality control based on testing samples of a product and accepting or rejecting a lot on the basis of test results suffers from a number of limitations. The inhomogeneous distribution of micro-organisms in food, the problems of representative sampling and the producer's and purchaser's risks associated with any sampling plan. To minimize these risks requires plans entailing the testing of large numbers of samples and these entail high costs as a result of both the amount of product required to be tested and the costs of laboratory resources. Even with representative samples there is the problem of the relative inaccuracy of traditional microbiological methods and their long elapsed times. If results of laboratory tests are required before a product can be released for sale (a positive release system), then the product's useful shelf-life is reduced. Finally, a major weakness of retrospective systems of quality control is that they provide little in the way of remedial information. The most effective way of controlling quality is through intervention at source, during the production process.

Training

Food handlers should be trained in the basic concepts and requirements of food and personal hygiene as well as those aspects particular to the specific food-processing operation. Training should give food handlers an understanding of the basic principles of hygiene. A core curriculum for any such course should emphasize:

- 1) Micro-organisms as the main cause of food spoilage and food-borne illness and the characteristics of the common types of food poisoning.

- (2) How to prevent food poisoning through the control of microbial growth, survival or contamination.
- (3) Standards of personal hygiene required of food handlers. These are principally to avoid contamination of food with bacteria the food handler may harbour as part of the body's flora, that they may bring in with them from the outside world.
- (4) Principles of the handling and storage of foods such as the correct use of refrigerators and freezers, the importance of temperature monitoring, the need for stock rotation and the avoidance of cross-contamination.
- (5) Correct cleaning procedures and the importance of the 'clean-as-you-go' philosophy.
- (6) Knowledge of the common pests found in food premises and methods for their exclusion and control.
- (7) An introduction to the requirements of current food legislation.

Some do's and don'ts of personal hygiene for food handlers

DO

Wash your hands regularly throughout the day and especially:

- after going to the toilet;
- on entering a food room and before handling food or equipment;
- after handling raw foods;
- after combing or touching the hair;
- after eating, smoking, coughing or blowing the nose;
- after handling waste food, refuse or chemicals.

Keep fingernails short and clean.

Cover any cuts, spots or boils with a waterproof dressing.

Keep hair clean and covered to prevent hair/dandruff entering the food.

Always wear clean protective clothing (including footwear) in food processing areas.

DON'T

Do not smoke, chew gum, tobacco, betel nut, fingernails or anything else.

Do not taste food.

Do not spit, sneeze or cough over food.

Do not pick nose, ears or any other body site.

Do not wear jewellery when handling food.

Do not wear protective clothing outside the production areas.

Facilities and Operations

The environment in which food processing is conducted is an important factor in determining product quality. The premises should be of sufficient size for the intended scale of operation and should be sited in areas which are free from problems such as a particular pest nuisance, objectionable odours, smoke or dust. The site should be well accessed by metalled roads and have supplies of power and potable water adequate to the intended purpose. Particular attention should also be paid to the provision of facilities for the efficient disposal of processing wastes.

Equipment

The main objectives of the design of hygienic food-processing equipment are to produce equipment that performs a prescribed task efficiently and economically while protecting the food under process from contamination.

(1) All surfaces in contact with food should be inert to the food under conditions of use and must not yield substances that might migrate to or be absorbed by the food.

(2) All surfaces in contact with the food should be microbiologically cleanable, smooth and non-porous so that particles are not caught in microscopic surface crevices, becoming difficult to dislodge and a potential source of contamination.

- (3) All surfaces in contact with food must be visible for inspection, or the equipment must be dismantled for inspection, or it must be demonstrated that routine cleaning procedures eliminate the possibility of contamination.
- (4) All surfaces in contact with food must be readily accessible for manual cleaning, or if clean-in-place techniques are used, it should be demonstrated that the results achieved without disassembly are equivalent to those obtained with disassembly and manual cleaning.
- (5) All interior surfaces in contact with food should be so arranged that the equipment is self-emptying or self-draining. In the design of equipment it is important to avoid dead space or other conditions which trap food and may allow microbial growth to take place.
- (6) Equipment must be so designed to protect the contents from external contamination and should not contaminate the product from leaking glands, lubricant drips and the like; or through inappropriate modifications or adaptations.
- (7) Exterior surfaces of equipment not in contact with food should be so arranged to prevent the harbouring of soils, micro-organisms or pests in and on equipment, floors, walls and supports. For example, equipment should fit either flush with the floor or be raised sufficiently to allow the floor underneath to be readily cleaned.
- (8) Where appropriate, equipment should be fitted with devices which monitor and record its performance by measuring factors such as temperature/time, flow, pH, weight.

Cleaning and Disinfection

Hygienic processing of food requires that both premises and equipment are cleaned frequently and thoroughly to restore them to the desired degree of cleanliness. Cleaning should be treated as an integral part of the production process and not regarded as an end-of-shift chore liable to be hurried or superficial. Cleaning operations in food processing have two purposes:

- (i) physical cleaning to remove 'soil' adhering to surfaces which can protect micro-organisms and serve as a source of nutrients; and

- (ii) microbiological cleaning, also called sanitizing or disinfection, to reduce to acceptable levels the numbers of adhering micro-organisms which survive physical cleaning.

There are three main types of surfactant, classified according to the nature of the hydrophilic portion of the molecule:

- (i) anionic – in these, which include soaps, alkyl and alkylbenzene sulfonates and alcohol sulfates, the hydrophilic portion is a negatively charged ion produced in solution. They are incompatible with the use of quaternary ammonium compounds (QUATs) which are positively charged;
- (ii) non-ionic – made by condensing ethylene oxide on to the polar end of a fatty acid, fatty alcohol or alkyl phenol;
- (iii) cationic – quaternary ammonium compounds (QUATs) which have a positive charge in solution and are used mainly for their bacteriostatic and bacteriocidal activity rather than their cleaning properties.

Six types of chemical disinfectant are most commonly used in food processing:

- (1) chlorine and chlorine compounds
- (2) iodophors
- (3) quaternary ammonium compounds (QUATs)
- (4) biguanides
- (5) acid anionic surfactants
- (6) amphoteric surfactants

Hydrogen peroxide and peracetic acid are used in some applications such as the disinfection of packing materials. Chemical disinfectants do not act specifically on a single aspect of a microbial cell's metabolism but have a more broadly based inhibitory effect. In the case of chlorine, iodophors and peracetic acid, they act as non-specific oxidizing agents oxidizing proteins and other key molecules within the cell, while others such as QUATs and amphoteric surfactants act as surfactants, disrupting the cell membrane's integrity.

The main considerations in choosing a chemical disinfectant for use in the food industry are:

- (1) Its microbiological performance – the numbers and types of organisms to be killed.
- (2) How toxic is it and what is its effect on the food?
- (3) What is its effect on plant – does it stain or corrode equipment?
- (4) Does it pose any hazard to staff using it?
- (5) Is it adversely affected by residual soil?
- (6) What are the optimal conditions for its use, i.e. temperature, contact time, pH, water hardness?
- (7) How expensive is it?

All disinfectants are deactivated to some extent by organic matter. Chlorine in the form of hypochlorite solution is the cheapest effective disinfectant with a broad range of antimicrobial activity which includes spores. The active species is hypochlorous acid (HOCl) which is present in aqueous solutions at pH 5–8. It is corrosive to many metals including stainless steel although this can be minimized by using it at low concentrations, at alkaline pH, at low temperature and with short contact times. Organochlorine disinfectants such as the chloramines are weaker antimicrobials but are more stable and less corrosive than hypochlorite allowing longer contact times to be used. QUATs are highly stable with a long shelf-life in concentrated form. They are non-corrosive and can be used at higher temperatures and with longer contact times than other disinfectants.

Codes of Good Manufacturing Practice

GMP is defined as those procedures in a food-processing plant which consistently yield products of acceptable microbiological quality suitably monitored by laboratory and in-line tests. A code of GMP must define details of the process that are necessary to achieve this goal such as times, temperatures, etc., details of equipment, plant layout, disinfection (sanitation) and hygiene practices and laboratory tests. Codes of GMP have been produced by a variety of

organizations including national regulatory bodies, international organizations such as the Codex Alimentarius Commission as well as trade associations and professional bodies. They can be used by manufacturers as the basis for producing good quality product but may be used by inspectors from regulatory bodies.

The Hazard Analysis and Critical Control Point (HACCP) Concept

The Hazard Analysis Critical Control Point (HACCP) concept has improved on traditional practices by introducing a more systematic, rule-based approach for applying our knowledge of food microbiology to the control of microbiological quality. The same system can be adopted with physical and chemical factors affecting food safety or acceptability, microbiological hazards. It should also be remembered that HACCP is primarily a preventative approach to quality assurance and as such it is not just a tool to control quality during processing but can be used to design quality into new products during their development.

Seven essential principles of a HACCP system:

- (1) Conduct a hazard analysis.
- (2) Determine the Critical Control Points (CCPs).
- (3) Establish critical limits.
- (4) Establish a system to monitor control of the CCP.
- (5) Establish corrective action to be taken when monitoring indicates that a particular CCP is not under control.
- (6) Establish procedures to verify that the HACCP system is working effectively.
- (7) Establish documentation concerning all procedures and records appropriate to these principles and their application.

A HACCP study is best conducted by a multidisciplinary team comprising a microbiologist, a process supervisor, an engineer and a quality assurance manager, all of whom will be able to bring their own particular expertise and experience to bear on the task in hand.

Hazard Analysis

Hazard Analysis determines which hazards could pose a realistic threat to the safety of those consuming the product and must be controlled by the production process. It is best approached in a systematic way by working through a list of raw materials, ingredients and steps in processing, packaging, distribution and storage, listing alongside each the hazards that might be expected to occur. It must identify:

- (i) raw materials or ingredients that may contain micro-organisms or metabolites of concern, the likely occurrence of these hazards and the severity of their adverse health effects;
- (ii) the potential for contamination at different stages in processing;
- (iii) intermediates and products whose physical and chemical characteristics permit microbial growth and/or survival, or the production and persistence of toxic metabolites; and
- (iv) measures that will control hazards such as process steps which are lethal or bacteriostatic.

Identification of Critical Control Points (CCPs)

Once the hazard analysis has produced a list of the potential hazards, where they could occur, and measures that would control them, critical control points (CCPs) are identified. A CCP is defined as a location, step or procedure at which some degree of control can be exercised over a microbial hazard; that is, the hazard can be either prevented, eliminated, or reduced to acceptable levels. Loss of control at a CCP would result in an unacceptable risk to the consumer or product. A raw material could be a CCP if it is likely to contain a microbial hazard and subsequent processing, including correct consumer use, will not guarantee its control. Specific processing steps such as cooking, chilling, freezing, or some feature of formulation may be CCPs, as could aspects of plant layout, cleaning and disinfection procedures, or employee hygiene. Many are self-evident, but decision trees can be used to help in their identification.

Establishment of CCP Critical Limits

For each of the CCPs identified, criteria must be specified that will indicate that the process is under control at that point. These will usually take the form of critical limits necessary to achieve control of the hazard. Criteria may include:

- (i) **physical parameters** such as temperature/time, humidity, quantity of product in a pack, dimensions of can seams, or depth of product in trays to be chilled;
- (ii) **chemical parameters** such as pH in fermented or acidified foods, aw in intermediate-moisture foods, salt concentration, available chlorine in can cooling water, or level of preservative;
- (iii) **sensory information** such as texture, appearance, or odour; or,
- (iv) **management factors** such as the correct labelling of products with instructions for use and handling, or efficient stock rotation.

Monitoring Procedures for CCPs

CCPs is the introduction of monitoring procedures to confirm and record that control is maintained. It is important to remember that the assurance given by monitoring procedures will only be as good as the methods used and these too must be regularly tested and calibrated. To achieve the on-line control of a processing operation, monitoring procedures should wherever possible be continuous and give 'real time' measurement of the status of a CCP. In some cases, the availability of appropriate monitoring procedures could govern the choice of criteria. If continuous monitoring is not possible then it should be of a frequency sufficient to guarantee detection of deviations from critical limits, and those limits should be set taking into account the errors involved in periodic sampling.

Protocols for CCP Deviations

When routine monitoring indicates that a CCP is out of control there should be clearly described procedures for its restoration, who is responsible for taking action and for recording the action taken. In addition to measures to restore the process, it should also prescribe what should be done with product produced while the CCP was out of control.

Verification

Verification is the process of checking that a HACCP plan is being applied correctly and working effectively. It is an essential feature of quality control based on HACCP and is used both when a system is first introduced and to review existing systems. Verification uses supplementary information to that gathered in the normal operation of the system and this can include extensive microbiological testing. To verify that criteria or critical limits applied at CCPs are satisfactory will often require microbiological and other, more searching, forms of testing. In normal operation, only limited end product testing is required because of the safeguards built into the process itself, but more detailed qualitative and quantitative microbiological analyses of final product and product-in-process may be required in a verification programme.

Record Keeping

The HACCP scheme should be documented and kept on file. Documentation should include details of the HACCP team and their responsibilities; material from the Hazard Analysis details of the CCPs – the hazards associated with them and critical limits; monitoring systems and corrective action; procedures for record keeping and for verification of the HACCP system. This should be accompanied by associated process records obtained during operation of the scheme. It will include material such as documentation to verify suppliers' compliance with the processor's requirements, records from all monitored CCPs, validation records and employee training records.

Quality Systems: BS 5750 AND ISO 9000 SERIES

This is best illustrated by the British Standard BS 5750 and its International Standards Organization (ISO) equivalent, the ISO 9000 series, on Quality Systems which are applicable to any processing or productive activity. A quality system is a means of ensuring that products of a defined quality are produced consistently and it represents an organized commitment to quality. Quality systems work by requiring documented evidence at all stages, from product research and development, through raw materials purchase, to supply to the customer, that quality is rigorously controlled. BS 5750 from a certifying body such as the British Standards Institution. Quality assessors study the company's 'quality manual' to ensure it meets all the requirements of the standard and then make a detailed on-site assessment of actual practices to verify that prescribed procedures are understood and followed. Following certification, regular follow-up visits are made to ensure continued conformance with the standard.

Risk Analysis

Risk assessment is the scientific component of an overall system known as risk analysis. Risk assessment should provide an estimate, preferably quantitative, of the probability of occurrence and the severity of adverse health effects resulting from human exposure to foodborne hazards, known as the risk estimate. There are four steps in risk assessment.

(1) Hazard identification is similar to the hazard analysis stage in HACCP and must identify the agents that are hazards to health and that may be present in a particular food. These will be the focus of subsequent stages in the risk assessment process. As with HACCP, these hazards may be chemical, physical or biological, though in this case we are concerned with micro-organisms and their toxins.

(2) Exposure assessment is a qualitative/quantitative evaluation of the likely intake of a hazardous agent. This must employ information on consumption patterns, i.e. the amounts of a particular food consumed by individuals, taking into account any variation with factors such as age, socio-economic status, religion, etc. It must also estimate the level of the microbial hazard in the food at the time of consumption

– information that could be obtained from survey data and the use of predictive models describing the growth/survival of the organisms under likely conditions of storage and processing prior to consumption.

(3) Hazard characterization is the qualitative and/or quantitative evaluation of the adverse effects associated with the particular hazard.

(4) Risk characterization integrates the results from the previous three stages to give an estimate, including attendant uncertainties, of the probability and severity of illness in a given population. The accuracy of the estimate can be assessed by comparison with independent epidemiological data where available.

Risk management is the process of deciding, in collaboration with risk assessors, which risk assessments should be undertaken and then weighing policy alternatives to accept, minimize or reduce assessed risks. Risk managers have to decide what level of risk is acceptable (zero risk is an unachievable objective), assess the costs and benefits of different control options and if required select and implement appropriate controls, including regulatory measures. The final component in risk analysis is risk communication – the interactive exchange of information and opinions between risk assessors, risk managers, consumers and other interested parties. This is an integral part of risk analysis and has a number of goals including the promotion of awareness, understanding, consistency and transparency.

Assignment for FTech-305 Plant-Based Fermented Food and Beverage Technology

Fermented Cereal Products (Breads and Related Products)

In wheat-producing countries or areas, baked yeast bread is a major staple in the people's diet. Baked bread may come in different forms such as regular yeast breads, flat breads, and specialty breads. Wheat used for making bread includes hard wheat, soft wheat, or a combination of both, to meet product specifications. Wheat kernels are milled by the removal of the bran and germ and processed into wheat flour. This flour is the major ingredient for baking bread. Wheat bran is added to increase the fiber content of the product. In the manufacture of various wheat-based breads and related products, the major ingredients are wheat flour, yeast, sourdough bacteria (optional), salt, and water. The basic ingredients, optional ingredients, additives, and processing aids used in the manufacturing of bread.

Types of Bread and Related Products

Baked breads:

- Regular yeast breads: Bread (white, whole wheat, or multigrain)
- Flat (layered) breads: Pocket bread, croissants
- Specialty breads: Sourdough bread, rye bread, hamburger bun, part-baked bread, Danish pastry, stuffed bun

Chilled or frozen doughs:

Ready-to-bake doughs, retarded pizza doughs, frozen proved dough

- Steamed breads: Chinese steamed bread (mantou), steamed stuffed bun
- Fried breads: Doughnuts
- Boiled breads: Pretzels

Bread-Making Functional Ingredients

Basic ingredient

- Wheat flour: Bread flour, whole wheat flour
- Yeast: Compressed yeast, granular yeast, cream yeast, dried yeast, instant yeast, encapsulated yeast, frozen yeast, pizza yeast, deactivated yeast
Saccharomyces cerevisiae, *S. carlsbergensis*, *S. exiguus*
- Salt
- Water

Optional ingredients

- Whole wheat flour, gluten, soya flour, wheat bran, other cereals or seeds, milk powder, fat, malt flour, egg, dried fruit, vitamins
- Sourdough bacteria: *Lactobacillus plantarum*, *L. brevis*, *L. fermentum*, *L. sanfrancisco*
- Other yeasts

Additives

- Emulsifier: Diacetylated tartaric acid esters of monoglycerides and diglycerides of fatty acids (DATA esters), sodium stearyl-2-lactylate (SSL), distilled monoglyceride, Lecithin
- Flour treatment agents: Ascorbic acid, l-cysteine, potassium bromate, potassium iodate, azodicarbonamide
- Preservatives: Acetic acid, potassium acetate, sodium diacetate, sorbic acid, potassium sorbate, calcium sorbate, propionic acid, sodium propionate, calcium propionate, potassium propionate

Processing aids

- Alpha-amylase, hemicellulose, proteinase, novel enzyme systems (lipases, oxidases, peroxidases)

Basic Steps in Regular or Common Bread-Making

- Preparation of basic and optional ingredients
- Preparation of yeast or sourdough for inoculation
- Mixing of proper ingredients to make dough
- Fermentation
- Remixing of dough (optional)
- Sheeting
- Molding and panning
- Proofing in a temperature- and relative humidity–controlled chamber
- Decorative cutting of dough surface (optional)
- Baking, steaming, frying, or boiling
- Cooling
- Packaging
- Storage

Various Bread-Making Processes

Straight Dough Baking Process:

- Weigh out all ingredients
- Add all ingredients to mixing bowl
- Mix to optimum development
- First fermentation: 100 minutes at room temperature, or at 27°C for 1.5 hours
- Punch
- Second fermentation: 55 minutes at room temperature, or at 27°C for 1.5 hours
- Divide
- Intermediate proofing: 25 minutes at 30°C to 35°C, 85% RH
- Mold and pan
- Final proofing: 55 minutes at 30°C to 35°C, 85% RH
- Bake at 191°C to 232°C for 18 to 35 minutes to approximately 100°C internal temperature

Sponge-and-Dough Baking Process:

- Weigh out all ingredients
- Mix part of flour, part of water, yeast and yeast food to a loose dough (not developed)
- Ferment 3 to 5 hours at room temperature, or at 21°C for 12 to 16 hours
- Add other ingredients and mix to optimum development
- Fermentation (floor time), 40 minutes
- Divide
- Intermediate proofing: 20 minutes at 30°C to 35°C, 85% RH, or at 27°C for 30 minutes
- Mold and pan
- Final proofing: 55 minutes at 30°C to 35°C, 85% RH
- Baking at 191°C to 232°C for 18 to 35 minutes to approximately 100°C internal temperature

Continuous Baking Process:

- Weigh out all ingredients
- Mixing of yeast, water, and maybe part of the flour to form a liquid sponge
- Addition of remaining flour and other dry ingredients
- Mixing in dough incorporator
- Fermentation, 2 to 4 hours at 27°C
- Pumping of dough to development chamber
- Dough development under pressure at 80 psi
- Extrusion within 1 minute with 14.5°C and panning
- Proofing for 90 minutes
- Baking at 191°C to 232°C for 18 to 35 minutes to approximately 100°C internal temperature

Flavors and Food Fermentation

Fermentation is one of the most ancient food processing and preservation methods used in the food industry. Raw food materials are transformed through fermentation from perishable, sometimes non-functional forms into more stable, functional forms such as milk to cheese and yogurt, grape juice to wine, wheat to bread, barley/malt to beer, and soybean to soy sauce. The fundamental roles of food fermentation include preservation, enhancement of sensory characteristics (flavor, texture, or color), and transformation of nutrients (improvement of digestibility and biofortification).

Flavor is one sensory attribute that is most transformed by fermentation. Food substrates (carbohydrates, proteins, lipids, organic acids, amino acids, phenolic compounds, glycosides, etc.) are transformed into nonvolatile and volatile flavor compounds that affect not only taste but also aroma, and food acceptance. These flavor compounds impart a range of sensory properties such as sweetness (e.g., mannitol), sourness (e.g., lactic acid), savoriness or umami (e.g., l-glutamic acid), bitterness (e.g., hydrophobic peptides), fruitiness (esters), and sulfurous notes (volatile sulfur compounds). The desirability or undesirability of the flavor compounds is dependent on their concentrations and the food matrices in which they are produced. Consumer acceptance and choice of foods depend on flavor (aroma and taste). Flavor consistency is of critical importance to food quality in modern food manufacture. Bacteria, yeasts, and fungi are the microorganisms that are responsible for food fermentation and flavor formation.

Type of Fermentation

Food fermentation can be classified into several types according to the microorganisms involved, main product produced, pH (acidity or alkalinity) changes, and moisture content of the food matrices. Fermented foods can be produced by relying on the microflora that are naturally present on or in the raw materials (the so-called natural, spontaneous, or wild fermentations), for example, raw milk cheeses and fermented leafy vegetables. Microorganisms involved in food fermentation include bacteria, yeasts, and fungi (molds). There are four main types of food fermentation on the basis of the key microorganisms responsible:

bacterial fermentation, yeast fermentation, fungal fermentation, and mixed culture fermentation. The process of food fermentation can be categorized into alcoholic, acidic, and alkaline fermentations based on the main products formed or pH changes. The fermentation of foods can be performed in liquid state (“submerged culture”), solid state (little or no free water), or mixed state. Type of fermentation and flavor are:

- Microorganisms and Starter Cultures Involved in Food Fermentations
- General Flavors Associated with Type of Food Fermentations
- Carbohydrate-Derived Flavors
- Protein-Derived Flavors
- Amino Acid–Derived Flavors
- Lipid-Derived Flavors
- Organic Acid–Derived Flavors
- Glycoside-Derived Flavors
- Phenolic Acid–Derived Flavors

Fermentation is central to the generation of flavor compounds that impart sensory characteristics to fermented foods and beverages. Microbial physiology and metabolism will enable better control of microbial flavor formation so as to accentuate, diversify, or minimize the formation of certain flavor compounds (desirable or undesirable). This can be achieved using molecular tools such as metabolic engineering and genomics approaches. Examples of metabolically engineered microorganisms are yeast strains of *S. cerevisiae* with altered enzyme activities for ester biosynthesis in alcoholic beverage fermentations such as beer, sake, and wine. Many food fermentations are performed using mixed cultures and microbial interactions that affect flavor formation would occur. These molecular approaches are expected to play a significant part in future food fermentations in terms of flavor modulation, consumer acceptance, and application of genetically modified microorganisms in food production.

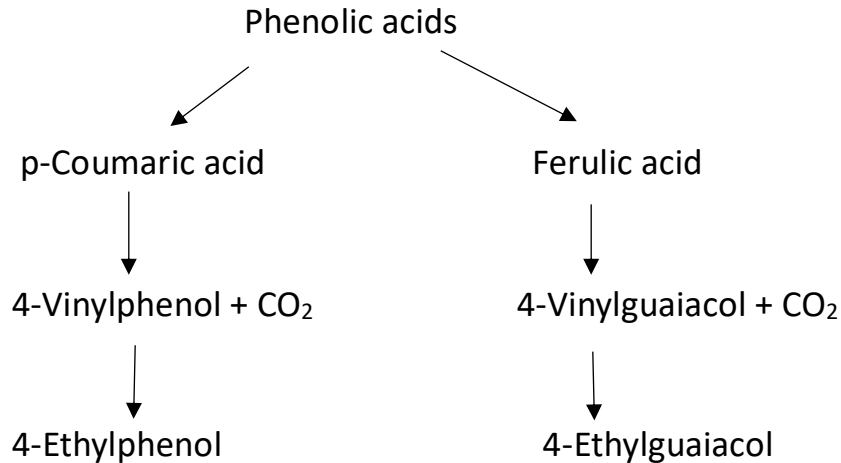


Fig : A simplified scheme of flavor compound formation from phenolic acids via microbial fermentation

Lactic Acid Bacteria (LAB)

Lactic acid bacteria (LAB) is the term used for a large and diverse group of prokaryotes, which have in common the production of lactic acid as their main metabolic end product. LAB have no use for oxygen as they don't carry out oxidative phosphorylation but only use substrate level phosphorylation or fermentation to create energy. LAB naturally occurs in a large variety of natural environments in which soluble carbohydrates, protein breakdown products, and low oxygen tension are found. The production of extracellular polysaccharides by many LAB allow them to adhere well to surfaces and making them excellent biofilm formers. LAB are resistant to low pH conditions and also have some resistance to higher osmotic pressures. These characteristics are important when it comes to the industrial use of LAB, in which bacteria play an important role in the preservation and microbial safety of many fermented foods. LAB, during the fermentation of plant material such as carrot juice, degrade oxalate, phytate, and tannins, which in combination with the decrease in pH, increase the solubility (bioavailability) of essential metals such as iron, manganese, and zinc but not copper.

Fermentation of Plant Material

Modern food preservation technologies such as refrigeration, controlled atmosphere storage, and freezing, the consumption of fermented vegetable products ensured continuous access to essential vitamins including vitamin C, minerals, and dietary fibers for people.

Kimchi

Kimchi is a traditional Korean fermented vegetable product, which is most prepared with Chinese cabbage as the main ingredient in combination with many minor ingredients such as red pepper powder, ginger, garlic, radish, and fish sauce. Kimchi preparation methods differ depending on the variety of kimchi and the ingredients used, the production takes place domestically or industrially. The types of kimchi differ from region to region because of differences in harvest and weather conditions. The final flavor profile is determined by the ingredients, condiments, the addition of salt and spices, and fermentation.

Fermentation Process

The principal process consists of pretreatment, brining, blending of ingredients, and fermentation steps. For example, the preparation method for Baechu kimchi (cut Chinese cabbage kimchi) is as follows: pretreated Chinese cabbage is cut into cubes of 3 to 5 cm, brined in a salt solution (8–15% w/v) for 2 to 7 hours, rinsed with fresh water, and drained. In a separate process, sliced Oriental radish, carrots, green onion, onion, chopped garlic, ginger, red pepper, salt-pickled seafood, other minor ingredients, and dry salt are combined to make a premixture according to the specific recipe. This premixture is blended well with the treated cabbage. This mixture is placed in a fermentation vessel sealed with a lid and fermented either for 1 to 3 weeks at low temperatures of 2°C to 10°C or for 1 to 3 days at 20°C to 25°C. After fermentation, kimchi is stored at temperatures between 0°C and 8°C and served cold. The fermentation occurs mainly due to LAB and yeast strains, which are naturally present in the diverse microflora of the raw material. The fermentation of kimchi is initiated by *Leuco. mesenteroides* under anaerobic conditions. This organism differs from other LAB species in that it can tolerate fairly high concentrations of salt and sugar. The most important factors

that affect kimchi fermentation are the endogenous plant microorganisms, salt concentration, fermentable carbohydrates, other available nutrients, presence of inhibitory compounds as well as oxygen, pH, and temperature. The effect of salt concentration, temperature and pH is mostly due to the influence of these factors on the rate and extent of lactic acid fermentation.

Microbiological Characteristics

The kimchi fermentation pattern is similar to that found in other vegetable lactic acid fermentations. Other vegetable fermentations, the brining step is very important for kimchi fermentation. Brining extracts the water and nutrients from the raw materials by osmotic activity and suppresses the growth of some undesirable bacteria that may spoil the kimchi. At the same time, it makes conditions relatively favorable for LAB by increasing the salt content in the Chinese cabbage or radish. The LAB count increases approximately fourfold after brining of the Chinese cabbage. Also, after the brining and rinsing/washing treatments, the counts of bacteria, yeasts, and molds are greatly decreased. The fermentation containers are covered with lids to provide anaerobic conditions and minimize the growth of aerobic microorganisms. *Leuco. mesenteroides* is the predominant LAB in the early fermentation stages but, because of the decrease in pH, is gradually replaced by other LAB. The growth of each species depends on its initial number in the raw material (Chinese cabbage and other ingredients), the concentrations of salt and sugar, the absence of oxygen, and the fermentation temperature. *Lb. plantarum* is commonly present in the greatest numbers after the initial fermentation and results in maximum acidity at the later stages. Aerobic yeasts and molds may appear on the surface of improperly covered vegetables at the later fermentation stages. The appearance of undesirable and spoiled kimchi, which is characterized by off-flavors and softened texture, is due to excessive aerobic growth of molds and film-forming yeasts. Softening and excessive acidification of kimchi at the overripening stages during fermentation and storage are the most serious problems. Kimchi is ready-to-eat at any stage of the fermentation depending on the individual consumer's preferential taste. Because there is no sterilizing process during kimchi processing, microbial quality and safety are very important issues for the shelf life of kimchi.

Bio-preservation of Vegetable Products

The idea of using bio-preservation with innocuous commensal bacteria to inhibit foodborne microbial pathogens and spoilage organisms is not new but has mainly been explored in meat and fish products. This purposeful use of microorganisms and their metabolites aims to extend the shelf life and improve the safety of foods. Bio-preservation by use of active LAB cultures and their metabolites including bacteriocins that has gained considerable interest both in terms of their antibacterial and antifungal effects. As fresh-cut, ready-to-eat fruit and vegetable products are becoming more popular with consumers, the food industry needs to seek out ways of managing the associated microbial hazards and quality problems. Bio-preservation with LAB of plant origin may present an attractive alternative to chemical washes and preservatives.

Fermented Vegetables

Gundruk

Gundruk is an ethnic fermented vegetable of the Himalayan regions of India, Nepal, and Bhutan. Gundruk is prepared from the fresh leaves of a local vegetable called rayo-sag (*Brassicca rapa* subspecies *campestris* variety *cuneifolia*), mustard, and cauliflower. This mixture is wilted and shredded, crushed mildly, and pressed into an airtight earthen jar or container. The container is kept in a warm place and allowed to ferment naturally for approximately 7 to 10 days. Unlike kimchi and sauerkraut, freshly fermented gundruk is sun-dried for 3 to 4 days before consumption whereas dried gundruk can be preserved for more than 2 years at room temperature. Gundruk is eaten as a soup or pickle. *Lactobacillus fermentum*, *Lactobacillus plantarum*, *Lactobacillus casei*, *Lactobacillus casei* subsp. *pseudopantarum*, and *Pediococcus pentosaceus* have been isolated from gundruk. Gundruk fermentation is initiated by *Lb. fermentum*, followed by *P. pentosaceus* and, finally, by *Lb. plantarum*, *Lb. casei*, and *Lb. casei* subsp. *Pseudopantarum*. *Lb. plantarum* MTCC 9483 and *P. pentosaceus* MTCC 9484 have been selected as starters for the production of gundruk. Some LAB isolated from gundruk showed strong acidification, antimicrobial properties, and the ability to degrade antinutritive factors and probiotic character. Gundruk contains organic

acids such as lactic, acetic, citric, malic, and acetic acids and is considered as a good appetizer. Cyanides and isothiocyanates are the main flavor components, followed by alcohols, esters, and phenyl acetaldehyde in gundruk. Increases of palmitic, oleic, linoleic, and linolenic acids and free amino acids, mostly glutamic acid, alanine, leucine, lysine, and threonine have been observed in gundruk.

Fermented Bamboo Shoots

Soibum

Soibum is an ethnic fermented bamboo shoot dish from India. Thin slices of young bamboo shoots are packed into this chamber, the upper surface is sealed with a polyethylene sheet, and weights are then put on top for proper pressing. The bottom of the chamber is perforated for draining any acidic juices before being left for 6 to 12 months for fermentation. After fermentation, soibum can be stored for 10 to 12 months. Different dishes are prepared from soibum such as ironba, athongba, kangou, and chagempomba. *Lb. plantarum*, *Lb. brevis*, *Leuc. fallax*, *Leuc. mesenteroides*, *Leuc. lactis*, and *Enterococcus durans* are present in soibum. *Bacillus subtilis*, *Bacillus licheniformis*, *B. coagulans*, and *Micrococcus luteus* were also isolated from soibum. An increase in free amino acids has been observed during the fermentation of soibum.

Fermented Legumes

Natto

Natto is an ethnic fermented soybean food from Japan, similar to kinema. In the traditional method of natto preparation, soybeans are soaked in water overnight, boiled, water is discarded, and the boiled beans are wrapped with tied rice straws which have been soaked in boiling water to sterilize the microorganisms, other than the heat-tolerant spores of *B. subtilis* (natto), which inhabit the surface of straws. A modern method to prepare natto is based on the classical method. After boiling, the soybeans are sprayed with a suspension of spores of *B. subtilis* (natto) and weighed out by 30 to 100 g in polystyrene paper

packages instead of wrapping in rice straws. The packages are transferred into incubators. After 16 hours at approximately 40°C, the packages are cooled for 6 to 8 hours for maturation. Natto is eaten directly with boiled rice, without frying or cooking. *Bacillus natto* was isolated from homemade natto. The bacterium is different from *B. subtilis* at the points of biotin requirement, production of polyglutamate, possession of 5.7 and 60 kb plasmids and insertion sequences. *B. subtilis* (natto) produces nattokinase, which has a high fibrinolytic activity equal to those of urokinase and plasmin. Actually, capsulated nattokinase showed a significant enhancement of fibrinolytic activity in plasma after being given to adults. Natto is a suitable soybean food for patients allergic to raw soybeans. Pyrazines are found to be the major flavor components contributing to the characteristic natto flavor.

Fermented Cereals

Nan

Nan is an ethnic leavened bread of India, Pakistan, and Afghanistan, and is made from wheat flour. Wheat flour is mixed with butter, baking powder, dahi (curd), milk, salt, sugar, and water are added to make a thick dough. The dough is fermented for 3 to 5 hours at room temperature. Fermented dough is sheeted between the palms of the hand to approximately 2 to 3 mm thickness, slightly wetted, and pasted on the inner wall of the tandoori oven. The baked product, called nan, has a typical soft texture and flavor. Nan is baked in a specially designed oven known as a tandoori with a temperature range of 300°C to 350°C. It is baked over live coals or a flame for a short time. Nan is eaten as a staple food with vegetable or dal (legume soup), and meats. *S. kluyveri* is the dominant yeast in nan.

Fermented Tea

Puer Tea

Puer tea is an ethnic fermented tea from China, mainly produced in Yunnan Province. Fresh leaves are heat-treated to inactivate polyphenol oxidases. There are two types of puer tea: raw puer tea and cooked puer tea. During the production of raw puer tea, the leaves are simply softened by steaming and compressed into different sizes before the natural fermentation starts. The production of cooked puer tea is a more complex and relatively recent process. The fermentation is initiated artificially. The dry black leaves are laid out in thick piles in a well-heated room and are sprayed with water and covered with a canvas or tarpaulin for a few weeks. During this fermentation period, the tea polyphenols are more intensively oxidized by the action of microorganisms and environmental oxygen than in the black tea fermentation process. The color turns from green to brown or brownish red, and a particular fragrance is produced. Puer tea acquires a characteristic flavor and numerous health-beneficial properties. The aging of puer tea is an essential process allowing the tea's aromatic bouquet to develop while mellowing the tannins and reducing the astringency. *A. niger* was identified as the predominating microorganism; *Aspergillus glaucus*, species of *Penicillium*, and *Rhizopus*, *Blastobotrys adeninivorans*, and *Saccharomyces* were isolated. Bacterial strains belonging to species of *Actinoplanes* and *Streptomyces* were also isolated from puer tea. Puer tea has hypolipidemic effects and antioxidative properties. The antimutagenic and antimicrobial activities of puer tea have been reported.

Vinegar

Vinegar has been used as a condiment, preservative, and medicine since ancient times in Asia. Vinegar is prepared from any sugar-containing substrate and hydrolyzes starchy materials through alcoholic fermentation followed by acetic acid fermentation. *Acetobacter pasteurianus*, *Acetobacter aceti*, *A. xylinum*, and *Acetobacter polyxygenes* are the dominant bacterium for vinegar fermentation. *Lactobacillus fructivorans*, *Lactobacillus acetotolerans*, and *Moniliella acetobutans* also supplement fermentation. Yeast species involved in the fermentation of

vinegar. The fungal denaturing gradient gel electrophoresis profile indicated that the transition from *A. oryzae* to *Saccharomyces* sp. took place at the initial stage of vinegar fermentation during which alcohol production was observed. The early stage was characterized by the coexistence of *Saccharomyces* sp. and LAB, and almost all of the LAB denaturing gradient gel electrophoresis bands were replaced by bands derived from *Lactobacillus acetotolerance* and *A. pasteurianus* at the stage during which acetic acid started to accumulate.

Amylolytic Mixed Cultures

Nuruk

Nuruk is an ethnic amylolytic starter from Korea. Traditionally, nuruk is prepared by moistening wheat flour, kneaded and molded into a ball, and fermented for 17 days at 30°C to 45°C, dried for 2 weeks, and cured for 1 to 2 months at room temperature. *A. oryzae*, *A. niger*, *Rhizopus* sp., along with a few bacteria and yeast species have been isolated from nuruk. Nuruk is prepared by natural inoculation of molds, bacteria, and yeasts; it can be prepared by inoculation with *Aspergillus usamii*.

Fermented Beverages and Alcoholic Drinks

Saké

Saké is the most popular, ethnic nondistilled alcoholic drink of Japan. It is prepared from rice using koji and is clear, pale yellow, containing 15% to 20% alcohol. Polished rice is washed, steeped in water, and steamed for 30 to 60 minutes, and then cooled, mixed with koji, water, and a selected yeast starter culture for alcoholic fermentation. Main fermentation takes place in open tanks in cool conditions, starting at approximately 10°C, increasing to approximately 15°C. After fermentation, the liquid material called moromi is separated from the solids to produce a clarified saké, which is settled, refiltered, pasteurized, and blended and diluted with water before bottling. Unique strains of *S. cerevisiae* have evolved to carry out those fermentations, generating products with high ethanol content (12–20%), attractive flavor and aroma, and odor. The first organisms

developed in the mash, under traditional fermentation conditions, are nitrate-reducing bacteria such as *Pseudomonas*, *Achromobacter*, *Flavobacterium*, or *Micrococcus* spp. These are followed by *Leuc. mesenteroides* variety saké and *Lb. saké* and yeasts. The highly refined saké brewed by the most skillful brewers using very highly polished rice at low temperatures of 9°C to 11°C for 25 to 30 days is known as gonjoshu. The difference in responses to osmotic stress between the laboratory and saké-brewing strains of *S. cerevisiae* at the translational level was compared and it was found that enhancement of glycerol formation due to enhancement of the translation of proteins Hor2p, is required for the growth of *S. cerevisiae* under high osmotic pressure conditions. *S. cerevisiae* strains with disrupted ubiquitin-related genes produced more ethanol than the parental strain during saké brewing.

Conclusions: Fermented foods and beverages have biological functions enhancing several health-promoting benefits to the consumers because of the functional microorganisms associated with them, such as the bio-preservation of perishable foods, bio-enrichment of nutritional value, protective properties, bioavailability of minerals, production of antioxidants and omega-3-polyunsaturated fatty acids, therapeutic values, and immunological effects. Some Asian ethnic fermented foods, such as tempe, natta, natto, shoyu, kimchi, etc., have been commercialized and marketed globally as health foods or functional foods.

Soy sauce

Soy sauce is a typical condiment and seasoning made from soybeans in a two-step fermentation procedure. The first step is a solid fermentation by fungi, followed by liquid fermentation in a high-concentration brine solution of osmophilic lactic acid bacteria and yeasts. These two fermentation steps involve three microbial groups that give the product a desirable taste, flavor, and color, serving as a basic condiment and seasoning for the cuisines of several Asian countries. The soybeans used for its production can be from yellow or black soybean varieties. In Japan, it is called shoyu, whereas in Indonesia, it is called kecap. Shoyu is made mostly from yellow soybeans; kecap is traditionally made

from black soybeans. Both soy sauce products have different chemical and sensorial characteristics, primarily because of the different molds, bacteria, and yeasts as well as the different raw material compositions used in their production. In addition, kecap typically has a deeper brown color and a thicker viscosity than that of common soy sauce because of the sugar added in the final process of production. Generally, in today's market, soy sauce is sold in three different categories, that is, fermented soy sauce, chemical or artificial soy sauce, and half-fermented soy sauce with a combination of the fermentation process and the addition of chemical soy sauce. The chemical soy sauce is made by rapid acid hydrolysis of soybean proteins at temperatures of 80°C or higher for a couple of hours, whereas the fermented variety needs several months of fermentation at room temperature between 25°C and 35°C to have complete protein hydrolysis. The two categories have wide differences in flavor and aroma characteristics.

Synbiotic Soy Beverages: Principles and Sensory Attributes

Hydrosoluble soy extract is a raw material with great potential in the development of food with a healthy appeal such as functional synbiotic and fermented drinks (with probiotic and prebiotic substances). Synbiotic soyfoods need to be carefully developed, mainly with regard to sensory characteristics, because it already presents good functional characteristics; if the product's sensorial characteristics are unsatisfactory, this will not be well accepted by the consumers. During storage, it is common to observe that fermented products have problems such as syneresis, changes in sensorial characteristics such as color, taste, viscosity, and other changes caused by high bacterial activity. For these problems, the trends of the new researches in this field are the optimization of the most important variables of the fermentative process, sensorial optimization of the functional soymilk beverages, shelf-life analysis, effects of several factors involved on product stability, determination of functional probiotic effects such as resistance to simulated conditions in the gastrointestinal tract, development of packs, and others. The functional foods involved countless variables that influence its fundamental characteristics as sensorial, functional, nutritional, and physicochemical aspects in all steps of the development and production chain. The raw material, process variables (i.e., temperature, pH, oxide reduction

potential, osmotic pressure, solvent solids concentration, and others), kind and number of probiotic strains involved, the mutual relations such as synergy, synbiosis, and symbiosis between the strains and the strains/ingredients (as the prebiotic agents and other foodstuffs) in the different states such as manufacturing, storage, and final consumption affect the final results. It is possible to improve functional foods to meet consumer expectations by using sensory techniques that adjust to the fundamental characteristics of each type of food.

Synbiotics

The positive influence of prebiotic substances, as soluble fibers, on intestinal flora has been tested in several studies, in which the utilization of probiotic species in combination with prebiotic substances provides a combined effect called “synbiotic”. Synbiotic functional foods are those that supply both prebiotics and probiotics. Given the potential synergy between probiotics and prebiotics, the foods that contains a combination of these ingredients are frequently called synbiotics, in which syn means synergy and biotic means life. The original term used in English was “symbiotic”. The probiotics, *B. longum* and *L. paracasei* subsp. *paracasei* pure, and the associated bacteria, *L. acidophilus* and *L. paracasei* subsp. *paracasei* and bifidobacteria, have acceptable growth in soy extract. Symbiotic relations were observed because of the protein availability and the reduction of acidity in the broth for *L. acidophilus*, and the availability of sugars for the bifidobacteria due to its β -galactosidase activity, fortifying the growth of *L. acidophilus*.

Description of Soymilk as a Substrate Used in the Development of Fermented Synbiotic Foods

The changes in some carbohydrates and organic acid production during fermentation of soybean water extract with probiotic bacteria (*L. acidophilus*, *L. paracasei* subsp. *paracasei*, and *B. longum*) in pure or mixed cultures. The analytical assays of different soymilk-fermented beverages by probiotics. The qualitative data for some sugars and oligosaccharides in extracts of soy with fermentation. The presence of monosaccharides, disaccharides, and oligosaccharides such as glucose, fructose, sucrose, galactose, raffinose, and stachyose in water-extracted soybeans can be verified. The nonreducing sugar concentrations (sucrose and oligosaccharides) changed during fermentation, being hydrolyzed to reducing sugars and used, at some period, by the microorganisms as a carbon source. Analyses of carbohydrates by ion chromatography and high performance liquid chromatography (HPLC) have proved difficult because of the requirement for different columns to separate the carbohydrates. Using HPLC with pulsed amperometric detection (HPLC-PAD) chromatograph and column PA100, the separation of fructose and sucrose is possible; the fructooligosaccharides and the sugars, raffinose and stachyose, overlapped, whereas the glucose and galactose presented the same retention times. Thus, column PA10 can be used for the separation of galactose, glucose, raffinose, and stachyose. Sucrose and fructose overlapped and the fructooligosaccharides were not separated. Using HPLC equipped with refractive index detector and HPX 87H column, glucose, fructose, and galactose can be separated, but sucrose and raffinose overlap; stachyose and fructooligosaccharides cannot be separated chromatographically.

Sensory Attributes

Sensory evaluation delivers complete and prompt information about product quality, determines acceptance on behalf of the consumer and, the purchasing intent for that product. The hedonic unstructured scale or self-adjusting scale is one of the sensory methods available, used to measure consumer acceptance of a product due to the reliability and validity of its results, as well as its simplicity for use by the tasters. Synbiotic fermented soy beverage

containing a mixture of *L. acidophilus* + *L. paracasei* sp. *paracasei* + *B. longum*, and supplemented this with prebiotic agents using combined techniques of sensory analyses and experimental design. The use of the just-about-right scale in sensory tests measures the ideal amount of a determined compound that should be added to promote greater acceptance and preference according to the taste panel. Thus, some studies aimed to optimize ideal characteristics such as consistency, sweetness, color, and flavor into others of a fermented soy beverage. In these cases, it would be convenient to use the combination of an experimental design and sensory analysis. An example would be to improve the sweetness for a product sweetened with sucrose, applying the ideal scale and determining the models to predict the acceptance and purchasing intention on behalf of potential consumers through a complete experimental rotational design. The aim of optimizing the ideal qualities of a synbiotically fermented soy beverage, the combination of an experimental design and sensory analysis techniques help to optimize the formulae, and to process and obtain predictive models.

Thua Nao and Related Products

Thua nao is a traditional fermented soybean food widely consumed in Northern Thailand. It is not only an important food/condiment but also serves as a low cost protein supplement for the local people. Traditional thua nao has a strong unpleasant ammoniacal smell, dark grayish or brownish color, and slightly slime matter. This is different from natto, which are a white mucous substance that has a unique flavor and a palatably soft texture, are light yellow, and are able to generate silky and sticky mass. Thua nao is an indigenous alkaline-fermented soybean of Thailand. This condiment plays a key role as dietary culture of local Thai people. In terms of nutrition, the product is acceptable as a good source of protein supplement in which other health benefits must be further explored. The use of pure starter culture is a good start and potential for product improvement. An alternative research relevant to nutritional quality (i.e., enhancement of amino acids and flavoring agents), health benefits (i.e., anticancer, antimicrobial, and antioxidant activities), and fermentation process would provide a new image of this indigenous food to the Thai and world community.

Thua Nao Fermentation Process

Three major raw ingredients for thua nao production are as follows: soybeans, water, and mixed natural bacterial culture. Four major steps are involved in the conventional thua nao manufacturing process consisting of soaking, boiling, fermenting, and incubating. Soaking of soybean for overnight and then boiling of soybean seeds for 3 to 4 hours until soft. The cooked soybeans are then packed in bamboo baskets lined and covered with banana leaves and allowed to undergo spontaneous fermentation at ambient temperature for 2 to 3 days. There are differences in the procedures and equipment used in different areas and communities. Dry soybeans are cooked in boiling water for 7 hours after being washed twice with clean water, fermented in woven bamboo baskets lined with fern leaves, and then covered with the plastic bags and placed outside the building exposed to sunlight for 3 days. Soybean seeds are soaked overnight (12–14 hours) in water before being boiled for a shorter time (4–6 hours). The fermentation conditions are also different, as cooked seeds are packed in bamboo basket lined and covered with banana leaves and left to stand at ambient temperature in the household for 2 to 3 days. The production of thua nao, except for omitting the soaking step of the seeds; instead, dry soybean seeds are immediately cooked by boiling in water for 3 to 4 h, and the banana leaves are used to enclose the cooked soybeans in bamboo baskets and allowed to spontaneously ferment at ambient temperature in the household for 3 to 4 days. The diversity of soaking and cooking steps including the variation of equipment and fermentation conditions leads to the inconsistency and safety qualities of the product. The complete fermented soybean is indicated by the grayish brown color of soybean seeds and the appearance of a slight mucilaginous substance and is dominated by a strong ammonia-like odor. Thua nao is regarded as spoiled when they liberate putrid or rancid smell or appeared contaminated with mold or yellow-pigmented slimy material on the beans. A major problem of cooked thua nao is a short shelf life, approximately 2 days, if stored under ambient conditions. Hence, to extend the shelf life of this product, a sun-dried process of thua nao is developed and widely known among the locals as thua nao kab which could be kept for several months.

Aroma and Flavoring Agents of Thua Nao

The microbial fermentation of soybeans causes biochemical changes including organoleptic properties. Such changes affect texture, odor, and flavors of the products. Traditionally produced thua nao is described as a fish sauce-like product due to a strong ammoniacal smell. In contrast, natto produced by a pure starter culture has a fruity/nutty aroma. Thua nao products contain aldehydes, aliphatic acids, esters, and sulfur compounds, whereas natto condiments are devoid of these chemicals. Several pyrazine compounds found in natto are proposed to be the main contributors to natto odor characteristics. As part of the program to improve thua nao quality, the use of pure starter culture of *B. subtilis* strain TN51 isolated from commercial thua nao product has been shown to improve the organoleptic quality of the product. The profile of volatile compounds responsible for the aroma of thua nao produced with pure and mixed cultures was determined using gas chromatography–mass spectrometry. There was a shift in volatile profiles from the cooked nonfermented to fermented products. A different pattern of the volatile compounds was also observed in the thua nao samples prepared with pure and mixed starter culture.

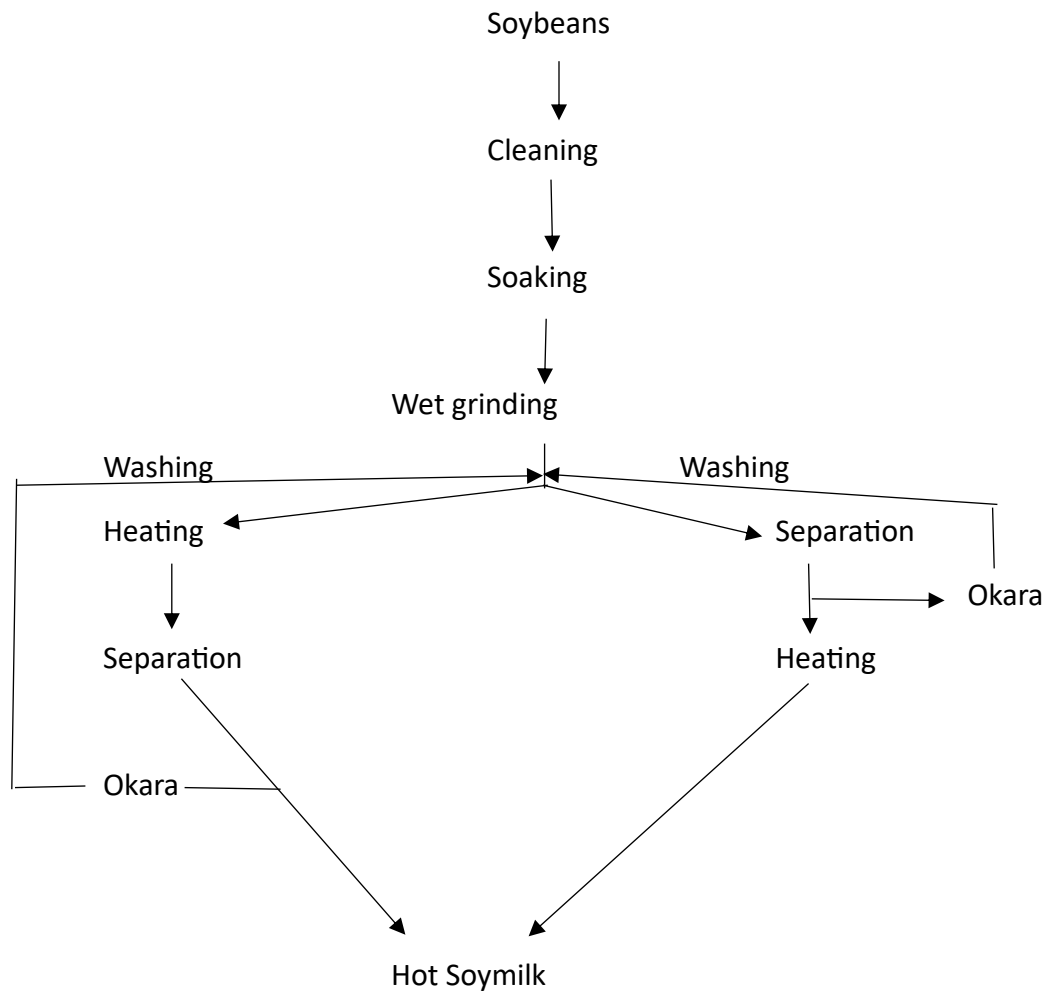
Manufacturing of Soymilk and Tofu

There are many methods for producing soymilk. Several types of tofu are produced nowadays, namely, momen (firm or extra firm) tofu, soft tofu, silken (Kinugoshi) tofu, and fill-packed silken tofu. These tofu products are usually packed in trays with water, pasteurized, and kept refrigerated in display chambers in retail stores for selling in developed countries. They have a shelf life of 3 to 4 weeks under proper refrigeration. In some countries, they may be sold as fresh tofu in plastic bags or containers with water, or even just cut into smaller blocks as ordered by the consumers. These types of tofu have a short shelf life, 1 to 3 days under proper refrigeration. Filled silken tofu has been sterilized and is shelf-stable for 6 months or longer under refrigeration.

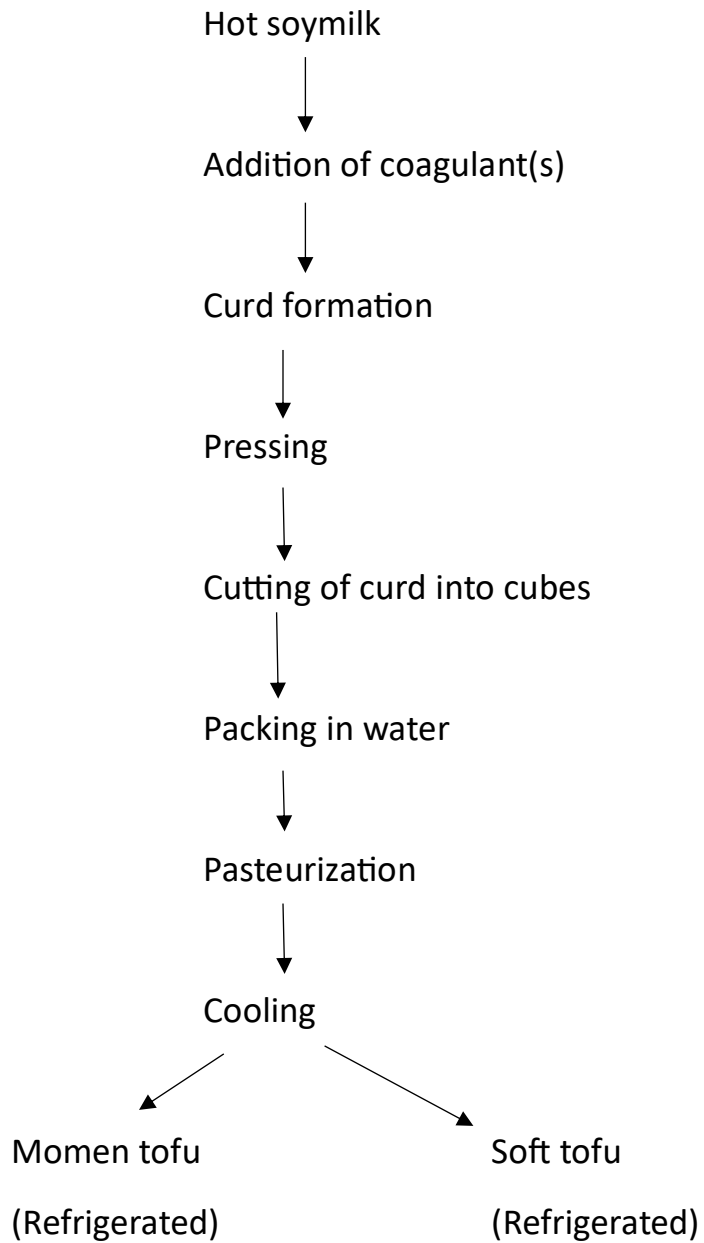
Raw soybeans are first cleaned to remove all the foreign matters, followed by soaking the cleaned beans in water to allow the dry beans to absorb enough water before grinding. Soaking time is dependent on soaking temperature and

raw material characteristics as affected by cultivar and storage. Usually, this soaking process takes 8 to 10 hours at 15°C to 20°C or 12 to 16 hours at 10°C to 15°C. This difference is due to ambient temperature difference at various locations of the manufacturing plant. Soaking time can be shortened to 3 to 6 hours if temperature is higher than 20°C. On the other hand, soaking could be performed at a low temperature (2°C–4°C) to prevent off-flavor development during soaking and grinding. After soaking, the beans weigh approximately 2.2 to 2.3 times their initial weight. When water is absorbed, it rehydrates the various components in the dry beans, making it easy to be dissolved or dispersed in water during the grinding process. Soymilk for tofu making also could be made from soybean powder or soybean flakes, which require less time to rehydrate. In addition, dry unsoaked soybeans or dehulled soybeans can be partially soaked at high temperature for a very short time and milled with hot water (80°C) to extract soymilk with a low beany flavor. Such practice will reduce the yield of soymilk. In preparing consumer soymilk products by some manufacturers, dehulling soybeans before extraction also removes germs (hypocotyls) and is carried out to improve the flavor of soymilk and to extend shelf life.

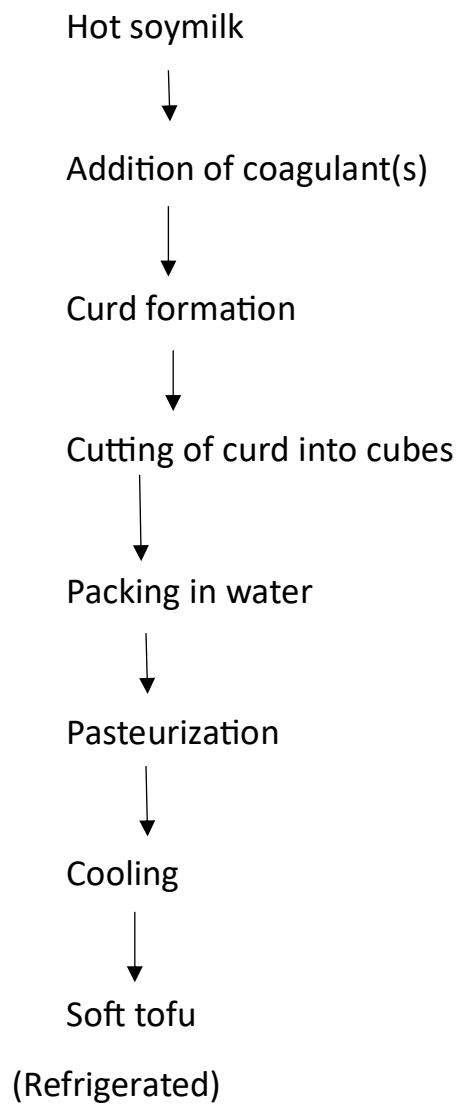
Grinding soaked soybeans breaks down the intact structure of the dry beans. The amount of water added in the grinding process should be carefully controlled to meet the requirements for the different types of tofu to be manufactured. For example, the water dosage for silken tofu, soft tofu, and regular tofu is 5, 7 to 8, and 10 times of raw soybean weight, respectively. This will give soymilk with 9 to 13°Brix or higher. Grinding can be conducted using a stone mill or stainless steel grinder. Solids content in °Brix can be rapidly measured using a hand-held refractometer for quality control. °Brix is proportionally related to soluble solid content of the soymilk. Water-soluble components such as sugars, amino acids, and water-soluble vitamins are dissolved in the water added during the grinding process. Proteins and lipids are dispersed in the slurry, and the fibers are broken down to smaller particulates. Proper grinding gives appropriate small particle sizes in the slurry and facilitates the extraction of solids and nutrients into the soymilk. The finer the slurry, the more components can be extracted, but it makes it harder for the separation of the soymilk and the residue (okara). This will also affect the yield of soymilk.



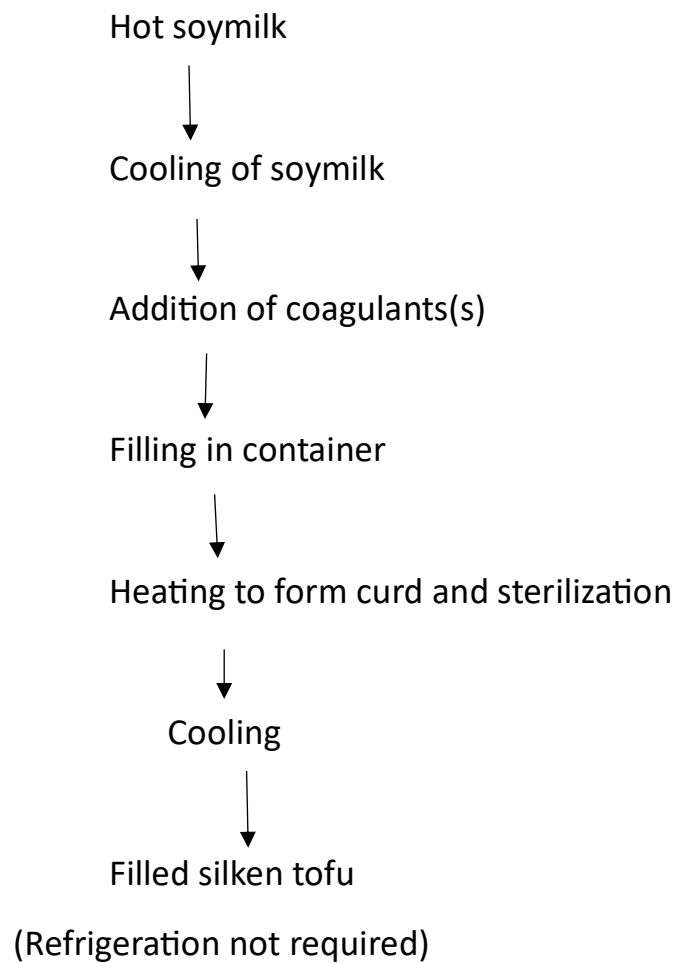
Preparation of soymilk for tofu making. *15°C to 20°C for 8 to 10 hours or 10°C to 15°C for 12 to 16 hours. **98 to 105°C for 2 to 5 minutes



Schematic diagram for production of momen (firm or extra firm) tofu and soft (silken) tofu. *9 to 10°Brix soymilk solid for momen tofu production and 10 to 12°Brix soymilk for soft tofu production



Schematic diagram for production of soft tofu. *13°Brix or higher soymilk solid for soft tofu production



Schematic diagram for production of shelf-stable–filled silken tofu. *13°Brix or higher soymilk solid for filled silken (Kinogoshi) tofu production

Sensory Analysis of Fruit and Fermented Fruit Product Flavors

Sensory evaluation is defined as a scientific method used to evoke, measure, analyze, and interpret those responses to foods and beverages as perceived through the five senses of sight, smell, touch, taste, and hearing. Integrating sensory science techniques assists in identifying specific properties of foods that may not be found instrumentally and also provides important and useful information to product developers, food scientists, and managers about the sensory characteristics of their products. Sensory evaluation has been used significantly in the identification and characterization of fruit and fermented fruit flavors. The main test methods used to assess these flavors have been descriptive analysis (DA), affective tests, quality rating methods, and difference tests. DA is conducted to determine how products differ in specific sensory characteristics and produces analytical data from highly trained panelists, which can be compared with instrumental measurements. Affective tests, which are also known as consumer tests, can be used to investigate how well products are accepted or preferred among a population of untrained regular users of the products. These sensory methods have focused on fruit and fermented fruit flavors. These methods have been applied, first, to fruit flavors and, second, for fermented fruit flavors. For the fruit flavors section, the outline will follow (1) various DA methods, (2) integration of consumer and descriptive studies, and (3) the correlation of instrumental and sensory measurements. For the fermented fruit flavors section, the outline will follow (1) DA methods, (2) quality rating methods, (3) consumer and affective testing methods, and (4) difference testing methods.

Vegetable Fermentation

There are different methods to conserve foods, and one of them is increasing the acidity. This can be achieved artificially with the addition of weak acids or naturally by fermentation, obtaining free additive products. The preservation of food by fermentation is an ancient and widely practiced technology. The fermentation processes can be developed by the action of native microflora or by lactic acid bacteria (LAB) inoculation. Fermentation increases not only the product's shelf life and microbiological food safety, but also improves the digestibility and nutritional value of the food.

Advantages of Fermenting Vegetables

Heating could destroy vitamins, provoke Maillard reactions, and reduce the availability of free amino acids. Lactic fermentation does not require or only requires very little energy in the form of heat, allowing the preservation of fresh or minimally processed vegetables. It also does not destroy amino acids or vitamins, unlike any form of thermal conservation. Fermentation increases the digestibility of plants and, if it is made with starter strains with beneficial properties, might have a probiotic effect.

Use of Starters

Fermentation can be carried out by natural flora or by inoculated starters like LAB. The fermentation is led by indigenous flora, which varies based on the substrate, temperature, and conditions of storage. Initiation of a spontaneous process takes a relatively long time, with a high risk for failure. Failure of fermentation processes can result in spoilage or the survival of pathogens, thereby creating unexpected health risks in food products. Thus, from both a hygiene and safety point of view, the use of starter cultures is recommended. The use of starter cultures would be an appropriate approach for the control and optimization of the fermentation process to minimize variations on organoleptic quality and microbiological stability.

Presence of LAB in Vegetables

LAB are responsible for fermentation of many vegetables. The most important commercial vegetable fermentation in Europe is for olives, cucumbers (pickles), and cabbages; in these vegetables, LAB represents 1.5% of the total bacterial population. Some species of LAB are found in various types of fermented vegetables. *Lactobacillus plantarum* and *Leuconostoc mesenteroides* were commonly identified within the microbiota of cucumber, tomato, pumpkin, persimmon, and in eggplant when they ferment spontaneously. One of the main advantages of LAB is the ability to inhibit the development of spoilage microorganisms that could affect consumer health or deteriorate the food.

Antimicrobial Activity

Three mechanisms may explain the antimicrobial efficiency of LAB: organic acid production (with pH diminution), competition for nutrients, and production of antagonistic compounds.

Organic Acids

LAB can produce lactic acid (homofermentative bacteria) or lactic acid over acetic acid (heterofermentative) from carbohydrates. Lactic acid, the most widely occurring hydroxylcarboxylic acid, has traditionally been used as a food preservative. Acidification inhibits the growth of microorganisms not adapted to low pH. The capability for rapid acidification is one of the most desirable properties of a starter culture. Organic acids occurring in foods are additives or end products of the carbohydrate metabolism of LAB. The direct antimicrobial effects of organic acids, including lactic and acetic acids, were observed against Enterobacteriaceae.

Microbial Interference

Microbial interference is an effective nonspecific control mechanism common to all populations and environments including foods.

Against Yeasts

Not all microorganisms are inhibited by low pH produced by the formation of acids by LAB. Some yeasts have a great capacity to develop in acidic environments. In fermented vegetables, spoilage yeasts appear after fermentation by LAB, but when a lactic starter is used, the growth of yeasts is usually inhibited. Results suggest that prefermentation of vegetables with LAB does not prevent the subsequent growth of yeast because residual sugars are found in the fermented products. Acidification with lactic acid alone to pH 3.74 is insufficient to prevent the growth of spoilage yeast in fermented vegetables, and the presence of other organic acids is desirable in this aim. The production of acetic acid during fermentation would seem to be a critical aspect of the preservation of fermented vegetables. The prevention of yeast spoilage would be improved by reducing the contamination levels of yeast, and by preventing the growth of yeast in the initial

stages of fermentation when the pH of the vegetable mixture is high. The inoculation of a selective lactic starter to rapidly lower the pH seems recommendable.

Inhibition of Mycotoxin-Producing Fungi

Food and feed spoilage molds cause great economic losses worldwide. It is estimated that between 5% and 10% of the world's food production is wasted because of fungal deterioration. Some strains of *Lactococcus* species to control mycotoxinogenic mold growth. Two LAB, *Lactobacillus fermentum* and *Lactobacillus rhamnosus*, which are widely used in the fermentation and preservation of food, were inhibitory against *Aspergillus nomius* assayed on their fungal inhibitory properties. The reduction of mold growth during the production and storage of food and feed is of great importance. *Aspergillus* produces mycotoxins in grains and represents a direct threat to crops. The most effective means to prevent the contamination of food with mycotoxins is to avoid the growth of mycotoxigenic fungi.

Pepper Fermentation

Pepper is a solanaceous agricultural crop belonging to the *Capsicum annum* L. species. Health-promoting, nutritional, and sensory attributes make pepper one of the most consumed vegetables worldwide that contain a large spectrum of antioxidant compounds (polyphenols, vitamin C, flavonoids, and carotenoids) with free radical scavenging properties, are essential antioxidants that may protect against the propagation of the oxidative chain. When consumed in the daily diet, these compounds may prevent several human diseases, including several forms of cancer, arteriosclerosis, and cardiovascular diseases. Peppers are consumed mature or immature, as crude fruits, or in Spanish stews, and in preserves or pickles. There is little information available on the fermentation of peppers. A protocol for the manufacture of fermented peppers includes a thermal blanching at 85°C for 2 minutes. Blanching is used to decrease the microbial population and to inactivate deleterious enzymes (e.g., peroxidase, polyphenol oxidase, and pectin methylesterase) that may cause undesirable nutritional and sensory changes. In addition, blanching of peppers in the presence of water promotes chemical or enzymatic reactions leading to positive variations of the aroma profile. The advantage of using a starter culture is that the pH decreases more

quickly and it confers microbiological stability to the product. A spontaneous fermentation generally needs four to six days before the pH stabilizes, but a high-level inoculation. The microorganisms that used in these fermentations consume as much glucose as fructose. From these results, it is possible to suggest that fermentation is controlled at 30°C because the fast pH diminution confers greater microbiological stability to the product. Fermentation can be carried out with different concentrations of sugar and sodium chloride. In the fermentation of peppers, the acid production depends on the initial glucose concentration. The fermentation of peppers with the smaller concentration of glucose is excellent, contributing to the possibility of reducing the costs for the manufacturing industry. For the pepper fermentation starter, as selected by the tasting panel, the lactic acid and acetic acid relation is between 2.8 and 3.1. In the mixed culture, the acetic acid in the heterofermentative microorganism contributes toward reaching the balanced acidity in the taste examination. The fermentations in the juice of peppers have patterns similar to the fermentations of the fruit in solution with 20 g/L of glucose. In the juice, the pH decreases at a greater speed when it is incubated to 30°C. The dominant species identified in peppers were found in other vegetable matrices. The dominant presence of health-promoting compounds and the sensory features of pepper fruits may encourage food processing that aims at preserving the functional compounds and agreeable sensory characteristics of pepper for extended shelf life, possibly at room temperature.

Sugar Cane Fermentation

Sugarcane blunting is the upper part of the cane that usually contains lower sugar levels than the rest of the cane, and is discarded to increase the sugar yield of a given amount of cane. With no other use for the discards, the residues are commonly placed in earthen excavations. Because of their high humidity levels, they decompose, generating abundant effluents. Blunting may have lower sugar content than the rest of the cane; it contains sufficient sugar to be a carbohydrate source for the growth of pathogenic or detrimental organisms when discarded.

Sugar production from sugarcane generates residual products, many of which are, currently, waste products. Because of its sugar content, its discards can be fermented, which will reduce the levels of sugar and the pH. The fermentation

product will be microbiologically stable. Silage produced in this way can be used as a nutrient for cattle, goats, and sheep. A residue from sugarcane harvests, blunting, could be used as a ruminant animal food supplement with suitable DM, carbohydrate, and fiber contents. Moreover, a ruminant probiotic survives on this product, increasing blunting's effectiveness. That sugarcane blunting has a significant amount of sugar content, even after being fermented for 60 days. When ruminant diets are supplemented, there is a concomitant reduction in pasturing time because the animals' energy demand is reduced. The presence of glucose in the food enhances the survival of the inoculants LAB in the rumen fluid. These factors indicate the advantages of fermented sugarcane blunting silage. A reduction in Enterobacteria is considered advantageous from a medical perspective because those bacteria are frequently associated with infections after intestinal surgery. Some strains of Lactobacillus may protect the host from infection. LAB, under certain growth conditions, seems to inhibit the development of fungus. Similar effects have been observed after inoculating vegetable juices with a LAB mixture to enhance the fermentation growth of yeasts. The inhibition of spoilage yeasts in fermented salads has been associated with a combination of lactic acid and carbon dioxide formation, along with a reduction in the concentration of residual oxygen.

Inhibition of yeasts can be a result of their competition for nutrients with LAB and not to the production of lactic acid. In the presence of the two LAB isolated from sugarcane, the inhibition of yeast growth was higher than that observed in the presence of the goat probiotic bacteria alone. These results could be due to acetic acid being more inhibitory with yeasts, molds, and bacteria compared with lactic acid.

Lactobacillus species are found in the gut of humans and other animals, but their numbers may vary with the animal species, the age of the host, or the location within the gut. LAB may enhance the digestion of silage, not all microorganisms improve silage after fermentation.

The postfermentation characteristics of sugarcane blunting were deemed beneficial, as suggested by the low pH values, high lactic acid levels, low Enterobacteriaceae and fungus abundance, and high LAB contents relative to the uninoculated, control blunting. The lactic acid production was higher than that

observed in the fermentation of some fruits. In addition, the fermentation of this residue can serve as a medium for introducing probiotic bacteria to goats, suggesting its use as a useful ruminant feed supplement. LAB-enhanced silage production of vegetative residuals from sugarcane processing plants can produce beneficial dietary supplements for ruminants. These results suggested that LAB-enhanced silage production of vegetative residuals from sugarcane processing plants can produce potentially beneficial dietary supplements for ruminants.

Perspectives

The concept that LAB are beneficial to health is well accepted. It is known that the beneficial properties to the consumer are strain-dependent. When one thinks of probiotics, what usually only comes to mind are dairy products. Probiotic strains, combined with lactic acid strains with good fermentative capabilities, can ferment sugar cane silage and survive at least 60 days. When these strains were administered to goats, the fecal mutagenicity diminished 60% and the putrescine levels, cancer markers in the gut, decreased nearly 10 times, whereas the fecal microflora were enhanced. The survival of LAB in peppers at 22°C was greater than at 30°C. At 30°C, there was a greater percentage of survival in the uncontrolled fermentations. At 30 days of incubation, a lower level of microbial survival was observed in selected control peppers heated inoculated with in pure culture or combined with one or two of the other LAB. In the mix of fermentation that involves different combinations between heterofermentative and homofermentative LAB, survival at 30 days was log 5.40 CFU/g sample indicating the possibility of considering the medium to preserve the probiotic bacteria. This is the time to add value to the fermentation of vegetables, and design it as a functional food. It is well established that lactic acid has beneficial properties in the gastrointestinal tract of humans; this is the main acid formed in the fermentation of vegetables. This demonstrates that early removal of Enterobacteriaceae eliminates the risk of the formation of mutagens from promutagens in food.

Fermented Red Beet Juice

Red beet (*Beta vulgaris*, also known as beetroot, table beet, garden beet, or blood turnip) is a popular vegetable all over the world. This vegetable plant is a considerable source of vitamins C and B (B1, B2, and B6), minerals (such as calcium, iron, potassium, magnesium, phosphorus), and it contains a relatively high level of folic acid. The most important bioactive agents of the red beet are the water-soluble plant pigments, the betalains. The original purpose for the fermentation of raw materials was to preserve it, and this was accomplished with naturally occurring fermentations because the ancient people were not aware of the role of the microorganisms in this process. Fermentation depends on the biological activity of microorganisms. The raw material (vegetables) provides the substrate for the LAB, which excrete a range of microbial metabolites; both the type of substrate and the genera of bacteria and their enzyme activity influence the quality of the end product. LAB could produce energy for their activity or for propagation through lactofermentation. The uptaken or intracellularly hydrolyzed carbohydrates can be fermented by lactobacillus strains through two major pathways: glycolysis is used by the homofermentative LAB, and the 6-phosphogluconate/phosphoketolase pathway is used by heterofermentative LAB. During the fermentation of carbohydrate, when the sugars are converted to cellular energy, LAB excrete lactate as a metabolic by-product. Lactic acid is the predominant end product (always by the obligate homofermentative strains), but under various conditions, the amount of other by-products (acetic and other acids, alcohol, and carbon dioxide) could be increased by the facultative homofermentative strains, whereas the obligate heterofermentative strains always produce significant amounts of by-product, other than lactic acid. The acids produced play an important role in the preservation of the product as well as enhancing the shelf life and microbiological safety of the fermented food.

The Process of Fermentation

Fermentation is the preparation of the raw material for inoculation with the starter culture. The surface of the harvested red beet root contains a wide range of numerous microorganisms, and the elimination of soil and microbes from the surface of the roots by washing is the first important step. This is followed by the

peeling of the root and a repeat washing. The cleaned red beet root, after chopping, can be used directly in this form or a juice could be made from it. Heat treatment (blanching or pasteurization) can be considered before the inoculation. The microbial safety of the product can be increased and the chopped form will be softer, but the heat treatment can cause change in the color, the red-violet can turn to brown and the activity of the bioactive molecules could vanish. Good manufacturing practice—what is necessary during the whole process—can produce a microbiologically safe raw material without heat treatment. The juice can be produced both mechanically by centrifuge and enzymatically by liquefaction. For this enzymatic procedure, the red beet root should be mixed with the same amount of water and, after heat treatment at 80°C for 2 minutes, cooled down to 40°C. A macerating-type pectolytic enzyme mixture should be added to this mixture and treated at 40°C for 2 hours. Then, the reaction should be stopped by heating at 80°C and the mixture homogenized and the pH adjusted. For the fermentation of red beet slices, these should be filled up with brine before the inoculation. After the preparation of red beets, the next step is inoculation with the starter culture. The population of the starter culture should be at the exponential growth phase, culturing for one night is optimal. The amount of inoculum is usually 1% to 2% of the volume of the raw material. The initial cell concentration in the product should be at least 10^6 cell/mL juice/brine to guarantee fast growth and rapid acidification to keep down the other potential microbes present. The optimal incubation temperature is 30°C to 37°C. The optimal incubation time depends on the temperature and the initial cell concentration, but at 30°C, the 10^6 cell/mL initial cell concentration and pH drop reaches the maximum after 32 to 48 hours.

Health Benefits of Fermented Products

Both the red beet and the potential probiotic starter culture have in themselves beneficial health effects on human consumers. Red beet in the treatment of several gastrointestinal diseases, fevers, and anemia, as well as in wound healing. Red beet has traditionally been used in folk medicine because it has been considered to have blood-forming and antitumor properties. The most important bioactive components of the red beet are the betalains. Similar to other

natural plant colorants, betalains have a wide range of desirable biological activities. Betalains are radical scavengers and show antioxidant activity, whereby they prevent active oxygen-induced and free radical-mediated oxidation of biological molecules. Together with the antioxidant activity, the betalains show anti-inflammatory, hepatoprotective, and anticancer properties, their presence in the human diet may reduce the risk of cancer, cardiovascular disease, and other diseases associated with aging. Beetroot contains one of the most useful, natural, cancer-preventive agents. In the red beet, the main betalains are betanin (red) and vulgaxanthine I (yellow). Lactic acid fermentation can be an alternative method to preserve (even partially) the active components. The red beet can accumulate a significant amount of nitrates which, after consumption, can easily be reduced to nitrites in the human organism and can be hazardous to human health. Nitrite can react with secondary amines and result in nitroso-amino compounds. Increased nitrate from red beet juice improves brain function and reduces blood pressure and the occurrence of cardiovascular diseases.

Nutritional Quality of Vegetables

Fruits and vegetables are important components of a healthy diet. Vegetables contain most of the essential components of human nutrition. The nutrient composition of vegetables is very complex and difficult to assess. Among amino acids, fatty acids, and vitamins, there is recognition now that many compounds in vegetables, such as dietary fiber, flavonoids, sterols, phenolic acid, glucosinolates, and so forth, are associated with lower disease risk. These compounds might exert protective effects against many diseases such as cancer, coronary heart disease, diabetes, high blood pressure, cataracts, degenerative diseases, and obesity.

Probiotic Fermented Vegetable Juices

The lactic acid fermentation of vegetable products, applied as a preservation method for the production of finished and half-finished products, is considered as an important technology. Because of their positive effects on health, most fermented foods today are included in a special group known as

functional or therapeutic foods. The presence of functional foods in the daily diet could greatly improve the quality of human life, helping in the reduction of the risk of degenerative chronic diseases. Different varieties of functional foods are present, from which most are dairy-based fermented products. The unfavorable cholesterol content of fermented dairy products, has encouraged producers to develop a group of nondairy functional products, which include fermented vegetable juices. The list of potential functional food products are expanding at a very fast rate. Consumption of nondairy functional foods are of great importance especially for vegetarians whose diet is based on fruits, vegetables, legumes, and cereal products.

Viability of Probiotic Strains in Fermented Vegetable Products

To show healthy effects after consumption, probiotic microorganisms must be not only alive but also present in high numbers in the product at the time of purchase. Analysis of commercial probiotic foods conducted in the past decade showed that most of these products contained variable and very low concentrations of probiotics. This refers to probiotic foods containing species from the genera *Bifidobacterium*. Consumers require that every type of probiotic food produced, including fermented vegetable juice, should be labeled with the correct information not only about the species of probiotic bacteria used for fermentation, but also about the minimum daily quantities necessary to achieve confirmed specific health benefits to the consumer. A therapeutic effect are mainly caused by a possible decline in the concentration of probiotic organisms during processing and storage of the probiotic product, as well as by the fact that the fermented products could lower the activity during passage through the upper and lower parts of the gastrointestinal tract.

A large number of live probiotic cells in food, it is important to avoid many different stress conditions during the manufacturing process and subsequent storage of the probiotic products. In addition to environmental factors such as water activity, redox potential (presence of oxygen), incubation, and storage temperature, the final acidity of the product, and the viability and activity of the probiotic is also linked with genus, species, and strain biotype of the probiotic, interactions between microbial species used as a starter culture for the production of fermented vegetable juices, production of hydrogen peroxide due to

bacterial metabolism, availability of nutrients, growth promoters and inhibitors, concentration of sugar, composition and quality of other active ingredients present in the fermented vegetable juices, buffering capacity of the medium, inoculation level, and fermentation time. The production of certain types of probiotic fermented foods, it is recommended that starter cultures formed from several probiotic strains with different beneficial properties be used.

The presence of *S. salivarius* ssp. *thermophilus* in a starter culture, together with probiotic strains, may stimulate their growth because of the consumption of oxygen. Oxygen can be dissolved in the fermentation substrate and final products or can enter through packaging materials during storage. Its presence during fermentation and later in probiotic-containing products (positive redox potential) can have a detrimental effect on the viability of microaerophilic and anaerobic probiotic strains such as *Lb. acidophilus* and *Bifidobacterium* spp. Their characteristic is that they do not have electron-transport chains and incompletely reduce oxygen to hydrogen peroxide. They do not have catalase to convert hydrogen peroxide into water and its intracellular accumulation over time becomes toxic to the cell and leads to death.

Raw vegetable juices without nutrient supplementation and pH adjustment (tomato, cabbage, beetroot, carrot, or celery) are ideal substrates for the growth of probiotic strains. The total number of viable cells reached in certain types of fermented vegetable juice at the end of the fermentation process and their stability during cold storage at 4°C are presented. The total number of viable cells in most fermented vegetable juices is in the range of 10^8 to 10^9 CFU/mL at the end of the fermentation process, which indicates that the consumption of fermented vegetable juices immediately after the fermentation process could have a positive effect on human health. The total number of viable cells in fermented cabbage and beetroot juice at the end of fermentation largely depends on the strain and species of LAB used for fermentation.

Current Studies of Health-Promoting Properties of Some Fermented Vegetable Juices

The consumption of lactic acid–fermented food should be increased in the population. Another important factor is the supply of lactic acid–fermented vegetable juices with new quality characteristics, without application of preserving agents. Fermented vegetable juices are abundant in sugars, vitamins, specific substances, and various metabolites which are beneficial to our health.

Fermented beetroot juice can modify the metabolic activity of animals and thereby reduce the risk of diseases associated with food intolerance. Consumption of fermented food which contain live cells of LAB can positively modulate intestinal microflora and its metabolic activity, particularly enzymes which participate in the process of carcinogenesis. Regular intake of fermented beetroot juice can contribute to the stabilization of the intestinal microbial ecosystem.

The LAB used in heterofermentative metabolisms (*Lb. paracasei*) or strictly heterofermentative metabolisms (*Lb. brevis*). These bacteria form a mixture of organic acids rich in lactic and acetic acids.

Nontoxic cancer-chemopreventive agents, the antitumor promoting effects of several fermented vegetable juices or extracts as well as the natural colorants used in food and pharmaceutical products need to be evaluated and reported. The specific mechanism of how fermented foods prevent carcinogenesis is still unclear, but it may be attributed in part to the metabolisms of certain substances.

Combination of factors responsible for the positive consequences of fermented diets. The antitumor activity of vegetables and fruits fermented liquids. Their results indicate that vegetables and fruits fermented liquids may inhibit proliferation and promote apoptosis of hematomas. Apoptosis is an important mechanism in the cytotoxic effect of antitumor drugs.

Future Perspectives in the Production of Fermented Vegetable Juices

Fermented vegetable juices would be the next food category where healthy bacteria will make their mark. Probiotic bacteria must be live to exert their health benefits. The stability of probiotic strains during fermentation and cold storage in vegetable juices could be further improved with the development of microencapsulation technologies or by supplementation of fermented vegetable juices with an appropriate quantity of prebiotic. Microencapsulation is one of the newest and highly efficient methods, which is very intensively used today in several different fields, including food technology, because it prevents interfacial inactivation, stimulates production and excretion of secondary metabolites, and allows continuous use and protection against disadvantageous and unfavorable environments. During microencapsulation, probiotic cells remain closed within encapsulating membrane, which protects cells and enables them to survive various stress conditions present in the external environment, during the fermentation and cold storage. In addition, inside the microcapsule, probiotic cells better survive gastroduodenal transit and, in high concentrations, enter the jejunum and the ileum where they could attach to epithelial cells and temporarily or permanently inhabit the environment.

Different materials such as gelatin, vegetable gum, alginate, starch, mixture of xanthane-gellan, carrageenan, cellulose acetate phthalate, and chitosan, could be used as encapsulating materials for food application. The research conducted thus far has shown that microcapsules prepared from gelatin and vegetable gum could provide good protection, especially when acid-sensitive probiotic organisms are used. Because of the process requirements and overall cost of food products, a great potential for future application showed alginate microcapsules.

The fermented vegetable juices represent a basis for functional food products with high added value and may benefit consumers searching for an alternative beverage to replace fermented dairy products. Fermented vegetable juices would become an increasingly important category in the future.

Almagro Eggplant Production

The stages of the Almagro eggplant production process with the aim of controlling and ensuring the quality of the products accepted under the PGI, regulations were made public describing aspects relating to the characteristics of the raw material and finished product, as well as the production process that would be mandatory for any product to be admitted under the PGI.

The production process, the regulations state:

1. All the eggplants to be protected under the geographical indication must be carefully selected before they undergo the production process, removing those that are damaged or altered.
2. Almagro eggplant production will be comprised of the following stages:
 - Blanching in boiling water for 5 to 20 minutes, or in any event, sufficient time to inhibit undesired microbial activity while ensuring that the fruit preserves its texture, without softening.
 - Fermentation: after blanching, the eggplants are placed in suitable containers and the brine is added. The fermentation time is from 4 to 20 days.
 - Brine: the composition of the brine is vinegar, oil, salt, cumin, garlic, paprika, and water. Additives permitted by the corresponding quality standards may be used.
 - Packing: packing is carried out using the permitted mechanical methods and in the necessary hygienic and preservation conditions. Containers of metal, glass, or other materials permitted under the legislation in force can be used.

The manufacture of Almagro eggplant, although simple in essence, is a laborious process that combines traditional methods with new production technologies. The following stages can be defined:

1. Preliminary operations. In these operations, the fruit is prepared for subsequent processing. These include peeling, sorting, and grading. These operations are performed to discard products that are unsuitable for processing—damaged, unripe, or overripe fruit and fruits that fail to meet suitable size, color, or texture parameters.

- Peeling involves cutting off the stem and bracts so that they do not protrude from the fruit and as many prickles as possible are removed. These operations are carried out simultaneously and by hand.
- Next, the eggplants are measured and sorted according to size by using mechanical sorters.
- Grading homogenizes the product, improving heat processing efficiency. Trained staff normally carry out the quality control procedures.

2. Blanching. Also known as “cooking” of the eggplants. This heat process is applied to inhibit enzymatic activity or decrease microbial populations. The eggplants are placed in large stainless steel cages that are submerged in boiling water for the appropriate time depending on the size of the fruit to be blanched.

3. Cooling. After blanching, the cages are placed in tubs of water at room temperature until cooled.

4. Fermentation. The blanched eggplants are placed in barrels, frequently of plastic, with a capacity of approximately 250 liters (Figure 22.6). Before they are filled, a certain volume of brine is added to the barrels to prevent damage to the fruit. Once the barrels are filled, the brine, prepared according to a “secret” recipe passed down from generation to generation, is added. The composition of brine, although varying greatly, always contains as essential ingredients vinegar, salt, and water, to which spices and condiments are added.

5. Packaging. The aim of this operation is to maintain the same hygiene and quality conditions from processing to consumption. During this stage, the eggplants are placed in containers of tin or glass and, although in this operation, the use of mechanical procedures is permitted, it is often carried out by hand, especially when small containers are used. After placing the fruit in containers, hot seasoning is added, the composition of which varies depending on the product that has been prepared, although it is normally made up essentially of salt, vinegar, and spices. The filled containers then go through a tunnel for both the eggplants and the brine to reach a minimum temperature of 65°C, so that, once the containers are sealed, a vacuum occurs inside. The containers of the products accepted under the PGI must have the corresponding labels indicating this fact and the quality standards that they meet.

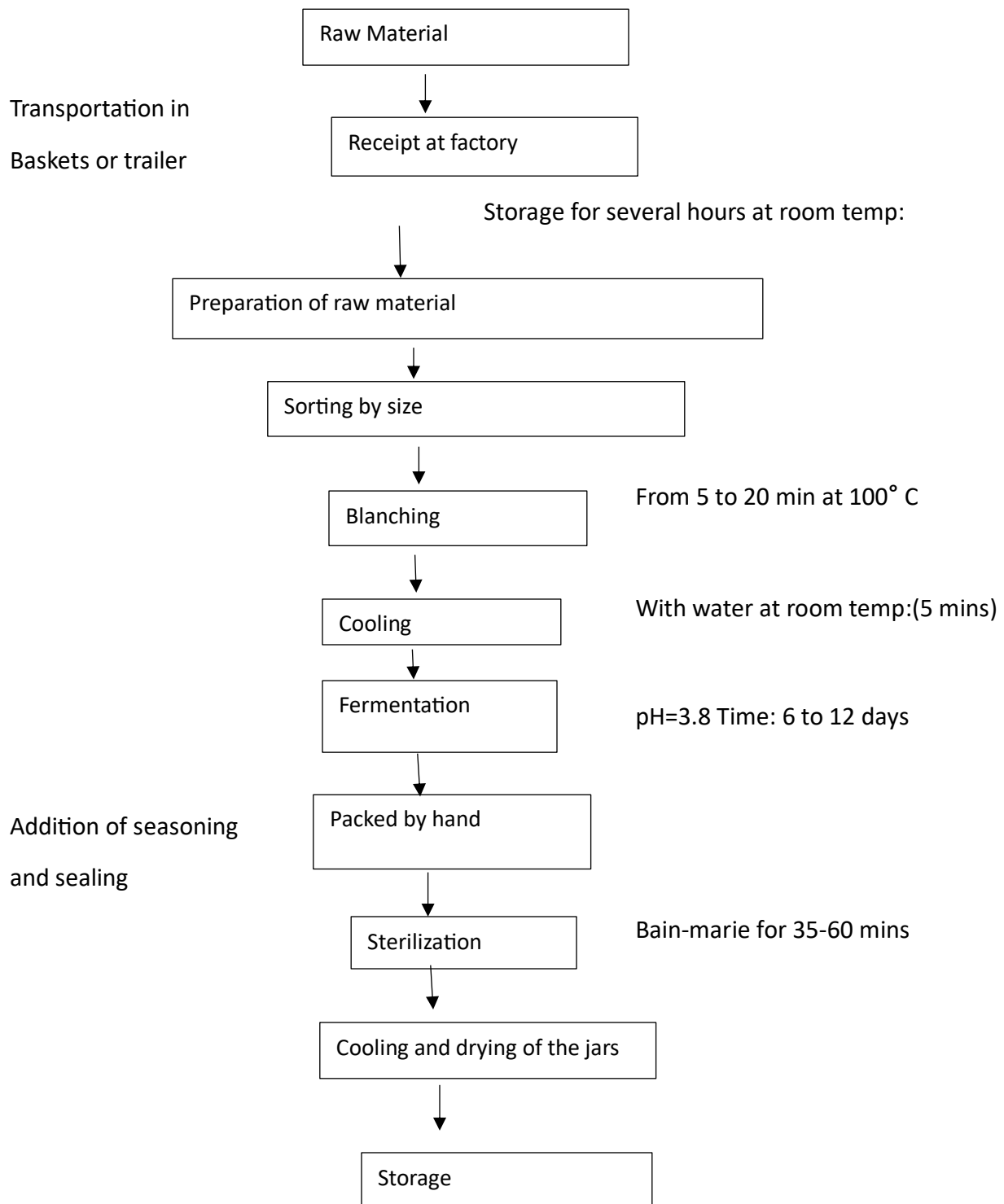


Diagram of the Traditional production process of "Almagro eggplants"

FDA Compliance Requirements

Canning olives must comply with requirements issued by the FDA. There are two important FDA requirements that should be mentioned. One is the use of color additives in canning olives. Ferrous gluconate and ferrous lactate may be safely used in amounts consistent with good manufacturing practices for the coloring of ripe olives. The other important consideration is adulteration. The FDA will take legal actions for olives with adulterations (pits, rot, or insect infestation) as indicated.

Insect Infestation

1. Salt-cured olives. Examine a minimum of six subs from each code or from the lot if no codes are present. The average is 10% or more by count of olives with 10 or more scale insects each.
2. Imported black. Actionable if 10% or more by count show damage by *Dacusa* (olive fruit fly).
3. Imported green. Actionable if 7% or more by count show damage by *Dacusa* (olive fruit fly).
4. Salad type, including broken, pitted, halved, quartered, sliced, and chopped or minced. Actionable if 9% or more by weight of olives show damage by *Dacusa* (olive fruit fly).

The following describes the indication of violations:

Pits: (i) Olives are adulterated if they contain pit fragments that have been substituted wholly or in part for pitted olives (ii) Olives are misbranded when the label statement “pitted olives” is false and misleading as applied to a product containing olives with pit fragments

Insect Infestation: Olives are adulterated when they consist wholly or in part of a filthy substance caused by the presence of insects or insect-damaged olives.

Mold: Olives are adulterated when they consist wholly or in part of a decomposed substance caused by the presence therein of moldy, decomposed olives.

Minimum Quality Requirements

Canned ripe olives should meet the following quality requirements, except that no requirements should be applicable with respect to color and blemishes for canned green-ripe olives.

1. Canned whole and pitted olives of the ripe type should meet the minimum quality requirements
2. Canned sliced, segmented (wedged), and halved olives of the ripe type should meet the minimum quality requirements
3. Canned chopped olives of the ripe type should meet the minimum quality requirements of this section and should be practically free from identifiable units of pit caps, end slices, and slices (“practically free from identifiable units” means that not more than 10%, by weight, of the unit of chopped style olives may be identifiable pit caps, end slices, or slices)
4. Canned broken pitted olives of the ripe type should meet the minimum quality requirements provided that broken pitted olives consist of large pieces that may have been broken in pitting but have not been sliced or cut
5. A lot of canned ripe olives is considered to meet the requirements if it complies with specifications
 - The number of sample units that do not meet the requirements should be less than an accepted number prescribed by regulations.
 - There is no “off-flavor” in any sample unit.

Cured Type

The pickles are cured by natural or controlled fermentation in a salt brine solution and may contain the dill herb or extracts thereof. The pickle ingredient may be partially desalted. The pickles may be further processed or preserved by the addition of vinegar and may contain other ingredients (spices, flavorings, firming, and preserving agents) that constitute the characteristics of the particular type of pickle. The pickles are preserved by acidification to maintain an

equilibrated pH of 4.6 or lower. The characteristics of the various types of cured pickles are as follows:

1. Dill pickles (natural or genuine) are cucumbers that are cured in a brine solution with dill herb and other flavoring agents.
2. Dill pickles (processed) are brine-cured pickles that have undergone a freshening process and are packed in a vinegar solution with dill flavoring and other flavoring agents.
3. Sour pickles are cured pickles that are packed in a vinegar solution with or without spices.
4. Sweet pickles and mild sweet pickles are cured pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s).
5. Sour mixed pickles are cured pickles that are packed in a vinegar solution. The pickles may be of any style or combination of styles other than relish and may contain other vegetable ingredients or any other suitable vegetable.
6. Sweet mixed pickles and mild sweet mixed pickles are cured pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s). The pickles may be of any style or combination of styles other than relish and may contain other vegetable ingredients or any other suitable vegetable.
7. Sour mustard pickles or sour chow chow pickles are cured pickles of the same styles and ingredients as sour mixed pickles except the pickles are packed in a prepared mustard sauce of proper consistency with or without spices and flavorings.
8. Sweet mustard pickles or sweet chow chow pickles are cured pickles of the same styles and ingredients as sweet mixed pickles except the pickles are packed in a sweetened, prepared mustard sauce of proper consistency with or without spices and flavorings.
9. Sour pickle relish consists of finely cut or chopped cured pickles that are packed in a vinegar solution. Sour pickle relish may contain other chopped or finely cut vegetable ingredients and may contain a stabilizer such as a starch or gum.

10. Sweet pickle relish and mild sweet pickle relish are finely cut or chopped cured pickles that are packed in a vinegar solution with a suitable nutritive sweetening ingredient(s). Sweet pickle relish and mild sweet pickle relish may contain other chopped or finely cut vegetable ingredients and may contain a stabilizer such as a starch or gum.

11. Hamburger relish consists of relish style pickles and other chopped or finely cut vegetable ingredients with tomato product added.

12. Mustard relish consists of sweet pickle relish with mustard and other chopped or finely cut vegetable ingredients

13. Dill relish consists of relish style pickles containing dill flavoring and other chopped or finely cut vegetable ingredients

Fresh-Pack Type

The pickles are prepared from uncured, unfermented cucumbers and are packed in a vinegar solution with other ingredients to produce the characteristics of the particular type of pack. The pickles are preserved by acidification to maintain an equilibrated pH of 4.6 or lower. In addition, the pickles are sufficiently processed by heat to ensure preservation of the product in hermetically sealed containers. The distinguishing characteristics of the various types of fresh-pack pickles are as follows:

1. Fresh-pack dill pickles are pickles that are packed in a vinegar solution with dill flavoring.

2. Fresh-pack sweetened dill pickles are pickles that are packed in a vinegar solution with suitable nutritive sweetening ingredient(s) and dill flavoring.

3. Fresh-pack sweetened dill relish consists of finely cut or chopped pickles packed in a vinegar solution with suitable nutritive sweetening ingredient(s) and dill flavoring. The relish may contain other finely cut or chopped vegetable ingredients

4. Fresh-pack sweet pickles and fresh-pack mild sweet pickles are pickles that are packed in a vinegar solution with nutritive sweetening ingredient(s).

5. Fresh-pack sweet pickle relish and fresh-pack mild sweet pickle relish consists of finely cut or chopped pickles that are packed in a vinegar solution with suitable

nutritive sweetening ingredient(s). The relish may contain other finely cut or chopped vegetable ingredients

6. Fresh-pack hamburger relish consists of relish style pickles and other chopped or finely cut vegetable ingredients with tomato product added.

7. Fresh-pack mustard relish consists of sweet pickle relish with mustard and other chopped or finely cut vegetable ingredients

8. Fresh-pack dill relish consists of relish style pickles containing dill flavoring and other chopped or finely cut vegetable ingredients

9. Fresh-pack dietetic pickles are pickles that are packed with or without the addition of sweetening ingredient(s), salt (NaCl), or other suitable ingredient(s) as declared and permitted under FDA regulations

Refrigerated Type

The pickles are prepared from fresh cucumbers and are packed in a vinegar solution with other ingredients to produce the fresh crisp characteristic of refrigerated type. The pickles are preserved by acidification to maintain an equilibrated pH of 4.6 or lower. They are stored, distributed, and displayed under refrigeration and may or may not contain one or more chemical preservatives. The various types of refrigerated pickles are the same as the types listed for fresh-pack type in earlier discussion with respect to ingredients except that they conform to the requirements for refrigerated type.

Technology in Fermented Bread Manufacture

Fermented bread can be manufactured using either natural fermentation or starter fermentation. Generally, indigenous flora in natural sourdough fermentation contains a mixture of yeasts, mainly *Saccharomyces cerevisiae* and lactic acid bacteria, mainly the genera of *Lactobacillus*, *Leuconostoc*, *Pediococcus*. Natural fermentation, it is not easy to control the consistency of fermented bread characteristics, depending on available microorganisms in the system. In industrial baking, fermentation with a starter culture is preferred, due to it being less laborious, having less or rare variation of microbial composition and having more standardized quality of baked goods. A starter culture has high viable

microorganism counts, which may be added to a substrate to produce desired characteristics. The first pure starter culture is *Lactococcus lactis* applied to industrial milk fermentation. A wide range of starter cultures has been developed for being used in industrial processes. Commercially available starter cultures of lactic acid bacteria for bread making are *Lactobacillus plantarum*, *Lactobacillus casei*, *Lactobacillus brevis*, *Lactobacillus fructivorans*, and *Lactobacillus fermentum*. Different mixtures of those starter strains yield variations of sourdough acidity, pH, and flavor. To make gluten-free sourdough from amaranth flour, *Lactobacillus plantarum* RTa12 and *Pediococcus pentosaceus* RTa11 were recommended as starters, due to the resulted fast acidification and stable fermentation under various temperatures. The type of microorganisms, available nutrients are also important to the results of fermentation. Supplementing flour with some enzymes may generate fermentable substrates. For example, adding α -amylase can help break down starch to maltose for yeast to grow in the dough. Sometimes, α -amylase is used together with proteases, which can hydrolyze gluten proteins. The enzymes can be from various sources and have different optimum temperatures for their activity.

Fermented bread is part of the traditional diets for human. The main microorganisms in bread fermentation include yeast and lactic acid bacteria. Variations in the number of cell count and microbial growth phase and interactions between yeast and lactic acid bacteria all affect dough fermentation and formation. Mechanisms during the fermentation include lactic acid fermentation (which is heterofermentation yielding lactic acid, alcohol, and acetic acid), proteolysis (which yields amino acids for yeast to grow and precursors of flavor compounds), and synthesis of volatile compounds and antifungal compounds (of which acetic acid is the major one). Roles of fermentation in bread manufacture are to develop flavor, structure, and texture. Due to improved moisture retention and development of antifungal compounds in fermented bread, the shelf life of bread can be extended. Biochemical reactions occurred during the fermentation can improve the nutritional value of bread and develop a prebiotic effect that is good for the human digestion system.

Brick Tea

Tea is one of the most consumed beverages worldwide. A fermentation process is necessary to produce black tea. Black tea can be further subdivided into naturally oxidized tea (although the term of fermentation is often used) and microbial fermented tea. The fermentation process for producing most black teas is actually an oxidation process catalyzed by enzymes that are originally present in tea leaves. Because no microorganisms are involved in this kind of enzyme-oxidized black tea, the use of the term fermentation is obviously not completely correct. Microbial fermentation in the production of black tea. Brick tea, a kind of re-produced tea made from black tea, is an indispensable beverage for people living in the Yunnan, Sinkiang, and Tibet areas where there are few vegetables and fruits, and it is regarded as a nutritional supplement. It is as important as meat and milk for daily life. Its functions on digestive promotion, antidisease, and general health care were long believed by people living there, so indigene have brick tea every day, every meal. Brick tea is made from microbially fermented black tea, steamed to soften the tea leaves, and then compressed into a brick shape for sale or storage. The tea soup has full body, with amber color and special flavor.

Brick Tea Processing

The production process is different from place to place; brick teas include Xiang Jian tea, black brick tea, dark green brick tea, Liupu tea, and Puer brick tea. Early processing of black tea and green tea is similar, but making microbial black tea needs a special process: pile fermentation. Pile fermentation is done at high temperature and humidity and involves a large number of microorganisms, leaving the tea compound drastically changed. Such produced black tea has a unique taste and color.

Sources of Commercial Proteolytic Bacteria and Applications

Microbial proteases are among the most important hydrolytic enzymes and since the advent of enzymology. Proteases are the most important category of industrial enzymes, accounting for more than 65% of the total industrial enzyme market. Microbial proteases are a group of enzymes that can have application in numerous industries. They are important tools in medical and pharmaceutical processes. In the food-processing industry, the proteolytic activity of microorganisms is associated with a wide variety of processes such as fermented foods, oil extraction, bakery, clarification of juices , and waste treatments. Bacteria, molds, and yeast are some of the microorganisms that are able to produce proteases. Microorganisms elaborate a large array of proteases, which are intracellular and/or extracellular. Intracellular proteases are important for various cellular and metabolic processes, such as sporulations, differentiation protein turnover, maturation of enzymes and hormones, and maintenance of the cellular protein pool. The extracellular ones are important for protein hydrolysis in cell free environments and able the cell to absorb and utilize hydrolytic products. Extracellular protease production by microorganisms is highly influenced by media components, variation in carbon/nitrogen ratio, presence of some easily metabolizable sugars, such as glucose and presence of metal ions. Several others factors, such as aeration, inoculums density, pH, temperature, and incubation time also affect the amount of protease production and their interaction plays an important role in the synthesis of these enzymes.

Isolation and Characterization of Proteolytic Bacteria from Fresh and Fermented Cabbage

The raw materials used to isolate proteolytic bacteria were thoroughly chopped leaves of fresh cabbage and thoroughly chopped and shredded leaves of cabbage fermented. The pH values varied from 6.5–6.7 for fresh cabbage juice to 3.6–3.7 for fermented material. The use of a basal medium (brain heart infusion, M) and a modified basal medium (minimal medium, MM), both supplemented with milk. The MM was limited in energy source from sugars and relatively poor in protein content, including yeast extract as a unique source of both vitamins and nucleic acids. This poor growing condition enhanced the microbial extracellular

proteases production, so it was chosen as the medium on which to grow the bacteria for characterization and examination of the proteolytic specificity of bacteria from fresh and fermented cabbage. As clearing zones surrounding the caseinolytic colonies were observed without trichloroacetic acid addition, the bacteria remain viable allowing to be grown on other protein substrates. The morphological and physiological characteristics of the proteolytic bacteria isolated from fresh and fermented cabbage. The proteolytic bacteria are characterized by ribosomal DNA genes analysis. Proteolytic bacteria isolated from fresh cabbage are typical in soil, water, and vegetables. Fermented cabbage contained proteolytic bacteria, which are resistant to acid grown media or are able to survive in that environmental condition. Some noncaseinolytic bacteria (exhibited nonclearing halo during the whole incubation period) from fresh and fermented cabbage were selected at random to determine their proteolytic activity on other protein substrates. The microorganisms isolated from fermented cabbages are exposed to various harsh conditions: the end of fermentation imposes a hostile environment on the microorganisms that involves low pH, low concentration of nutrients and, possibly, unfavorable osmotic environment. Therefore, it is possible that those microorganisms perform the former condition. In addition, based on their protein hydrolysis profiles, the characterized proteolytic bacteria could be useful in some industries like textile or leather, in laundry detergents, in medical and pharmaceutical processes, in bioremediation, in agriculture, or in food processing.

Use of Proteolytic Bacteria in Food Processing

Proteases have a wide range of applications: meat tenderization, beer, cheese, and bread elaboration, production of modified food proteins, lead manufacture, deterative industry, industrial wastes treatment, pharmaceuticals, etc. Isolate and characterize microorganisms with proteolytic activity isolated from divers agroindustrial waste or vegetables available in the region, emphasizing those microorganisms that have withstood severe conditions of stress during the various industrial operations applied (acidification, osmotic stress, mechanical pressing, extraction with organic solvents, use of high temperatures, etc.), using tools from the traditional microbial biotechnology, and to optimize its use in

products with higher added value from agroindustrial waste. For example, some subspecies of *Lactococcus lactis* are exposed to hostile conditions imposed by industrial processes in the production of dairy products.

Soymilk Fermentation and Enzymes Production

Soymilk is a substrate used for the production of a number of fermented products (fermented beverages, culture drinks, yogurt-like products, nondairy frozen desserts, cheese substitutes, tofu, sauces, and other typical Asian products). Different edible microorganisms (bacteria, yeast, and fungi) whose enzymes, particularly glycosidases, amylases, proteases, and lipases, hydrolyze the sugars, polysaccharides, proteins, and lipids to nontoxic products with flavors, aromas, and textures pleasant and attractive to the human consumer are used in the preparation of these fermented foods. The action of these microorganisms and its enzymes play different roles in food processing:

- Reduction of flatulence effects
- Improvement of protein digestibility and release of biopeptides with different healthy effects
- Isoflavone bioconversion
- Flavor improvement
- Lactic acid production as preservative

Soymilk and Fermented Soymilks

Soymilk is produced from the aqueous extraction of soybean. The basic methods of preparation are soaking the soybeans, grinding them with water, cooking, and filtering. The liquid that results after filtration is called soymilk. The nutritional composition, appearance, and flavor of good quality soymilk are remarkably similar to that of cow's milk. All traditional soymilks are filtered, whereby the okara (insoluble soybean pulp) was removed. Some modern soymilks are suspended and contain the entire original soybean except its hull, whereas others are made from soy protein isolates. Soymilk has a "beany" taste. The

“beany” off-flavor is predominantly because of the presence of aldehydes, ketones, and alcohols compounds. The formation of these compounds mainly results from the hydroperoxidation of polyunsaturated fatty acids, catalyzed by lipoxygenase. This “beany” taste can be reduced or eliminated. The recognition of its health benefits and with its improved flavor and texture, soymilk has a high and increasing acceptance. Soymilk has about total solids 8.4%–10%, and water 88%–92%, depending on the water/bean ratio in its processing. The main soluble sugars present are saccharose (2.1%–2.3%), raffinose (0.1%–0.3%), and stachyose (0.7%–0.9%); in addition, soymilk has insoluble carbohydrates such as cellulose, hemicelluloses, pectin, and trace amounts of starch. It also contains other minor components, including minerals, vitamins, phytate, and phenolic compounds (isoflavones). Soymilk has a high nutritional value, is an excellent source of good quality protein and B vitamins, and is inexpensive. The growth of the microorganisms in soymilk improved with the addition of skimmed milk, which contributes lactose. To prepare a fermented drink based on proteins of soybean, cow milk, and saccharose. They also added a mixture of amino acids (alanine, arginine, aspartic acid, sodium glutamate, lysine, methionine, and glycine) to mask the characteristic flavor of the soybean protein. Microbial survival and metabolic activity are important properties of starter cultures used in fermented foods. These properties were evaluated in fermented soymilk product using different lactic acid cultures and bifidobacterium. Several fermentation parameters such as changes in bacterial population and acidification properties of soymilk fermented with these cultures at different temperatures were analyzed to improve the performance of these microorganisms in probiotic products. Soymilk fermented using selected strains of lactic acid bacteria (able to grow in soy) were evaluated in vivo using a murine experimental model. The effect of heat treatment on the fermented SM product was also determined. Strains of lactic acid bacteria or bifidobacteria that are able to use sucrose, raffinose, and stachyose can be grown in soymilk substrate. An alternative to the use of fermented soybean products, which has low raffinose and stachyose content and has other healthy properties, could be realized with the use of these microorganisms. New fermented food from soybean using lactic acid bacteria and/or bifidobacteria, which would take advantage of the important nutritional and healthy properties of the microorganisms and substrate.

α -Galactosidase and Soymilk

The main sugars present in soybean are stachyose, raffinose, and saccharose. The first two sugars (so - luble galacto-oligosaccharides, or GOS) are not digested by the intestinal tract in humans and can cause flatulence and digestive problems. It is necessary to eliminate or reduce these sugars from soymilk using suitable treatments. Enzymatic processes or fermentation with selected microorganisms could be a good alternative. Raffinose and stachyose are α -galactosides of sucrose comprising three and four sugar moieties, respectively, and are nondigestible due to the absence of α -galactosidase in the small intestinal mucosa. α -Galactosidase is a homodimeric glycoprotein (glycoside hydrolase enzyme). It hydrolyzes the α -1,6-linked α -galactoside residues from simple oligosaccharides such as melibiose, raffinose, and stachyose and from polymeric galactomannans. α -Galactosidase is widely distributed in nature, mainly in microorganisms, plants, and animals. This enzyme is of particular interest because of its biotechnological applications. Microbial or plant α -galactosidases can be added to soybean products (meal, soymilk, or molasses) to hydrolyze GOS (raffinose/stachyose) to digestible carbohydrates and thereby moderate the flatulence-causing property of soybean products. The production of this enzyme from lactic acid bacteria and bifidobacteria was evaluated in soymilk substrate and raffinose medium. Enzyme production in soymilk was lower than in culture media. The production of α -galactosidase growth in culture media was evaluated under different pH conditions. Strains of lactic acid bacteria or bifidobacteria, such as *L. fermentum* or *B. longum*, have the ability to hydrolyze the stachyose or raffinose present in soymilk, reducing the level of this oligosaccharide by 60%–85%. Using these strains can produce fermented soy products with a low level of nondigestible GOS. These processes are used to minimize or remove such problems and enhance sensorial acceptability as well as nutritional content of fermented soy foods, which have greater consumer acceptability.

Proteases, Peptidases, and Soymilk

Soymilk is one of the popular and traditional soy products and is consumed as a nutritious and economical protein food. Soymilk was generated as an important replacement of cow milk due to lactose intolerance or allergic reaction to cow's milk and as a low-cost source of good quality protein and energy. Soy protein is a nourishing protein with high biological quality that contributes to essential amino acids such as phenylalanine, isoleucine, leucine, lysine, threonine, tryptophan, valine, and, in low concentration, the sulphur-containing amino acids (methionine/cystein). Soy protein is rich in lysine, and this amino acid is limited in cereals, which are rich in sulfur-containing amino acids. The soy protein is an ideal protein source to complement cereals. The nutritive value of food proteins depend on amino acid bioavailability or protein digestibility. The improvements in digestibility produce small chains of peptides and release bioactive peptides. Protein breakdown occurs during the food manufacture with lactic acid bacteria. The proteolytic system of the lactic acid bacteria is one of the most studied nowadays, not only because of the impact of the physiology of the lactic acid bacteria but also because of its relation with the texture and flavor of the fermented products. The structural components of the proteolytic systems can be divided in three groups on the basis of their function: (1) cell envelopment proteinase that degrades the protein into oligopeptides; (2) peptide transport systems that move hydrolysis products through the cytoplasmic membrane; and (3) intracellular peptidases that degrade the peptides into shorter peptides and free amino acids. These amino acids will be degraded thoroughly by dependent metabolic routes strains to generate volatile compounds responsible for the aroma profile of fermented products. The weak action of lactic acid bacteria enzymes on soy proteins in comparison with the strong proteolytic systems from fungi and yeast. Microorganisms that can hydrolyze soybean proteins, which would increase digestibility and diminish the allergenic fractions present in this substrate. The action of enzymatic system of whole lactic acid bacteria cell on soy protein extract. The breakdown of the individual soy protein fractions by proteolytic enzymes from lactic acid bacteria. Their hydrolytic ability and the nature of the generated products in relation to soy food. Using the selected proteolytic lactic acid strain in soymilk are being carried out. In the fermented soy beverage, soy protein degradation through whole-cell suspensions of the same

lactobacilli. The release of new peptides with potential biological activities was observed and confirmed using fermented soymilk. The main source of biopeptide is milk protein, but soy protein is an interesting alternative. Some of these researchers used yogurt starter (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*) combined with probiotic strains (*L. acidophilus*, *L. casei*, and *Bifidobacterium lactis*) grown in soymilk to prepare a soy-based beverage. lactic fermentation (*L. casei*, *Lactobacillus acidophilus*, *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, and *Bifidobacterium*) combined with commercial proteases to accelerate the production of bioactive peptides in fermented soymilk. Two bioactive substances of peptides (800–900 Da) with ACE inhibitory activity and γ -aminobutyric acid. They were produced simultaneously in this experiment by protease-facilitated lactic acid bacteria fermentation of soymilk. These bioactive substances contribute to lower blood pressure of spontaneously hypertensive rat (SHR).

β -Glucosidase and Soymilk

β -Glucosidase is another important enzyme that exerts an effect on soymilk micronutrients (isoflavones). β -Glucosidase hydrolyzes the β -(1–4)-glucosidic bonds with the release of glucose. Soybean and unfermented soybean products only contain glucoside forms, which comprise 80% to 95% of total isoflavones. The composition and content of isoflavones in soybean products are associated with certain processing techniques, such as fermented hydrolysis, fermentation, and removal of foam. Isoflavones exist in different types of aglycone forms (daidzein, genistein, and glycitein), glucoside forms (daidzin, genistin, and glycitin), and malonyl glucoside and acetyl glucoside forms. The glucoside conjugates of isoflavones are converted to aglycones by β -glucosidase during soybean processing. Soy isoflavones are a role in the prevention of osteoporosis, cardiovascular disease, and several hormone dependent cancers. The β -glucosidase activity produced by some strains of lactic acid bacteria (principally *Lactobacillus*) and *Bifidobacterium* hydrolyzes isoflavone glucosides into bioactive aglycones during soymilk fermentation.

Food Additives Derived from Microorganisms Listed in 21 CFR 172 and 173

§172.155: Natamycin derived from *Streptomyces natalensis* and *Streptomyces chattanoogensis*

§172.325: Bakers yeast protein derived from *Saccharomyces cerevisiae*

§172.590: Yeast-malt sprout extract, derived from *Saccharomyces cerevisiae*, *Saccharomyces fragilis*, *Candida utilis*

§172.620: Carrageenan, a hydrocolloid extracted from the following members of the families Gigartinaceae and Soliericeae of the class Rodophyceae (red seaweed): *Chondrus crispus*, *Chondrus ocellatus*, *Eucheuma cottonii*, *Eucheuma spinosum*, *Gigartina acicularis*, *Gigartina pistillata*, *Gigartina radula*, *Gigartina stellata*

§172.655: Furcelleran, the refined hydrocolloid extracted from *Furcellaria fastigiata* of the class Rodophyceae (red seaweed)

§172.695: Xanthan gum derived from *Xanthomonas campestris*

§172.725: Gibberellic acid derived by fermentation from *Fusarium moniliforme*

§172.896: Dried yeasts, *Saccharomyces cerevisiae*, *Saccharomyces fragilis*, and dried torula yeast, *Candida utilis*

§172.898: Bakers yeast glycan from *Saccharomyces cerevisiae*

§173.110: Amyloglucosidase derived from *Rhizopus niveus* for use in degrading gelatinized starch into constituent sugars

§173.120: Carbohydrase and cellulase derived from *Aspergillus niger* for use in clam and shrimp processing

§173.130: Carbohydrase derived from *Rhizopus oryzae* for use in the production of dextrose from starch

§173.135: Catalase derived from *Micrococcus lysodeikticus* for use in the manufacture of cheese

§173.140: Esterase-lipase derived from *Mucor miehei* var. Cooney et Emerson as a flavor enhancer in cheeses, fats and oils, and milk products

§173.145: α -Galactosidase derived from *Mortierella vinaceae* var. raffinoseutilizer for use in the production of sucrose from sugar beets

§173.150: Milk-clotting enzymes, microbial for use in the production of cheese (milk-clotting enzymes are derived from *Endothia parasitica*, *Bacillus cereus*, *Mucor pusillus* Lindt and *Mucor miehei* and *Aspergillus oryzae* modified to contain the gene for aspartic proteinase

§173.160: *Candida guilliermondii* as the organism for fermentation production of citric acid

§173.165: *Candida lipolytica* for fermentation production of citric acid

§173.280: A solvent extraction process for recovery of citric acid from *Aspergillus niger* fermentation liquor

Substances Derived from Microorganisms Affirmed by FDA as GRAS in 21 CFR184

§184.1005: Acetic acid may be produced by fermentation

§184.1011: Alginic acid made from certain brown algae

§184.1012: α -Amylase enzyme preparation from *Bacillus stearothermophilus* used to hydrolyze edible starch to produce maltodextrin and nutritive carbohydrate sweeteners

§184.1027: Mixed carbohydrase and protease enzyme product derived from *Bacillus licheniformis* for use in hydrolyzing proteins and carbohydrates in the preparation of alcoholic beverages, candy, nutritive sweeteners, and protein hydrolysates

§184.1061: Lactic acid may be produced by fermentation

§184.1081: Propionic acid from bacterial fermentation

§184.1115: Agar-agar, extracted from a number of related species of red algae class Rhodophyceae

§184.1120: Brown algae, to be used dried as a flavor enhancer, are seaweeds of the species: *Analipus japonicus*, *Eisenia bicyclis*, *Hizikia fusiforme*, *Kjellmaniella gyrate*, *Laminaria angustata*, *Laminaria longiruris*, *Laminaria Longissima*, *Laminaria ochotensis*, *Laminaria cloustonia*, *Laminaria saccharina*, *Laminaria digitata*, *Laminaria japonica*, *Macrocystis pyrifera*, *Petalonia fascia*, *Scytosiphon lome*

§184.1121: Red algae, to be used dried as a flavor enhancer, are seaweeds of the species: *Gloiopeltis furcata*, *Porphyra crispata*, *Porhyra deutata*, *Porhyra perforata*, *Porhyra suborbiculata*, *Porphyra tenera*, *Rhodymenis palmata*

§184.1133: Ammonium alginate from certain brown algae

§184.1187: Calcium alginate from certain brown algae

§184.1318: Glucono delta-lactone, by oxidation of d-glucose by microorganisms that are nonpathogenic and nontoxicogenic to man or other animals. These include but are not restricted to *Aspergillus niger* and *Acetobactor suboxydans*

§184.1372: Insoluble glucose isomerase enzyme preparations are derived from recognized species of precisely classified, nonpathogenic, and nontoxicogenic microorganisms, including *Streptomyces rubiginosus*, *Actinoplane missouriensis*, *Streptomyces olivaceus*, *Streptomyces olivochromogenes*, and *Bacillus coagulans* grown in a pure culture fermentation that produces no antibiotic

§184.1387: Lactase enzyme preparation from *Candida pseudotropicalis* for use in hydrolyzing lactose to glucose and galactose

§184.1388: Lactase enzyme preparation from *Kluyveromyces lactis* (previously called *Saccharomyces lactis*) for use in hydrolyzing lactose in milk

§184.1420: Lipase enzyme preparation from *Rhizopus niveus* used in the interesterification of fats and oils

§184.1538: Nisin preparation from *Lactococcus lactis* Lancefield Group N for use as an antimicrobial agent to inhibit the outgrowth of *Clostridium botulinum* spores and toxin formation in pasteurized cheese spreads

§184.1610: Potassium alginate, the potassium salt of alginic acid, derived from certain brown algae

§184.1685: Rennet (animal-derived) and chymosin preparation from *Escherichia coli* K-12, *Kluyveromyces marxianus* var. *lactis* or *Aspergillus niger* var. *awamori* to coagulate milk in cheeses and other dairy products

§184.1695: Riboflavin biosynthesized by *Eremothecium ashbyii*

§184.1724: Sodium alginate, the sodium salt of alginic acid, derived from certain brown algae

§184.1848: Butter starter distillate from milk cultures of *Streptococcus lactis*, *Streptococcus cremoris*. *Streptococcus lactis* subspecies *diacetylactis*, *Leuconostoc citovororum*, *Leuconostoc dextranicum*

§184.1924: Urease enzyme preparation from *Lactobacillus fermentum* for use in the production of wine

§184.1945: Vitamin B12 from *Streptomyces griseus*

§184.1950: Vitamin D, produced by ultraviolet irradiation of ergosterol isolated from yeast and related fungi

§184.1983: Bakers yeast extract from *Saccharomyces cerevisiae*

§184.1985: Aminopeptidase enzyme preparation from *Lactococcus lactis* used as an optional ingredient for flavor development in the manufacture of cheddar cheese

Foods for Human Consumption That May Contain or Be Derived from Microorganisms Listed in 21 CFR Parts 131, 133, 136, and 137

§131.111: Acidified milk, with or without the addition of characterizing microbial organisms, and aroma-, and flavor-producing microbial culture. Conditions for their use in the referent regulations

§131.200: Yogurt made by the lactic acid–producing bacteria *Lactobacillus bulgaricus* and *Streptococcus thermophilus*

§133.106: Blue cheese, characterized by the presence of the mold *Penicillium roquefortii*

§133.113: Cheddar cheese, subjected to the action of a lactic acid producing bacterial culture and clotting enzymes of animal, plant, or microbial origin used in curing or flavor development

§136.110: Bread, rolls, and buns may contain as optional ingredients lactic acid–producing bacteria

§137.105: Flour may contain α -amylase obtained from the fungus *Aspergillus oryzae*

Assignment for FTech 306 Food Science Technology and Engineering

Food Additives

A food additive is any substance that becomes part of a food product, either directly or indirectly, during some phase of processing, storage, or packaging. The universe of food additives encompasses. Direct food additives, those that are intentionally added to food for a functional purpose, in controlled amounts, usually at low levels (from parts per million to 1–2%, by weight), and Indirect or incidental food additives, those entering into food products in small quantities as a result of growing, processing, or packaging. Food additives are as minor ingredients incorporated into foods to affect their properties in some desired way. The effects desired relate to color, flavor, texture, nutritive value, or stability in storage.

Functions of Food Additives

The basic functions of direct food additives include the following:

(i)Preservation (ii)Processing (iii)Appeal and Convenience (iv)Nutrition.

Preservation

Food preservation techniques include thermal processing, concentration and drying, refrigeration and freezing, modified atmosphere, and irradiation. The use of chemical preservatives frequently augments these basic preservation techniques and represents the most economical way for food manufacturers to ensure a reasonable shelf life for their product. Antioxidants and antimicrobial agents perform some of these functions as well.

Processing

Food processors are increasingly using food additives to ensure the integrity and appeal of their finished products. Emulsifiers maintain mixtures and improve texture in breads, dressings, and other foods. They are used in ice cream when smoothness is desired, in breads to increase shelf life and volume and to distribute the shortening, and in cake mixes to achieve batter consistency. Stabilizers and thickeners assist in presenting an appealing product with consistent texture. Sorbitol, a humectant and sweetener, is used to retain moisture and enhance flavor. With the removal of sugar from many foods for dietetic reasons, a substitute bulking agent is needed.

Appeal and Convenience

These types of foods, it is essential that a variety of additives be used to provide the taste, color, texture, body, and general acceptability that are required. This need for convenience, while maintaining aesthetic appeal and taste, is becoming extremely important. Most food additives such as gums, flavoring agents, colorants, and sweeteners are included by food processors because consumers demand that food look and taste good.

Nutrition

Human nutrition, and consumers are increasingly aware of the value of good nutrition. Vitamins, antioxidants, proteins, and minerals are added to foods and beverages as supplements in an attempt to ensure proper nutrition for those who do not eat a well-balanced diet. Additives such as antioxidants are used to prevent deterioration of natural nutrients during processing. Recently more importance has been attributed to disease prevention through proper nutrition, as well as to increasing performance through sport nutrition products. The desire for good nutrition through a balanced diet may adversely affect consumer demand for some food additives such as fat substitutes.

Food Additive Categories

Substances that come under the general definition of direct food additive number in the thousands and include Inorganic chemicals (e.g., phosphates, sulfites, calcium chloride, etc.) Synthetic organic chemicals (e.g., dyes, benzoates, aroma chemicals, vitamin A, etc.) Extraction products from and derivatives of natural sources (e.g., pectin, essential oils, vitamin E, etc.) Fermentation-derived products (e.g., enzymes, citric acid, xanthan gum, etc.) Some are chemicals of industry that are upgraded in terms of purity to allow their use in food. Major categories of food additives include preservatives, colorants, antioxidants, flavors, thickeners and stabilizers, emulsifiers, acidifiers and buffers, enzymes, and sweeteners. Certain food additives, such as colors, flavors, gums, emulsifiers, and preservatives may find use also in pharmaceutical products and in toiletries and cosmetics (e.g., toothpaste, lipstick, etc.). The same Food Chemical Codex (FCC) grade as in food is typically used in these applications, the combined value of the additive for these other applications does not exceed 10% of food use. Other applications does not exceed 10% of food use. Indirect food additives have no purposeful function in food and may be divided into the following categories:

- Components of adhesives (e.g., calcium ethyl acetoacetate 1,4-butanediol modified with adipic acid)
- Components of coatings (e.g., acrylate ester copolymer coatings and polyvinyl fluoride resins)
- Components of paper and paperboard (e.g., slimicides, sodium nitrate/urea complex, and alkyl ketone dimers)
- Basic components of single- and repeated-use food contact surfaces (e.g., cellophane, ethyleneacrylic acid copolymers, isobutylene copolymers, and nylon resins)
- Components of articles intended for repeated use (e.g., ultrafiltration membranes and textiles and textile fibers)
- Compounds controlling growth of microorganisms (e.g., sanitizing solutions)
- Antioxidants and stabilizers (e.g., octyltin stabilizers in vinyl chloride plastics)

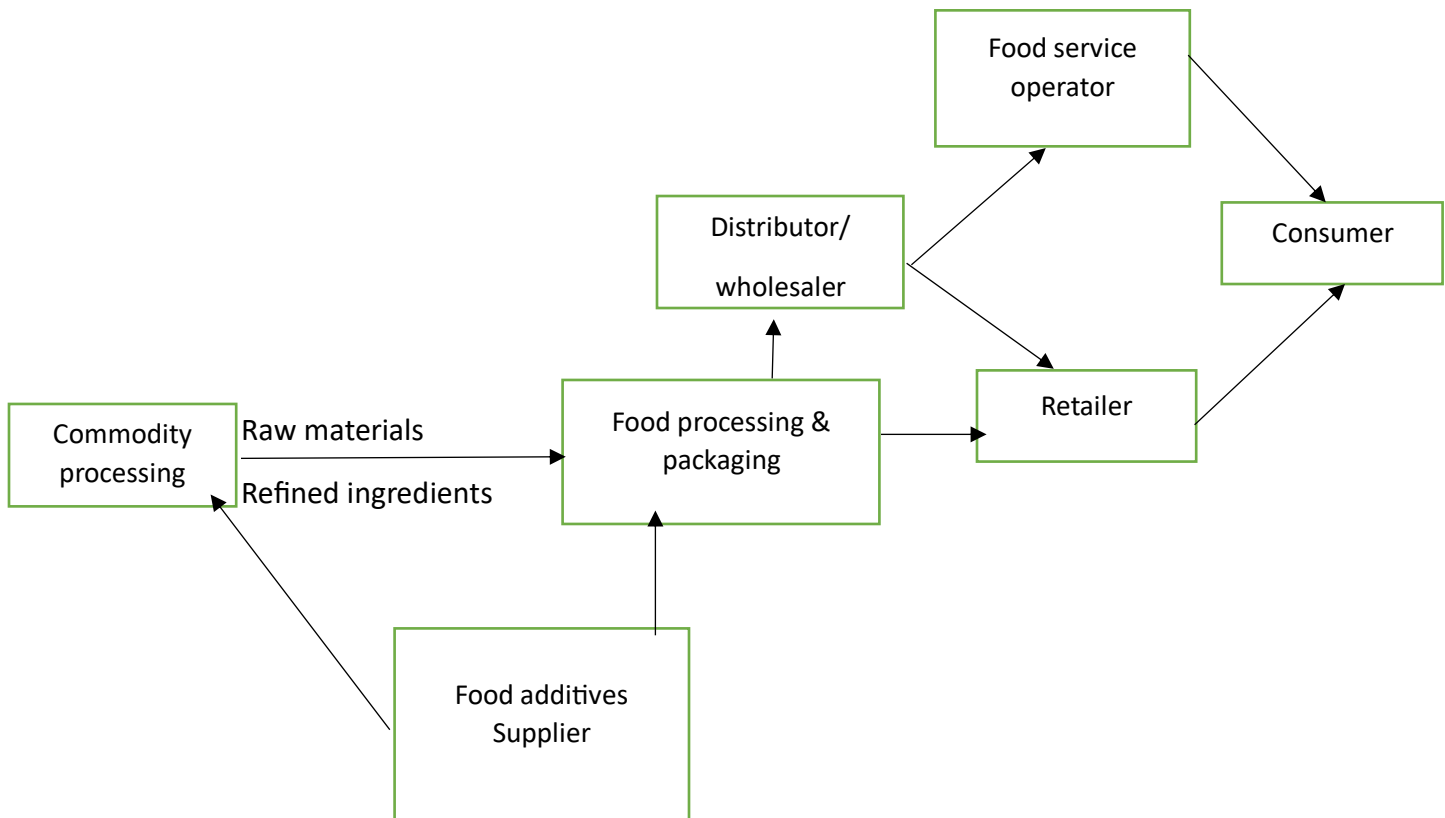
- Certain adjuvants and production aids (e.g., animal glue, hydrogenated castor oil, synthetic fatty alcohols, and petrolatum)

In many countries, these materials are defined and regulated as contaminants. These materials are food additives under the law. They are commonly classed as indirect food additives, but the FDA handles them in the same way as direct additives. Direct additives, they may be recognized as safe (GRAS) substances and thereby escape explicit regulation because that status makes them, in fact, not food additives. Packaging materials which have been used for a long time, such as glass, receive less close scrutiny than more newly introduced materials and those materials just being proposed for introduction.

Food Additive Supply Industry

Food additive suppliers are an important part of the food manufacturing system, supplying products to both commodity processors and food processors. Practically every food manufacturing operation depends to some degree on the use of food additives, but the range of additives necessary for the formulation varies. The food additive industry appears to be highly fragmented, consisting a variety of chemically and functionally different products that serve a common end-use market — the food industry. Manufacturers are involved in supplying additives in a limited number of product categories (e.g., colors, vitamins, or enzymes) or servicing selected food sectors (e.g., processed meats, dairy-based products, or bakery products). The food additive industry structure and the flow of its products. Some 60–70% of food additives are used in the manufacture of food: about 20–30% are used in commodity processing operations such as flour milling, meat packing, oilseed crushing and refining, vegetable packaging, animal feeds, and fruit juice processing; and the remaining 5–10% are used for things such as pharmaceuticals and cosmetics. Specialty compounders formulate mixed products for the food industry such as dairy ingredients, baker's mixes, curing blends, thickener and emulsifier blends, cheese aids, ethnic flavors, total seasoning packages, and spice blends. They are very knowledgeable about additive and ingredient properties and are experienced in food technology overall. Distributors also play an important role in the distribution of food additives. Additive producers use distributors to service their smaller accounts or for

warehousing and servicing of accounts that geographically the producers cannot cover effectively or economically.



Integrated view of the U.S. food manufacturing system

Food Additives Derived from Allergenic Foods

A few foods are responsible for the majority of allergic reactions. In adults, these foods include nuts, peanuts, fish, and shellfish. In children, the main culprits include eggs, milk, peanuts, soy, wheat, and fish. Elimination of these foods from the allergic individual's diet is essential. Many food additives are derived from these basic food items, and the allergen compound may be carried over even into highly refined derivatives. Recognition of the presence of such potentially allergenic compounds is sometimes difficult. The industry must provide these consumers with the information necessary for them to practice such avoidance effectively. Ingredient labeling statements are the key to implementation of safe and effective avoidance diet. FDA regulation exempts specific substance declaration of flavors, spices and colorings. The agency strongly encourages specific declaration of an allergenic ingredient if present among these exempt ingredients. Manufacturers must be aware that certain processing practices such as the use of shared equipment can result in undeclared residues of allergenic foods existing in other products. These situations can be hazardous for allergic consumers especially if larger quantities of the allergenic foods are present on an undeclared basis.

Sanitation

Sanitation in a food processing plant is to assure that the food product the company manufactures is wholesome and safe to eat. This means that the food does not contain any potential undesirable substances including:

- Biological toxins
- Chemical toxicants
- Environmental contaminants
- Extraneous substances

Food Plant Sanitation Program

Most food processors have a sanitation program to make sure that their products are safe. Most programs have the following components, among others:

1. The product and its ingredients
2. Cleaning
3. Housekeeping
4. Personnel hygiene and safety
5. Warehousing
6. Distribution and transportation
7. Sanitation inspections

For eg., Manufacturing of bakery products.

Bakery goods include bread cakes, pies, cookies, rolls, crackers and pastries. Ingredients consisting of flour, baking powder, sugar, salt, yeast, milk, eggs, cream, butter, lard shortening, extracts, jellies, syrups, nuts, artificial coloring, and dried or fresh fruits are blended in a vertical or horizontal mixer after being brought from storage, measured, weighed, sifted, and mixed. After mixing, the dough is raised, divided, formed, and proofed. Fruit or flavored fillings are cooked and poured into dough shells. The final product is then baked in electric or gas-fired ovens, processed, wrapped, and shipped. Loaves of bread are also sliced and wrapped.

Raw Ingredients and the Final Product

Sanitation considerations apply to every stage of the processing operation: raw materials, operations.

Critical Factors in the Evaluation of Raw Materials:

- Raw materials must come from warehouses that comply with local, county, state and federal requirements for food warehouse sanitation.

- For certain ingredients such as egg and milk products, their sources, types, etc. should be ascertained. If frozen eggs are used, are they pasteurized. Some food plants require routine testing of critical raw materials for bacterial load including Salmonella and other pathogens.
- Are raw materials requiring refrigeration (or freezing) or refrigerated (or frozen)?
- Is there any “blend off,” mixing contaminated raw materials with clean raw materials?

Critical Factors in Evaluating the Sanitation of Operations:

- Room temperature, bottleneck, and bacterial contamination. During certain stages of an assembly line operation, always check sites where “bottleneck” frequently occurs. Room temperature and period of bottlenecking are related to chances of bacterial contamination.
- Metal detection. During a production operation, always check metal detection or removal devices to make sure that they are working properly.
- Time and temperature. Identify stages in the operation where time and temperature are major and/or critical variables. Intense education must assure that any abuses which may allow growth and possible toxin formation of microbial contaminants are strictly forbidden.
- Equipment design. Be alert for poorly designed conveyors or equipment which might add to bacterial load through product delay or “seeding.”

Cleaning

The objective of cleaning any equipment that has been used in food processing is to remove any residue or dirt from the surfaces which may or may not touch any food or ingredient. Some of the equipment may be subjected to further sanitization and sterilization. Such attempts will be questioned if there is still visible dirt or debris attached to any surface of the equipment. The wet-cleaning process, used by all food processors, has three components: pre-rinse, cleaning, post-rinse. This can be done manually or by circulation.

- Pre-rinse. This uses water to separate loosely adhered particles (dirt, residue, etc.), using two basic considerations. Perform the cleaning after the production cycle is completed to get ready for the next work day. Predetermined criteria: method for specific surfaces (vessels, components, pipelines), period of rinsing, temperature. For both factors, most food processing plants have established appropriate policy to handle the pre-rinse.

- Clean. Under most circumstances, soaking, scrubbing and more soaking, characterize any cleaning process. The goal is to remove sticky residues or particles from the surface. Of course, cleaning detergents or solutions are used in the soaking and scrubbing. The chemical reactions are the standard: saponification, hydrolysis, emulsification, dispersion, and so on. All chemical reactions are time- and temperature-dependent.

- Post-rinse. This is no difference from rinsing cooking utensils after they have been scrubbed and soaked. This stage removes all detergents/sanitizers used and any particles left behind.

For all three stages, the water used must comply with rigid standards to avoid damage to equipment, corrosion, and status of microbiological presence. Apart from manual cleaning, we have the Clean In Place (CIP) which uses a circulation system of chemical solutions pumped through the equipment “in place.” Much food processing equipment is designed to have this built-in feature. Any automatic process has inherent problems that must be dealt with in a manner dictated by circumstances. The use of a circulatory method in cleaning is dependent on two groups of factors:

1. Substances used in the detergent or cleaning solutions.
2. The variables.

Substances used can include an array of chemicals: caustic soda, acid, etc. The concentration of such chemicals is a critical factor. The variables include: contact temperature, contact time, flow rate between surfaces and substances in cleaning solution.

Housekeeping

We keep the inside clean, dusting, vacuuming, sweeping, and so on. We keep the outside of our house clean: garbage, leaves, droppings, peeling paints, and so on. It is of paramount importance that a food processing plant is clean inside and outside. For internal housekeeping, part of the information has been discussed in the cleaning process. We still need to worry about cleaning windows, debris under counters and in the corner of a room, emptying garbage cans, and so on. Most food companies hire regular maintenance crews to do the job. Unfortunately, the plant manager will still need to develop policy, implement and evaluate procedures. The environment of a food processing plant has always been a problem: garbage, birds, insects, rodents, and so on. Housekeeping for the immediate vicinity outside a food plant requires close monitoring. Many professionals consider housekeeping as “nonglamorous” and “menial.” It is important that it requires complete attention from management. The reason is simple. Regulatory officials from local, county, and state levels are serious about this aspect of food processing. If the company ships products across state lines, the United States FDA has the authority to issue warning letters about any unacceptable conditions, including sloppy housekeeping.

- Most dry cleaning methods increase dust in the air, e.g., wiping with a rag, vacuum cleaners, brooms, brushes, pressurized air.
- Since dust particles are charged electrically, they will adhere to any surfaces that are electrically or electrostatically charged. This results in contamination.
- Dust contamination is heightened when the environment is moist, including surfaces, resulting in molds. When the molds occur on piping, back of tanks, ducts and cables, corner of ceilings and other places that are obscured from vision, the problem increases.
- Dust moves from room to room by normal air flow from temperature differences or window and door draft. That is further contamination.
- Dust dispersion is a risk replacing the risk that has just been removed by cleaning.

Wet-cleaning by hands or machines is acceptable. Modern technology has made available gel, foam, aerosols, and special equipment. Wet-cleaning must take the following into consideration:

- All materials that can absorb moisture, such as cardboard boxes, pallets, etc. should be removed.
- After wet-cleaning, the surfaces must be dried carefully.
- Proper draining systems should be in place and maintained, clean and free of debris around the openings.

Quality Assurance

The principles and procedures for quality assurance are as applicable and beneficial to small plants as to larger plants. Quality control systems can be more efficiently administered in small plants because of a simpler organizational structure and more direct communication among employees. The term quality control is not the same as quality assurance. In general “control” refers to one aspect of “assurance.”

Cost Versus Benefit

Quality assurance or control is a good management tool. A quality control system specifically tailored to the volume and complexity of a plant operation can be cost-effective. A properly designed and operated total quality control system will minimize the likelihood of mistakes during processing, give an indication of problems immediately and provide the information quickly to locate and correct the cause of problems. As a result, production delays are reduced, the need for re-processing or re-labeling is lessened, and the possibility of product recall and condemnation is reduced.

Product Consistency Improved

Quality control systems provide the information necessary to consistently produce a uniform quality product at a predicted cost. Some processors have questioned whether the cost of implementing a total quality control system would be recovered unless the quality of the plants product had been so poor that the plant suffered reduced sales and a high return of product. The lack of a quality control system results in a product that is more variable and not as well defined. With organized controls and objective sampling, the plant has more extensive and precise information about its operation. As a result, management has better control and product quality is stabilized.

Equipment Costs

Quality control systems require highly trained technicians and expensive equipment, a plant quality control system can be fairly simple and inexpensive and still be effective. The expense of equipment is related to the type and complexity of products and operations and the volume of production. A total quality control system in a small plant would require only inexpensive thermometers, calculators, knives, grinders, and existing testing equipment used for traditional inspection and quality assurance.

Elements of a Total Quality Control System

The good manufacturing regulations promulgated by the FDA are the most appropriate. For each processing area, designate the person responsible for the controls or inspection — the name of a plant employee or an outside contractor. How often is the control or inspection check to be done? What records are kept? This information can be compiled by a clerical or administrative employee, and the FDA or USDA inspector can assist. A rough outline of a total quality control system has been developed. It can be compared, area by area, to descriptions of the elements in the sample system in the appendix of the manual that records the system. As each element is reviewed, note where controls may be missing. The outline that remains, with missing controls added, is another step closer to a total

quality system. The final step is to convert this outline into a written format, as though it were a set of instructions for plant employees. In reality, it can be the operating manual for the persons responsible for conducting quality control in the plant.

General Elements of Total Quality Control

The general outline of a plant quality control system. Within the system are various elements, determined by the type of operation in the plant. In this section, the specific operations will be discussed and the elements of a good quality control system will be outlined.

Receiving

Examples of controls:

- Examine (and possibly sample) incoming lots
- Verify identification marks
- Check carriers
- Log deliveries

A plant's total quality control system will include written instructions for checking incoming raw materials, such as raw fruit, flour, frozen fish, spices, salt, liquid ingredients, additives and extenders, and for recording the results. These materials must be verified for wholesomeness (free from indications of mishandling, decomposition, infestation), acceptability for intended use, and approval for use. The air temperature and product temperature in the receiving area should be checked enough to assure that the company's requirements are being met. This would include checks of freezers, doors, door seals, incoming railroad cars, and trucks. The quality control plan should include procedures for taking corrective action in the event a product is contaminated during shipment. The receiving log should be checked to assure that entries are accurate and up to date and that all requirements regarding incoming products and materials are met. The log will be useful in indicating trends, so problems can be spotted early.

The person who checks the log can keep a record of the dates and results of the verifications.

Manufacturing

Examples of Controls:

- Verifying wholesomeness
- Verifying identification, weight or volume of ingredients
- Verifying ambient temperature
- Handling of rejected ingredients or product

Although ingredients may have been checked earlier for wholesomeness and acceptability, it is a good idea to make another check just prior to actual use in the manufacturing process. A method for controlling the weight of each ingredient is essential in order to assure a uniform and consistent finished product that complies with the company's quality requirements for the products and FDA's good manufacturing regulations for the products. Maintaining the correct temperature in an area is important to good quality product. Unacceptable ingredients or materials will arrive in the manufacturing area, and procedures should be outlined for these situations. Good management sets realistic and effective controls for dealing with these situations.

Packaging and Labeling

Examples of Controls:

- Verify label approval
- Verify accuracy of labeling
- Check temperatures
- Finished product sampling

This is one of the last steps prior to shipping, it is essential that no regulatory requirement be overlooked. Checks must be made to assure that all labels have been approved by state and federal regulators and that proper labels are being used. Particular attention should be paid to the new nutrition labeling. It must be verified that illustrations represent the product, net weight and count declarations are accurate, and packaging meets the company's specifications. The temperatures of frozen products, as well as the condition of all containers and cases, should be checked and the findings recorded. Routine systematic sampling, inspection, or analysis of a finished product must be part of the approved total quality control system, especially for a product going to retail outlets.

Shipping

Examples of Controls:

- "First in, first out"
- Record of shipments
- Checking order sizes and temperatures
- Checking containers and carriers

Records of the destination of products shipped from the plant are important to good quality control. The plant may find it beneficial to have some type of container coding and dating system. This would identify the date of processing and packaging for returned goods. Quality control checks should be made to verify the adequacy of the container codes and to verify order sizes, temperatures, and the condition of containers, rail cars, or trucks used for shipping.

General Sanitation

Examples of Controls:

- Rodents and pests
- Product contamination
- Employee hygiene
- Facilities and environmental appearance

A procedure to check the overall sanitation of plant facilities and operations, including outside adjacent areas and storage areas on plant property, should be included in a total quality control system. In a total quality control system, a designated plant official will make the sanitation inspection and record the findings. If sanitation deficiencies are discovered, a plan for corrective action is necessary. Corrective action might include re-cleaning, tagging a piece of equipment, or closing off an area until a repair is completed. Systematic sanitation inspection procedure should be used where product contamination is possible, such as packaging failure, moisture dripping, or grease escaping from machinery onto product or surfaces which come into contact with product.

Employee Training

Examples of Controls:

- New employee orientation
- Refresher training

When new employees begin work at a plant, it is useful to acquaint them with all aspects of the plant. The quality control system should provide for instruction of new employees on the plant's operations and products and on good hygiene practices. Employee training should not end with orientation, but should include an ongoing program to continually remind employees of the importance of good sanitation. How are employees continually reminded of important functions, such as personal hygiene after a visit to the restroom? Will posting a sign or poster which fades over time communicate the appropriate level of

importance? There are many ways of continuing employee training and maintaining sensitivity.

Completing the Total Quality Control System

The result is essentially the plant's "operating manual." It will serve as the plant's total quality control system. Upon completion, it should be reviewed. A definition or description may be needed for such points as control limits, variability in weights, or number of defects per sample. All critical control points should be covered. In addition, those sections of the FDA's good manufacturing practice regulations applicable to the operations of the plant must be listed. For each, identify the specific part of the quality control system which is designated to assure compliance. When the proposed total quality control system is completed, it is ready to be submitted to the company's management.

Food Code

The Food Code provide a foundation on which to develop a food safety system based on the principles of HACCP. Major interventions in the Food Code demonstrate the knowledge of the person-in-charge, regarding employee health, avoiding contact with ready-to-eat food with bare hands, time and temperature control, and the use of a consumer advisory regarding the consumption of raw or undercooked animal foods. Food safety program which may entail inclusion in SOPs (Standard Operation Procedures) which can be considered as the major frame of reference of sanitation and HACCP.

Standard Operation Procedures

Three purposes for establishing SOPs for your operation are to protect your products from contamination from microbial, chemical, and physical hazards; to control microbial growth that can result from temperature abuse; and to ensure procedures are in place for maintaining equipment.

SOP procedures ensure that:

1. Products are purchased from approved suppliers/ sources
2. The water in contact with food and food-contact surfaces and used in the manufacture of ice is potable
3. Food-contact surfaces, including utensils are cleaned, sanitized, and maintained in good condition
4. Uncleaned and nonsanitized surfaces of equipment and utensils do not contact raw or cooked ready-to-eat food
5. Raw animal foods do not contaminate raw or cooked ready-to-eat food
6. Toilet facilities are accessible and maintained
7. Handwashing facilities are located in food preparation, food dispensing, warewashing areas, and immediately adjacent to toilet rooms and are equipped with hand cleaning preparations and single-service towels or acceptable hand drying devices
8. An effective pest control system is in place
9. Toxic compounds are properly labeled, stored, and safely used
10. Contaminants such as condensate, lubricants, pesticides, cleaning compounds, sanitizing agents, and additional toxic materials do not contact food, food packaging material, and foodcontact surfaces
11. Food, food packaging materials, and foodcontact surfaces do not come in contact with, and are not contaminated by physical hazards such as broken glass from light fixtures, jewelry, etc.

SOPs to Control Contamination of Food

Procedures must be in place to ensure that proper personnel health and hygienic practices are implemented including:

1. Restricting or excluding workers with certain symptoms such as vomiting or diarrhea

2. Practicing effective handwashing
3. Restricting eating, smoking, and drinking in food preparation areas
4. Using hair restraints
5. Wearing clean clothing
6. Restricting the wearing of jewelry

Control Microbial Growth

These procedures ensure that all potentially hazardous food is received and stored at a refrigerated temperature of 41°F (5°C) or below.

Maintain Equipment

These procedures ensure that:

1. Temperature measuring devices (e.g., thermometer or temperature recording device) are calibrated regularly
2. Cooking and hot holding equipment (grills, ovens, steam tables, conveyor cookers, etc.) are routinely checked, calibrated if necessary and are operating to ensure correct product temperature
3. Cooling equipment (refrigerators, rapid chill units, freezers, salad bars, etc.) are routinely checked, calibrated if necessary and are operating to ensure correct product temperature
4. Warewashing equipment is operating according to manufacturer's specifications.

The Flow of Food

The flow of food, which is the path that food follows from receiving through serving, is important for determining where potentially significant food safety hazards may occur. At each operational step in the flow, active management of food preparation and processes is an essential part of business operations. With a HACCP system, you set up control measures to protect food at each stage in the process.

FOOD PROCESSING WITH NO COOK STEP

Receive — Store — Prepare — Hold — Serve

The important feature of this type of process is the absence of a cooking step. Heating foods destroys bacteria, parasites, and viruses, and is often a CCP. But since this particular food flow does not include cooking, there is no step that will eliminate or kill bacteria, parasites, or viruses. An example is tuna salad that is prepared and served cold. Control in this process will focus on preventing:

1. Bacterial growth (e.g., storage under refrigeration)
2. Contamination from employees (e.g., restriction of employees ill with diarrhea, proper handwashing, preventing bare hand contact with ready-to-eat foods, etc.)
3. Cross-contamination from other foods (e.g., raw to ready-to-eat)
4. Cross-contamination from soiled equipment (e.g., cleaning and sanitizing)
5. Obtaining foods from approved sources (e.g., a supplier of raw fish for sushi who adequately freezes fish to control parasites).

FOOD PREPARATION FOR SAME DAY SERVICE

Receive — Store — Prepare — Cook — Hold — Serve

In this process, a food is prepared and served the same day. The food will be cooked and held hot until service, such as chili. The food will pass through the temperature danger zone only once before it is served to the customer, thus

minimizing the opportunity for bacterial growth. The preparation step may involve several processes, including thawing a frozen food, mixing in other ingredients, or cutting or chopping. Cutting or chopping must be done carefully so that cross contamination from cutting boards, utensils, aprons, or hands does not occur. Control points at this operational step include good sanitation and handwashing. During cooking, food will be subjected to hot temperatures that will kill most harmful bacteria, parasites, and viruses that might be introduced before cooking, making cooking a CCP. It is the operational step where raw animal foods are made safe to eat, and time and temperature measurement is very important. Temperature of foods during hot holding must be maintained until service so that harmful bacteria do not survive and grow.

COMPLEX PROCESSES

Receive — Store — Prepare — Cook — Cool — Reheat — Hot Hold — Serve

Foods prepared in large volumes or in advance for next day service usually follow an extended process flow. These foods are likely to pass through the temperature danger zone several times. The key in managing the operational steps within the process is to minimize the time foods are at unsafe temperatures. A variety of foods and ingredients that require extensive employee product preparation may be part of the process. A sound food safety management system will incorporate SOPs for personal hygiene and cross contamination prevention throughout the flow of the food. Multiple step processes require proper equipment and facilities. Your equipment needs to be designed to handle the volume of food you plan to prepare.

Conduct Hazard Analysis

In developing a food safety system, you need to identify the hazards that exist in the flow of foods in your operation from receiving to serving. Hazards include:

1. Pathogens or toxins present in food when you receive them
2. Pathogens that may be introduced during preparation (e.g., using a raw animal food as one ingredient)
3. Pathogen growth or toxin production during storage, preparation, or holding
4. Pathogens or toxins that survive heating
5. Contaminants (i.e., pathogens, chemicals, physical objects), that are introduced to food by food workers or equipment.

The hazards associated with various foods and ingredients, such as:

1. Salmonella and Campylobacter jejuni in raw poultry
2. E. Coli O157:H7 in raw ground beef
3. Staphylococcus aureus toxin formation in cooked ham
4. Bacillus cereus spore survival and toxin formation in cooked rice
5. Clostridium perfringens spore survival and subsequent growth in cooked foods
6. Hazards specific to seafood (see Food Code)

FOOD SAFETY MANAGEMENT WORKSHEETS AND SUMMARIES FOR OPERATIONAL STEPS

Worksheets and summaries are provided to enable you to:

1. Identify those operational steps in the food flow that are specific to your operation
2. Write in your SOPs which are the general procedures that cross all flows and products

3. Reference the CCPs and critical limits pertaining to those process steps
4. Develop monitoring procedures and corrective actions which are customized to fit your operation
5. Consider the type of record keeping you need to document you are controlling significant food safety hazards

HACCP allows the flexibility for you to customize a food safety management system specific to your operations. The worksheets are provided to assist you in developing procedures to:

1. Monitor CCPs
2. Take corrective actions when critical limits are not met
3. Establish a verification procedure
4. Establish a record keeping system

Receiving: At receiving, your main concern is contamination from pathogens and the formation of harmful toxins. Obtaining food from approved sources and at proper temperatures are important purchase specifications for preventing growth and contamination during receiving. Approved sources are suppliers who are regulated and inspected by appropriate regulatory authorities.

Storage: When food is in refrigerated storage, your management system should focus on preventing the growth of bacteria that may be present in the product. This is primarily achieved through temperature control. Special attention needs to be given to controlling and monitoring the temperatures of potentially hazardous ready-to-eat foods.

Preparation: Of all the operational steps in food processes, preparation has the greatest variety of activities that must be controlled, monitored, and in some cases documented. It is impossible to include in this model a summary guide that covers the diversity in menus, employee skills, and facility design that impact the preparation of food. The preparation step may involve several processes, including thawing a frozen food, mixing together several ingredients, cutting, chopping, slicing, or breading. At the preparation step, SOPs can be developed to control

some hazards and assist in implementation of a food safety system that minimizes the potential for bacterial growth and contamination from employees and equipment.

Cooking: Cooking foods of animal origin is the most effective operational step in food processes for reducing and eliminating biological contamination. Hot temperatures will kill most harmful bacteria and with relatively few exceptions, such as cooking plant foods, this is a CCP. It is at this step that food will be made safe to eat. Product temperature and time measurements are very important. If the appropriate product temperature for the required amount of time is not achieved, bacteria, parasites, or viruses may survive in the food. Critical time and temperature limits vary according to the type of food. Employees should view ensuring proper cooking temperatures as an essential element in producing an acceptable product.

Cooling: One of the most labor intensive operational steps is rapidly cooling hot foods to control microbial growth. Excessive time for the cooling of potentially hazardous foods has been consistently identified as one of the factors contributing to foodborne illness. Foods that have been cooked and held at improper temperatures provide an excellent environment for the growth of disease causing microorganisms that may have survived the cooking process (spore-formers). Recontamination of a cooked food item by poor employee practices or cross contamination from other food products, utensils and equipment is a concern at this operational step. Special consideration should be given to large food items, such as roasts, turkeys, thick soups, stews, chili, and large containers of rice or refried beans. These foods take a long time to cool because of their mass and volume. If the hot food container is tightly covered, the cooling rate will be slowed down. By reducing the volume of the food in an individual container and leaving an opening for heat to escape by keeping the cover loose, the rate of cooling is dramatically increased.

Reheating: If food is held at improper temperatures for enough time, pathogens have the opportunity to multiply to dangerous numbers. Proper reheating provides an important control for eliminating these organisms. It is especially effective in reducing contamination from bacterial spore-formers which survived the cooking process and may have multiplied because foods were held at

improper temperatures. Although proper reheating will kill most organisms of concern, it will not eliminate toxins, such as that produced by *Staphylococcus aureus*. If microbial controls and SOPs at previous operational steps have not been followed correctly and Staph toxin has been formed in the food, reheating will not make the food safe. The process will minimize the risk from Staph toxin. Along with personal hygiene, preventing cross contamination through the use of cleaned and sanitized equipment and utensils is an important control measure.

Holding: Proper temperature of the food while being held is essential in controlling the growth of harmful bacteria. A cooking step as a CCP to eliminate pathogens, all but the spore-forming organisms should be killed or inactivated. If cooked food is not held at the proper temperature, the rapid growth of these spore-forming bacteria is a major food safety concern. When food is held, cooled, and reheated in a food establishment there is an increased risk from contamination caused by personnel, equipment, procedures, or other factors. Harmful bacteria that are introduced into a product that is not held at proper temperature have the opportunity to multiply to large numbers in a short period of time. Once again management of personal hygiene and the prevention of cross contamination impact the safety of the food at this operational step. When determining the monitoring frequency of cold product temperatures, it is important to make sure that the interval between temperature checks is established to ensure that the hazard is being controlled and time is allowed for an appropriate corrective action. Special consideration should be given to the time and temperature in the hot or cold holding of potentially hazardous foods to control pathogens. It is recommended that hot or cold holding be a CCP, based upon the critical limits established by the Food Code, unless you can show through scientific data that the food safety hazard will not result.

Setup and Packing: Setup and packing is an operational step used by some retail food establishments including caterers (e.g., restaurant/caterer or interstate conveyance caterer), commissaries, grocery stores (for display cases), schools, nursing homes, hospitals, or services such as delivery of meals to home-bound persons. Setup and packing can be controlled through an SOP and may involve wrapping food items, assembling these items onto trays, and packing them into a transportation carrier or placing them in a display case. This process can be controlled by strict adherence to SOPs to minimize the potential for bacterial

contamination and growth, to eliminate bare hand contact with ready-to-eat foods, to ensure proper handwashing, and to ensure food comes into contact with cleaned and sanitized surfaces.

Serving: This is the final operational step before the food reaches the customer. When employees work with food and food-contact surfaces, they can easily spread bacteria, parasites, and viruses and contaminate these items. Managing employees' personal hygienic practices is important to controlling these hazards. A management program for employee personal hygiene includes proper handwashing, the appropriate use of gloves and dispensing utensils, and controlling bare hand contact with ready-to-eat foods. Minimizing the growth of bacteria is also a concern at hot and cold holding customer display areas. Maintaining food products at proper temperature within these display units will control the growth of microorganisms. Customer self-service displays, such as salad bars, require specific procedures to protect the food from contamination. Some suggestions for protecting food on display include:

- The use of packaging
- Counter, service line, or salad bar food guards
- Display cases
- Suitable utensils or effective dispensing methods
- Not mixing an old product with fresh
- Having employees monitor self-serve stations

Standard Industrial Classification (SIC) of Food Establishments

Food and kindred products may be classified according to the "Standard Industrial Classification Manual" (Occupational Safety and Health Administration). This major group includes establishments manufacturing or processing foods and beverages for human consumption, and certain related products, such as manufactured ice, chewing gum, vegetable and animal fats and oils, and prepared feeds for animals and fowls.

Food Processes, Safety Hazards and Controls

Controls Process	Occupational Condition	Potential Hazard	Control
Meat processing, SIC 201	<ul style="list-style-type: none"> • Handling live, immobile, and slaughtered animals • Cutting and use of sharp tools • Wet flooring, platforms, decks • Steam • Animal borne microorganisms 	<ul style="list-style-type: none"> • Strains, contusions • Lacerations, loss of body members • Falls, sprains • Burns, scalds • Brucellosis, dermatitis 	<ul style="list-style-type: none"> • Mechanization, training • Protective clothing, gloves, guards, training • Drains, shields • Shields, reliefs • Inspection
Dairy processes, SIC 202	<ul style="list-style-type: none"> • Handling churns, homogenizers, plasticizers, evaporators, freezers • Handling in-process materials, products 	<ul style="list-style-type: none"> • Lacerations, contusions, etc., from moving machine parts • Strains and contusions 	<ul style="list-style-type: none"> • Guards, shields, layout, clothing insulation • Mechanization, training
Food preservation processes, SIC 203	<ul style="list-style-type: none"> • Cleaning, cutting, screening, • peeling raw fruit and vegetables • Blanching, cooking, pasteurizing, • curing, freezing products • Storing, packaging, shipping 	<ul style="list-style-type: none"> • Lacerations, bruises, pinches in operating and maintaining the tools and machines • Burns, scalds, extreme temperatures 	<ul style="list-style-type: none"> • Guards, shields, clothing layout, training • Insulation, shields • Guards, gloves, shields, mechanization

		<ul style="list-style-type: none"> • Cuts, bruises from packaging machines, sprains 	
Grain mill processes, SIC 204	<ul style="list-style-type: none"> • Operating and servicing breakingrolls, sieves, conveying and elevating equipment, man-lifts • Handling feed, in-process material products • Dust, noise, vibration 	<ul style="list-style-type: none"> • Bruises, contusions, pinches, lacerations, falls • Body strains • Respiratory effects, hearing 	<ul style="list-style-type: none"> • Guards, barriers, training • Mechanization, training • Ventilation, insulation
Bakery processes, SIC 205	<ul style="list-style-type: none"> • Mixing, kneading, and forming machinery-conveyors • Baking ovens • Handling in-process materials, products 	<ul style="list-style-type: none"> • Injuries from moving parts • Burns, hot working environments • Strains 	<ul style="list-style-type: none"> • Guards, shields, layout • Insulation, clothing, air conditioning • Mechanization, training
Fat and oil recovery processes, SIC 207	<ul style="list-style-type: none"> • Extracting oil and fat from animal and vegetable processes by steam distillation, mechanical 	<ul style="list-style-type: none"> • Burns and scalds from steam and liquor leaks, spills; breaks and leaks from presses; vapors 	<ul style="list-style-type: none"> • Insulation, barriers, layout, controls against overloads, spills, ventilation and monitoring

	expression, solvent extraction <ul style="list-style-type: none"> • Cleaning, grinding, shredding feeds • Purification, hydrogenation processing 	and gases from extractors <ul style="list-style-type: none"> • Machine injuries • Chemical effects 	<ul style="list-style-type: none"> • Guards, training • Ventilation
Beverages, SIC 208	<ul style="list-style-type: none"> • Handling in-Processing materials • Broken glass 	<ul style="list-style-type: none"> • Body straining from lifting • Lacerations 	<ul style="list-style-type: none"> • Increasing mechanization, training • Protective clothing, gloves

AN EXAMPLE OF WORKERS SAFETY IN A BAKERY ESTABLISHMENT

A. Identification

Industry: Bakery products. Sub-group: Bread, cake and related products; cookies and crackers.

B. Process Description

Bakery goods include bread, cakes, pies, cookies, rolls, crackers and pastries. Ingredients consisting of flour, baking powder, sugar, salt, yeast, milk, eggs, cream, butter, lard, shortening, extracts, jellies, syrups, nuts, artificial coloring, and dried or fresh fruits are blended in a vertical or horizontal mixer after being brought from storage, measured, weighed, sifted, and mixed. After mixing, the dough is raised, divided, formed, and proofed. Fruit or flavored fillings are cooked and poured into dough shells. The final product is then baked in electric or gas-fired ovens, processed, wrapped, and shipped. Loaves of bread are also sliced and wrapped.

C. Injury Type and Sources

In bakery products, most of the injured employees are struck by or struck against some object, fell or slipped or were caught in, under or between objects. These injuries most commonly encountered are dislocations, sprains and strains and often involve machines and working surfaces as sources of injury.

D. Inspection Analysis

When a company officer inspects the bakery establishment for safety concerns. The inspection should begin in the receiving and storage areas where bins must be checked for safety ladders of non-splintering material. Mixers should then be checked for interlocks, along with agitator guards, size of openings, and cranes for moving bowls over 80 lbs. Bread rollers must have in running rollers guarded and the slicing machine must have a device to push the last loaf of bread through and be interlocked. Employees must be checked for personal protective equipment at hot fat kettles. Machines must be grounded and have power transmission and guarded throughout. Any hot water or steam pipe must be guarded, especially in mixing and oven areas. Any conveyor passing over an aisle must have a lower guard to protect employees passing underneath baking machinery.

E. OSHA Hazards Analysis

The types of hazards, their causes and their occurrence in the bakery processing plant.

F. Other Pertinent Information

An Industrial Hygienist referral must be made for flour dust, which can cause rhinitis, buccopharyngeal disorders, bronchial asthma and eye diseases. There is a high incidence of pulmonary tuberculosis among bakers.

OSHA Hazards Analysis

	Activities or Equipment	Location
Major Hazards <ul style="list-style-type: none"> • Amputation and mangled limbs from contact with gears, shafts, pulleys, belts, chains and sprockets • Slipping, tripping and falling hazards • Amputation and mangled limbs from nip points and sharp blades • Electrocuting from inadequate grounding • Burns from hot pipes and hot fat splashes. • Inhalation of carbon monoxide 	<ul style="list-style-type: none"> • Mechanical power transmission apparatus • Housekeeping • Point of operation • Electrical connections • Ovens and open fat kettles 	<ul style="list-style-type: none"> • Throughout plant • Throughout plant • Throughout plant • Throughout plant • Throughout plant
Other Hazards <ul style="list-style-type: none"> • Broken chain links and pulleys causing mixing bowls to fall on employees • Back strains and pulled muscles • Explosion or fire 	<ul style="list-style-type: none"> • Cranes and hoists • Lifting • Combustible dusts 	<ul style="list-style-type: none"> • Mixing • Mixing and baking areas • Storage

Food Allergy

Adverse reactions to foods may be classified as those that are induced by biologically active microbial toxins (e.g., shiga toxin, vomitoxin, etc.) contained in the foods and those that are triggered by specific food constituents by nontoxic mechanisms. Some of the nontoxic adverse reactions to foods are mediated by the immune system while others are not. Food induced adverse reactions mediated by the immune system are grouped as food induced hypersensitivity reactions. This disease begins in infancy. Earliest lesions are erythematous, weepy patches on the cheeks with subsequent extension to other parts of the body including the face, neck, wrists, hands, and abdomen. Similar to food allergies, recent evidence also suggests that other atopic diseases (e.g., atopic rhinitis, dermatitis, and asthma).

PREVALENCE AND SIGNIFICANCE OF FOOD ALLERGY

Current prevalence of food allergies that are relatively common among many western countries has been estimated to be ~2% among adults and ~7% among children. More data is warranted to test this hypothesis and to examine whether this may be true for all types of food allergies in addition to that of peanut allergy. Food-induced systemic anaphylaxis — a generalized hypersensitivity response involving multiple organ systems including circulatory system, that can be fatal within minutes to hours after the onset of symptoms if untreated.

ALLERGENIC FOODS vs. FOOD ALLERGENS

Any food can cause allergic reaction in a sensitized individual. Food and Agriculture Organization (FAO) and the Food Allergy Task Force of the International Life Sciences Institute (ILSI), Europe, 90% of food allergies are caused by only eight food types: Chicken egg, cow's milk, peanut, soybean, wheat, tree-nuts (almond, hazelnut etc.), fish, and shellfish. These food types have been regarded by the food regulatory agencies as “big eight” or “red flag” allergenic foods. These food allergies appear to be not restricted to any geographical region

in particular but rather are widespread in the world. Allergy to sesame, expressed as systemic anaphylaxis similar to peanut allergy.

FOOD ALLERGY: CLASSIFICATION

Clinically food allergic reactions are expressed within minutes of exposure with a variety of symptoms. These include urticaria (skin rashes), hives (or raised rashes), angioedema, rhinoconjunctivitis, vomiting, diarrhea, airway allergy symptoms (such as asthma, runny and itchy nose) or systemic anaphylaxis and shock. Accordingly, based on the target organ involvement, food allergies have been classified as (i) gastrointestinal food allergy; (ii) dermatological form of food allergy; (iii) respiratory form of food allergy; and (iv) food-induced systemic anaphylaxis involving multiple organ systems including the cardiovascular system. Some food allergies following exercise immediately after eating, presumably due to increased absorption and distribution of allergens via enhanced circulation. Foods such as peanut, tree-nuts, fish, and shellfish are more often associated with systemic anaphylactic reactions than other food types. Clinically food allergies are also expressed in two distinguishable forms: (i) transient food allergies (that are commonly outgrown); and (ii) persistent food allergies (that are rarely outgrown).

MECHANISMS OF FOOD ALLERGY: IMMUNE RESPONSE MODEL

As opposed to food allergy, immune mechanisms underlying other types of allergies such as allergic rhinitis and allergic asthma are very well established. Allergies are regarded as complex heterogeneous genetic disorders involving interaction between multiple genetic susceptibility genes and environmental factors. Similar genetic susceptibility is thought to underlie food allergies. Environmental exposure to allergen is essential for initiation of an allergic immune response as well as expression and maintenance of the clinical disease. According to this model, exposure to peanut leads to peanut antigen presentation by professional antigenpresenting cells of the immune system to peanut-specific T helper (Th) cells. This results in the formation of Th2 lymphocytes that help peanut-specific B-lymphocytes to produce peanut-specific IgE antibodies. These immune cells are equipped with granules containing histamine and other pro-

inflammatory mediators. The same food allergen (peanut allergen in this case) results in cross-linking of cell surface-bound IgE molecules by peanut allergens leading to activation and degranulation of mast cells and basophils. The release of inflammatory mediators results in expression of clinical symptoms of disease. In extreme cases, this reaction could be widespread, involving multiple organs (referred to as systemic anaphylaxis and shock) that is often fatal if untreated. Specific mechanisms of disease are not clear, although many appear to involve delayed hypersensitivity reactions. The disease-eliciting food components also remain to be characterized. One well-characterized non-IgE mediated food-induced disease is gluten enteropathy. It afflicts children as well adults and is particularly prevalent among Caucasians. Gluten is a component of many cereals such as wheat, rye, and barley. Wheat gluten in particular consists of a complex mixture of many gliadins and glutenin polypeptides. Gliadins are monomers and glutenins are polymers. There is clear evidence that celiac disease patients have T cells infiltrating the intestinal mucosa that react to deamidated gluten peptides. Gluten-specific T lymphocytes appear to be involved in the pathogenesis of this disease.

FOOD ALLERGY: PREVENTION, DIAGNOSIS, AND THERAPY

An effective preventive method such as a vaccine available for food allergy. Strict avoidance of contact with the food allergen is the only recommended preventive method. Following are some of the strategies especially for decreasing risk of atopy (i.e., tendency to develop an IgE antibody response) in infancy: (i) prolonged exclusive breast-feeding; (ii) maternal avoidance of commonly allergenic foods so as to prevent transfer of these proteins via breast milk to infants; (iii) delayed introduction of solid foods for the first 6 months of life; and (iv) use of hydrolyzed infant formulas (commonly referred to as hypoallergenic foods). Food allergies are typically diagnosed with clinical history in combination with one or more of the following diagnostic tests. (i) Skin prick test: a small amount of allergen is placed on the surface of the skin and a quick prick is done to enable the allergen to cross the skin barrier and reach the underlying mast cells. If an individual has IgE antibodies specific for the allergen bound to the mast cells, it leads to IgE cross-linking, mediator release, and a wheal (swelling) and flare

(redness) reaction at the site of allergen prick within 20–30 minutes. A saline solution is used as a negative control and a histamine solution as a positive control. Comparison of wheal size is made to determine the diagnosis. (ii) Double-blind placebo-controlled oral food challenge (DBPCFC) test: this is the gold standard test for food allergy diagnosis. However, the risk of severe reactions such as anaphylaxis makes this a difficult (and potentially very dangerous) choice for individuals with such a history. (iii) Food-specific IgE antibody measurement: immunoassay-based tests (such as radio allergosorbent test, or RAST) are available to determine the level of food specific IgE antibody levels in the peripheral blood. Therapeutic approaches for allergic diseases including food allergies. (i) Antihistamines are widely used for most allergic reactions. Antihistamines block histamine binding to H1 receptor and prevent cellular response to histamine. (ii) Corticosteroids are general anti-inflammatory agents that can be used locally or systemically. (iii) Epinephrine injections (intramuscular) are recommended for severe food induced reactions such as systemic anaphylaxis. Epinephrine is the only life-saving medicine available to treat them. It works as follows: constricts blood vessels and restores blood pressure, dilates bronchi and prevents choking, and increases heart action. (iv) Allergy shots: a technique called Preventive Allergy Treatment (PAT) (also called desensitization) has been used clinically for treating airway allergies. They are not recommended for food allergies due to serious risk of systemic anaphylaxis.

Biosensor Technology

Biosensor technology is a powerful alternative to conventional analytical techniques, harnessing the specificity and sensitivity of biological systems in small, low cost devices. Despite the promising biosensors developed in research laboratories, there are not many reports of real applications in food safety and quality monitoring. A sensor is the device that can detect a property or group of properties in a food product and respond to it by a signal, an electric signal. This signal may provide direct information about the quality factor(s) measured, or may have known relation to the quality factor.

NEEDS OF FOOD QUALITY/SAFETY CONTROL

Food quality control is essential in the food industry; an efficient quality assurance is becoming increasingly important. Consumers expect adequate quality of food product at a fair price, long shelf-life, and high product safety, while food inspectors require safe manufacturing practices, adequate product labeling, and compliance with the FDA regulations. Food producers are increasingly demanding the efficient control methods, particularly through on-line or at-line quality sensors to satisfy consumers' and regulatory requirements, and also to improve the feasibility of automated food processing, quality of sorting, and to reduce the production time (increase throughput) and the final product cost. Biosensors for food safety and quality control were stimulated by acquiring several new food safety and key quality concepts during the last decade: Hazard Analysis Critical Control Points (HACCP), Total Quality Management (TQM), ISO 9000 Certifications. Biosensors in food safety and quality management, showing the sources of biohazard contaminations in foods and their influence on technological, "shelf-life," and perception properties of food products. The sources of food raw materials and their quality are the issue of biosafety/biosecurity in the agricultural processing including post-harvesting technologies and logistics.

(1) Food Processing: Many important nutrients are denaturalized, altered, or even destroyed by the faulty processing of foods. Food can also become contaminated during processing, handling, distribution, and consumption. Many undesirable or even harmful substances can enter the food as additives and toxic metabolites during its processing and preservation.

(2) Food Contamination: Food can become contaminated during every step of food processing sequence, from cultivation to consumption. The contaminants may be:

- Microbiological: viral, bacterial, parasitological, and fungal;
- Chemical: pesticide residues, nitrates, nitrites, high salinity, fluorides, arsenic compounds, lead, and other heavy metals. These pose serious and longterm health threats;

- Harmful metabolites and biological toxins (e.g., methyl alcohol, estrogen-like substances, hormones, biotoxins including mycotoxins especially aflatoxins, allergens, and carcinogens).

(3) Sources/Raw Materials: The major aspect in the area is the utilization of food sources, which were previously wasted or not used. This is mainly to enrich fodder, thus ensuring better recovery for human consumption indirectly.

(4) Food Substitutes and Genetically Modified Foods (GMF): There has been incredible progress in new biotechnology with commercialized products of insulin, human growth hormones, interferon, and recombinant vaccines using human cell culture or “novel” bacteria. Some people are allergic to some food ingredients. Allergies to natural foods are less common and less serious compared to those to food additives and untraditional or inedible food varieties.

(5) Food Industry Hygiene: The need for development of appropriate policy related to health, agriculture, trade, manufacture, and licensing, the rational consumer protection regulatory systems are to be developed and enforced. The major types of changes in foods caused by the sources of undesirable contaminants. They can be instrumentally controlled, represent the primary targets for biosensors development and design. The great challenge is to develop the real-time and on-line sensors and data systems suitable for surveying processes and products, controlling automated processes and the raw material stream, sensing the final products quality, typing the product labels with nutritional and health information.

SOURCES OF INFORMATION FOR BIOHAZARDS DETECTION

The detection of biohazards can be performed directly by measurements of the pollutants/ pathogens concentration in a food product with specifically aimed biosensors. Another (indirect) approach to determining the presence/level of biohazard is through the measurements of changes in processing parameters (temperature, pressure, water activity, etc.) that lead to variations in microbial contamination levels. External information can alert the food safety management system on possible increase of bacterial contamination or risk of bioterrorists’

attack and/or environmental pollution splash. This information, i.e., expectations of high contamination level, can be used to perform changes in screening and sampling procedures, and extend the range of pathogens to be detected. Internal knowledge base (“sensor-free detection”) is the set of accumulated data/records giving the correlation between the properties of raw materials, process parameters, and biohazard level in manufactured products.

The most important quality parameters and concepts in food production control are:

- Sensory: appearance, flavor, taste, texture, stability, etc.;
- Nutritional, including health implications, such as “high in fiber,” “low cholesterol,” “GMF free,” etc.;
- Composition and labeling: additives lists, quality and ethical claims (e.g., ecological information), etc.;
- Pollutants record: environmental pollutants, veterinary drugs, agricultural chemicals, BSE-prions and mycotoxins;
- Detection of foreign bodies, such as stones, glass, or metal fragments;
- Microbial safety, in particular *Listeria*, *Salmonella*, *Campylobacter*, *E. coli*, and *Yersinia*;
- Shelf-life: microbial, sensory, chemical, sterility testing, F0-values;
- Production hygiene: cleaning, decontamination;
- HACCP: traceability and authentication;
- Process parameters control: machine settings, temperature, pressure, flow, aseptic conditions, and many others;
- Packaging: integrity, pinholes, gas permeability, migration control.

BIOSENSORS: GENERAL FACTS

Biosensors are small analytical bio-electronic devices that combine a transducer with a sensing biological component (biologically active substance). The transducer, which is in intimate contact with the biologically sensitive material, can measure weight, electrical charge, potential, current, temperature, or optical activity of the substance. The biologically active species include enzymes, multi-enzyme systems, antibodies or antigens, receptors, populations of bacterial or eukaryotic cells, or whole slices of mammalian or plant tissue, to name a few. Substances such as sugars, amino acids, alcohols, lipids, nucleotides, etc. can be identified and their concentration measured by these sensors. The biosensor consists of a biological sensing element integrated with a signal transducer; together they produce a reagent-free sensing system specific for the target analyte. The biological component of a biosensor used for the molecular detection is made of highly specialized macro-molecules or complex systems with the appropriate selectivity and sensitivity. Biosensors can be classified according to the biocomponents used for the detection. One of the bio-selective elements most frequently used in biosensors is an enzyme. These are large protein molecules that act as catalysts in chemical reactions, but remain themselves unchanged at the end of reaction.

Biosensors classification

Biosensors

Bio-element

Antibody

Enzyme

Nuclei
acid

Molecular

Cell-based

Tissue-based

Transducer

Optical

Mechanical

Electrochemical

Principle of operation

Fluorescence

Surface plasma resonance

Adsorbance / reflectance

Piezoelectric

Surface acoustic wave

Cantilever resonance frequency

Amperometric

Potentiometric

Impedimetric

TYPES OF BIOSENSORS

The types of biosensors are:

1. Mechanical (Resonant) Biosensors
2. Optical Detection Biosensors
3. Electrochemical Biosensors
4. Impedimetric / Conductometric Biosensors
5. Amperometric Biosensors
6. Potentiometric Biosensors
7. Cell-Based Biosensors
8. Lab-on- a- Chip Systems and DNA Detection Devices
9. DNA-Based Sensors / Assays

APPLICATIONS OF BIOSENSORS IN FOOD SCIENCE AND MANUFACTURING

Biosensors in food safety/ biosecurity management systems and existing biosensor technologies. The following articles about bio-detection in poultry industry, and pathogen detection in muscle foods. The needs for fast, on-line, and accurate sensing, e.g., in situ analysis of pollutants in crops and soils, detection, and identification of infectious diseases in crops and livestock, on-line measurements of important food processing parameters, monitoring animal fertility, and screening therapeutic drugs in veterinary testing are well-described in another work.

(1) SENSORS FOR PATHOGENS DETECTION

The broad spectrum of foodborne infections keeps changing dramatically over time, as well-known pathogens have been controlled or eliminated, and new ones have emerged. The emergence or recognition of new pathogens, other trends include global pandemics of some foodborne pathogens, the emergence of antimicrobial resistance, the identification of pathogens that are highly opportunistic, affecting only the most high-risk subpopulations, and the increasing identification of large and dispersed outbreaks. New pathogens can emerge because of changing ecology or technology that connects a potential pathogen

with the food chain. Over the past decade many improvements have been seen in both conventional and modern methods of pathogenic bacteria detection in foods. Modification and automation of conventional methods in food microbiology involve sample preparation, plating techniques, counting, and identification test kits. ATP bio-luminescence techniques are increasingly used for measuring the efficacy of surfaces and utensils cleaning. A surface plasmon resonance biosensor was used to detect a Salmonella pathogen through antibodies reacting with Salmonella group A, B, D, and E. The detection is based on the immunomagnetic separation of the target pathogen from a sample and absorbance measurements of p-nitrophenol at 400 nm from p-nitrophenyl phosphate hydrolysis by alkaline phosphatase. A label-free immunosensor for the detection of pathogenic bacteria using screen-printed gold electrodes (SPGEs) and a potassium hexacyanoferrate.

(2) SENSORS TO MONITOR FOOD PACKAGING AND SHELF-LIFE

A cell-based biosensor has been used to control meat freshness. Samples of fresh meat stored at 5°C were periodically removed from storage and washed with water for periods of up to 2 weeks. The water was then charged into a flow injection analysis (FIA) system combined with the microbial sensor using yeast as a sensitive element. This sensor has been specifically developed in this work for monitoring the freshness of meat. The amounts of polyamines and amino acids produced from the meat, and the number of bacteria that had been multiplying in the meat during the aging process were investigated. The sensor response has been found to correspond to the increase in amino acid levels and viable counts in the meat during the first stage of aging. This is due to the fact that amino acids produced initially by enzymes in the meat serve as a nutrition source for septic bacteria, and as a result, the amount of bacterial cells increases with an increasing level of amino acids.

(3) BIOSENSORS FOR FOOD QUALITY/ADDITIVES CONTROL

Existing food processing equipment includes microprocessors that are activated by electronic or biological sensors. The development of new sensors and instruments in this area is focused on measuring/evaluating the product's internal and external quality and flavor. The aim of food additives control and measurement is to develop, extend, and enhance the instrumental methods in order to improve consumer-perceived macroscopic quality factors. For quality assessment, grading, and sorting of food products, several types of electronic sensors that can provide rapid and non-destructive determination of product internal qualities have been investigated and described in the literature. A near infrared sensing technique can rapidly determine the sugar content of intact peaches. This technology has been extended to a number of other commodities, including testing avocados for oil content, and kiwifruits for starch and sugar content. NMR method can be used for nondestructive detection and evaluation of internal product quality factors, such as existence of bruises, dry regions or worm damage, stage of maturity, oil content, sugar content, tissue breakdown, and the presence of voids, seeds, and pits. Quality features are computed from digitized images, and the control system allows for product grading and sorting. Chlorophyll fluorescence and reflectance in the NIR/VIS spectrum has been used for the mechanical quality factors assessment of green beans, broccoli, and carrots. Biosensors have been used for evaluating the effects of pasteurization on vegetable quality by measuring the remaining enzymatic activity. The target quality factor assessed in this project was the presence of toxic chloro-phenolic fungicides and their chloroanisole breakdown products in potable water, wine, and fruit juices. The electrochemical immunosensor uses monoclonal antibody preparations. The investigations of the effects of liquid food matrices on electrochemical transduction processes indicated that horseradish peroxidase is a suitable label for interrogation of the analyte-antibody immune complex, using amperometry and in-house fabricated screen-printed electrodes. The sensor has to be used prior to slaughtering, and can detect and measure testosterone, methyltestosterone, 19-nortestosterone, stanozolol, and trenbolone levels in biological fluids (blood).

(4) BIOSENSORS FOR SENSORY EVALUATION OF FOOD PRODUCTS

“Electronic noses” and “electronic tongues” are the common names of devices responding to the flavor/ odor (volatiles) or taste (solubles) of a product using an array of simple and non-specific sensors, and the pattern recognition software system. Electronic noses and tongues are used in food production and quality control of different products, typically for laboratory tests or at-line control. Testing times are often in the range of a few minutes, and the largest drawback of these devices is the lack of sensor stability. Examples of claimed successful applications include:

- Discrimination between single volatile compounds;
- Tracking of aroma evolution of ice-stored fish or meat;
- Tracking of the evolution of cheese aroma during aging;
- Classification of wines;
- Determination of boar odor (androsterone) in pork fat;
- Classification of peaches and other fruits;
- Differentiation of spices by the area;
- General raw materials control;
- Testing of coffee, soft drinks, and whisky;
- Control of beer quality and faults.

Each odor or taste leaves a characteristic pattern or fingerprint on the sensor array, and an artificial neural network is trained to distinguish and recognize these patterns. Pattern recognition is gained by building a library of flavors from known flavor mixtures given to the network. Thus, e-noses and tongues are the devices intended to simulate human sensory response to a specific flavor, sourness, sweetness, saltiness, bitterness, etc. The potentiometric chemical sensors such as ion selective sensors are most used in the electronic noses. Considerable interest exists in the development of cheap, portable electronic noses to detect, on-line or at-line, odor quality of many foods.

ROLE OF BIOSENSORS IN THE FOOD SAFETY MANAGEMENT SYSTEM

(i) Biosensors and Biosecurity: Food industry is one of the major potential targets for bioterrorism. The most damage can be attained through: (1) final product contamination using either chemical or biological agents with an intent to kill or cause illness among consumers; (2) disruption of food distribution systems; (3) damaging the food producing cycle by introducing devastating crop pathogens or exotic animal diseases such as foot-and-mouth disease, which could severely impact the food system. Efforts to develop recognizing preparedness and response strategies for protecting the nation's food supply pose substantial challenges for a number of reasons, including the following:

- The food system encompasses many different industries;
- A great variety of biological and chemical agents could potentially contaminate the food supply, and the possible scenarios for deliberate contamination are essentially limitless;
- The public health system is complex, and responsibilities for foodborne diseases prevention and control may overlap, or much worse, fall in the "gray area" between authorities of different agencies.

To achieve an adequate food supply chain and agricultural security, improvement is needed in the activities on bioterrorism prevention, detection, and response. Appropriate areas for applied research must be identified:

- Recognition of a foodborne bioterrorism attack. This may be delayed because of background levels of foodborne diseases and the potential wide distribution of the contaminated product or ingredient.
- Rapid diagnostic methods for identifying food contaminating agents. They are not yet consistently available, and coordinated laboratory systems for pathogens detection are not fully operational.
- Rapid trace-back procedures for potentially contaminated products.

(ii) Biosensors and HACCP: Timely detection of unsafe foods is the main issue that the food safety system should address, providing guidance for the design and integration of such system into the existing food safety management structures, i.e., HACCP. The preventive detection of the biohazard can be accomplished by direct measurements with the biosensors, or indirect detection by the process/environment monitoring and control. Such detection is based on the data from physical and chemical sensors, which are very reliable and allow scale-down, which means the possibility of easy integration into the existing information carriers. The HACCP system for food safety management is designed to identify health hazards, and to establish strategies to prevent, eliminate, or reduce their occurrence. An important purpose of corrective actions is to prevent potentially hazardous foods from reaching consumers. Corrective actions should include the following elements: (a) determine the disposition of non-compliant product; (b) determine and correct the cause of non-compliance; (c) record the corrective actions that have been taken. HACCP is a food safety management system in which food safety is addressed through the analysis and control of biological, chemical, and physical hazards from raw material production, procurement and handling, to manufacturing, distribution, and consumption of the final product. The ultimate goal is the integration of sensors and sensor networks into the food safety management structure. Such integration will allow one to perform on-line and “on-shelf” control of the internal and/or external food product quality and package environment. Food quality monitoring units consist of a sensor for the particular analyte, an electronic unit to convert the response into a digital signal, and a cable to communicate with the base station. Advances in technology now enable sensors to be integrated with the base station through wireless communication that frees sensors from being physically attached to it. The new sensor devices and networks must satisfy food industry needs by delivering new benefits to users, offering new ways of monitoring food product properties/contaminations, developing tests that are cheaper, or creating devices that have significant advantages over those already available.

Food Packaging

Food packaging is changing to meet new challenges in the market and new needs of the consumer. New technologies continue to emerge with innovations in new packaging materials and packaging techniques that offer new possibilities for manufacturing, packaging, and marketing a wide variety of foods. Food packaging is the process of wrapping food with a suitable package. The package may be made of one or more materials that provide proper functionalities and properties for holding and protecting the food from the point of production to the consumer, while the quality and safety of the food are maintained. Holding and protecting the food are two major functions for packaging of food. Food is sensitive and susceptible to environmental abuse, and deteriorates by chemical, biochemical, and/or microbiological changes that are usually accelerated by environmental factors such as oxygen, water, light, and temperature. With a suitable package, these changes can be prevented or delayed. A suitable package can prevent contamination by foodborne pathogens, which render the food hazardous and unwholesome for consumption. Food packaging provides wholesome, high-quality, and nutritious food products. Packaging technology is dynamic as a result of the new challenges and new technologies developed to accommodate new needs in the changing society. Many foods are still packaged in traditional glass bottles and tin cans, newer plastic, multilayer, and composite packaging materials are creating opportunities for improved product convenience, presentation, quality, and safety, as well as innovative food product development.

Recent Development of Barrier Packaging Systems

A barrier can be defined in many ways depending on the desired level of protection from physical damage and chemical and biological changes that affect food quality and safety. Since most food packages are plastics, a barrier is conceived to be for control of permeation of gases and vapor through the package. Barrier technology has been designed and developed for both flexible and rigid food containers. A desired barrier level can be achieved by using one or more barrier materials for food packages, or by incorporating this barrier material using multi-layer structure, lamination, or coating techniques.

Barrier materials

Although polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene, (PP), polyvinyl chloride (PVC), and polystyrene (PS) are widely used plastics for food packaging, they provide inadequate barrier properties. Newer barrier materials were desirable. Several barrier materials of current industry interest include polyvinylidene chloride (PVDC), ethylene vinyl alcohol copolymer (EVOH), nylon (PA), modified nylon (MXD6, Sellar PA), liquid crystal polymer (LCP), polyethylene naphthalate (PEN), adhesive barrier materials, nanocomposites, and oxygen scavengers. These materials are high priced, so they are used in as small amounts as possible to give the desired barrier properties. Barrier material can be incorporated into a lower cost material by using lamination for a multilayer structure or coating onto a monolayer material.

Barrier PET Containers

Polyethylene terephthalate (PET) is one of the most widely used polymers. It was the first polymer to successfully recycle, generating reclaimed materials for a wide range of non-food and food applications. The recyclability of PET material is a factor promoting its use beyond the carbonated soft drink market to include other foods and beverages. It is replacing glass bottles and some bottles made from other plastics such as HDPE, PP, and PS. PET's success is a result of its better barrier and clarity than the plastics being replaced, as well as technological development of the processes used to convert PET into flexible and rigid packages at high outputs, which is crucial for the minimization of packaging costs. Use of PET resins continues to rise because of new applications, as well as the innovation of barrier technologies that help enhance the barrier properties of PET, and thus making it suitable for other demanding applications including use with oxygen sensitive foods. PET is now a commodity polymer competing directly with polyolefins and styrenics in the markets for food and beverage packaging, as well as for other products. Monolayer PET packages are suitable for many food applications but are not suitable for beverages and food products that require better protection or gas barriers. The ideal approach to improve the gas barrier of PET is to design a monolayer PET structure that will provide package design

freedom. This approach requires blending a barrier resin, oxygen scavenger, or both with the PET. The monolayer solutions are less practical mainly because suitable materials are high-priced. A major obstacle is a unit cost that is much higher for barrier PET bottles compared to glass. Shifting to barrier PET bottles requires breweries and blow molders to invest heavily in new development. Blow molders are shifting their efforts toward designing barrier PET bottles for less demanding applications in juices, carbonated soft drinks, and hot-filled products.

Freezing Seafood and Seafood Products

Freezing preservation of food is an excellent method of preservation with wide applications. Freezing inhibits the activity of food spoilage and food poisoning organisms and the low storage temperature greatly slows down the enzymatic and biochemical reactions which normally occur in unfrozen foods. Freezing accomplishes these objectives in two ways: the lowering of the temperature of the food and the removal of water by converting it into ice. Lowering the temperature to below freezing point inhibits the growth and activity of many, but not all, microorganisms. Converting most of the water into ice with the concomitant increase in concentration of the dissolved substances reduces the water activity of the food to the point where no microorganisms can grow. Although biochemical reactions slow down at lower temperature, they will, unlike microbiological activities, progress even at low commercial freezer storage temperatures. In addition, conversion of water into ice initiates complex physical and physicochemical changes that can cause general deteriorative quality changes not ordinarily occurring in fresh foods. Pre-freezing processing, such as blanching, freezing and storage conditions should therefore be selected, individually, for each product to minimize the effect of these deteriorative reactions.

A proportion of water of a product without packaging will evaporate during freezing. The faster the freezing, the smaller the amount of evaporated water. If the product is enclosed in a water-vapor-proof package before freezing, the moisture that escapes from the packet will be nil, but when there is an air gap between the surface of the product and the internal surface of the package frost may be deposited inside the package to the same extent as moisture evaporates from the product. For products frozen unpackaged, moisture loss varies from 0.5

to 1.5% or more, depending on the temperature, rate, and method of freezing, as well as the type of product. The colder the air temperature, the less moisture the air can absorb before it is saturated. Faster freezing methods lower the surface temperature of the product quickly to a value where the rate of moisture evaporation or sublimation is small. Where the surface of a product consists of a moisture-resistant layer (skin of the fish or fat on beef) moisture losses are reduced in comparison with products with cut surfaces (fish fillets, hamburger patties, for example). Proper freezer design for a given product is an important factor in minimizing moisture loss during freezing.

In most foods frozen commercially, water is the major component. Most of the water in the tissue dissolves soluble cell components, while a small part is bound up in hydrates and in macromolecular colloidal complexes. In addition, much of the aqueous solution is part of the gel-like or fiber-like structures in the cell. The most obvious change that occurs on freezing is the solidification of water, which means that water is removed from its normal position within the tissues. It appears that removal of water from its normal position is only partly reversible upon thawing, leading to “drip” and other changes. “Drip” is the exudate from thawed tissue which is difficult in practice to distinguish from any superficial moisture or “glaze.” Freezing is an excellent process for keeping the original quality of foods, such as fish, for longer periods of time. Freezing preservation is also applied in a number of different products made from various fish species.

Measuring

Measurement is defined as the assignment of numbers to objects according to rules. This definition applies to the measurement of both the physical and psychological attributes of objects, and by extension, to their sensory, cognitive and emotional dimensions. The most rudimentary form of measurement is nominal measurement. It refers to the use of numbers to name objects. The second level of mathematical measurement is ordinal measurement. Ordinal measurement is used in consumer sensory testing when food samples are compared or ranked for preference. These tests are conducted only when a crude measure of the differences among test samples is needed. Most of sensory science, whether consumer or non-consumer oriented, has come to rely on the

last two levels of mathematical measurement — interval and ratio measurement. Interval scaling refers to the measurement of objects in such a way that the differences between adjoining numbers on the scale represent equal intervals along the dimension being measured. Common interval scales include the Fahrenheit and Celsius scales of temperature and the 9-pt hedonic scale for assessing food liking/disliking. Ratios scales represent the highest level of mathematical measurement and are defined by the fact that the ratios among the numbers reflect the ratios of the magnitudes among the test objects. Ratio scales require a true zero point. Neither the Fahrenheit nor Celsius scales of temperature are ratio scales, because the zeroes on these scales do not represent a true absence of thermal energy. Common ratio scales include metric measurements of line length, the Kelvin scale of temperature, and, in sensory science, magnitude estimation and labeled magnitude scales.

Chemical and Physical Aspects of Colour in Frozen Muscle-Based Foods

One of the most important quality attributes of many foods is colour. Colour is correlated with aspects of quality and disagreement may occur between buyer and seller. It is not surprising that the measurement of colour has become an area of much interest and practical importance. Colour properties and their measurement are critical quality control parameters. The quality of food products as perceived by humans is very difficult to describe and quantify as it is usually a function of several food properties including colour, which is affected by most of the technological processes involved in the manufacture of foodstuffs. Freezing is one such process and many problems are associated with the maintenance of the colour of frozen foods. The effects of freezing and frozen storage on the final colour of muscle-based food (meat, fish, shellfish and their products). Frozen storage is an important preservation method for muscle-based foods. Freezing offers advantages in terms of a long storage life and allows better control of production levels. Freezing and frozen storage can have marked effects on the structural and chemical properties of muscle foods, including changes in the muscle fibres, lipids and proteins, all of which have the potential for significantly influencing final quality attributes, especially colour. Quality deteriorates during

freezing and frozen storage due to the osmotic removal of water, protein denaturation and mechanical damage. The colour of muscle-based foods at the retail level exerts a strong influence on consumer purchasing decisions, and the most important factor in determining retail selection. Most of the frozen muscle-based foods are sold in cool or warm fluorescent illumination on a gondola, where different types of processing, e.g. glazing, and packaging are evident. However, to avoid colour damage especially in beef, the type of light used should be warm fluorescent light, which shows an excellent colour spectrum and has no adverse effect on meat pigments. Some types of product, especially fish and shellfish, are not sufficiently protected from the action of light and oxygen, and may show surface discoloration during frozen storage, for which reason they are packed in vacuum, in gas permeable packages or in modified atmospheres.

Food Packaging: Plastics

Use of plastics as packaging materials has grown rapidly during the last several decades. The development of new plastic resins and the combination of resins in multilayer structures has allowed plastics to substitute for glass and metal, in particular, in a variety of applications. Such changes generally result in smaller and lighter packages that take less space and consume less energy in manufacture, storage, and distribution. Plastics have also substituted for paper in a significant number of applications. A combination of paper and plastics, sometimes with aluminum foil has replaced glass or metal. The area of flexible packaging has been a major source of growth for the use of plastics. Plastics are certainly not confined to such uses. Plastic is used in crates, boxes, and trays where it usually substitutes for corrugated board, and in pallets where it substitutes for wood. Plastic bottles, drums, and other containers are widely used. The use of plastics for food packaging, and our concentration therefore will be on the primary package — the package that directly contacts the food. The properties and food-related uses of some of the major packaging plastics. Common plastics additives will be covered briefly. The major processing methods for forming plastic resins into food packages will also be described. For many food products, the barrier ability of the package, especially to water and oxygen, is critical, and package permeability and its relationship to product shelf life.

Paper and Paperboard Packaging

Various materials, functions, forms, and technologies of food packaging are used to protect and maintain product quality during shipping and storage. Recent concern on food safety, health, and resources conservation are evident ever before. Paper and paperboard are made of fibers from renewable, environmental resources. The characteristics of paper and paperboard most relevant to food packaging applications. Paper and paperboard are made of fibers from easily obtained natural, renewable resources such as wood or vegetable fibers. They are useful for packaging, writing, and a variety of other purposes. There is no distinct difference between paper and paperboard. Paperboard has characteristics of thick caliper. They are pliable, relatively low cost, easy to convert into various shapes, recyclable, biodegradable, and eco-friendly materials. Depending on purpose of packaging, paper and paperboard can withstand conditions of high and low temperatures which are experienced by sterilized food and frozen or chilled foods. Excellent printability and glueability are required for certain purposes. The various advantages of paper and paperboard, they have certain disadvantages such as easiness to burn, and weakness to water, which can be controlled to a certain extent. Modify properties of paper and paperboard various additives are added to paper or they are laminated with other materials. Various materials for packaging are used as the science, technology, and machineries are developed, because the packaging market is changing very rapidly. Convenient, high quality, and safe packaging is sought. Share of paper and paperboard in packaging material consumption is about 40% which is higher than plastic, metal, and glass materials. With growing concerns on environment, recyclability of paper and paperboard packaging materials appeals to customers. Properties can be controlled by changing raw materials, adding additives, and modifying papermaking processes, or using converting machines depending on purposes.

Frozen Food Packaging

The basic functions of the package are to contain the food, protect the food, provide convenience, and convey product information. The package protects the food against physical, chemical, and biological damages. It also acts as a physical barrier to moisture, oxygen, volatile compounds, and microorganisms that are detrimental to the food. The package provides the consumer with convenient features such as microwavability, resealability, single serving, and ease of use. The package conveys useful information such as product contents, nutritional values, and preparation instructions. All these functions are applicable to the packaging of frozen foods. The food package can function best when integrated into a food packaging system, which involves certain physical components and operations. The major physical components are the food, the package, and the environment. It is useful to divide the environment into internal and external. The internal environment refers to the conditions inside the package, which contains the food product and in many cases some air space. The external environment refers to the conditions outside the package, and it depends on the storage and distribution of the food package. The operations are the manufacturing, distribution, and disposal of the food package. In designing the food packaging system, these physical components and operations must be considered to prevent over-packaging or under-packaging, which results in higher costs, lower quality and in some cases, health risks. There are several requirements in the selection of packaging materials for frozen foods: temperature stability, barrier properties, thermal insulation properties, consumer appeal, and machine compatibility. Temperature stability is necessary since the packaging materials must be able to withstand the abuses encountered over a broad range of temperatures, including freezer temperatures during transportation and storage as well as high temperatures during the heating of the food package in the microwave or conventional oven. Barrier properties are necessary to minimize deteriorative effects of moisture, oxygen, and light to the food product. Thermal insulation helps maintain low temperatures for frozen foods during distribution, and minimize temperature fluctuations which may cause degradation of the products. Frozen food packages are typically made using carton machines, form-fill-seal machines, and pouch-forming machines.

Assignment for FTech 307 Physical Properties of Foods and Food Processing Systems

Viscometer Selection

Simple viscometers can be constructed very cheaply, e.g. using a length of capillary tube, a few small metal spheres and a clear tube (even from laboratory filter funnels); there is no reason why such viscometers should not be reasonably accurate (certainly for quality control purposes), but they might not be quick to use. At slightly more expense, but still relatively cheap, are the U-tube capillary flow viscometers. Each viscometer has a narrow measuring range, but within that range they are very accurate. Several U-tube viscometers would be required to cover the viscosities of typical food materials. Rotational viscometers are much more expensive but, at the cheaper end of the range, the Brookfield viscometer is extremely useful and popular. As the viscometer became more sophisticated, it became possible to program them, and to take a fluid through a shear stress-shear rate cycle, to increase or decrease the shear rate at fixed rates or to hold at a constant shear rate for a fixed time.

Viscosity Data

The viscosity characteristics of some of the major classes of fluid foodstuffs (namely dairy products, oils and fats and sugar solutions), and materials that are used in food formulations (such as hydrocolloids and proteins).

(1) Milk and milk products

Milk is an interesting colloidal system; it consists of an aqueous phase containing lactose, minerals, soluble proteins (whey proteins), water-soluble vitamins and trace elements. Dispersed in the aqueous phase as very small droplets or globules is a fat phase. The characteristic milky appearance is due to a colloidal dispersion of milk protein (casein) and calcium in the solution. Milk from

a particular species can show a considerable fluctuation in composition from animal to animal and from season to season. Ordinary cows' milk contains about 3.8% fat and 3.3% protein (2.6% casein). As such, the dynamic viscosity of full-cream milk is of the order of 2×10^{-2} (2 cP) at 20 °C and under moderate conditions of shear it acts as a Newtonian fluid. Milk can be processed by a variety of techniques to prolong its shelf-life and to convert it to milk-based products. Most processing techniques may alter the condition of one or both of the dispersed and aqueous phases, and the dynamic viscosity. Heat treatment of milk normally gives a slight increase in the viscosity, because of the denaturation of whey proteins. Homogenization will increase the viscosity of full-cream milk by up to 15%. Milk is to be sterilized or UHT treated will require homogenization to prevent fat separation during storage. Some pasteurized milk is also homogenized. Homogenization appears to give the milk a creamier mouth feel. Cream products also require homogenization. Single cream (18% fat) undergoes considerable homogenization (up to 200 bar) to improve the consistency and to give the cream some body. Whipping cream (35% fat) requires very little, or no, homogenization and appears to have a runny consistency before it is whipped; homogenization would impair the whipping behaviour of the cream. Double cream (48% fat) requires a low homogenization pressure (around 30 bar); if the homogenization pressure is too high, the cream may well solidify in the pack. The rheology of cream products is extremely complicated and the final viscosity of the cream will depend upon such factors as the separation temperature, fat content, heat treatment, rate of cooling and storage conditions. Skim-milk, full-cream milk and cheese whey are evaporated to as high a solids content as possible, prior to spray drying. The final concentration may be limited by either the viscosity of the feed or the solubility limits of lactose. Such fluids can be concentrated by membrane techniques such as reverse osmosis and ultrafiltration. The extent of the concentration is governed by the viscosity characteristics of the concentrate. Any process that results in the souring of milk normally increases the viscosity of the product.

(2) Oils and fats

Oils and fats are essentially esters of glycerol and fatty acids, derived from plant and animal sources. Different oils will have different fatty acid compositions and different viscosities. Oils are normally liquid at ambient temperature; fats are normally solid. Oils are more viscous than aqueous solutions. The viscosity will increase as the amount of long-chain fatty acids increase and as the degree of saturation increases. Thus, hydrogenation will increase the viscosity. Viscosity is not one of the physical tests that is used to characterize an oil, but the viscosity will be important when processing oils and fats. The viscosities of the major saturated fatty acids and their methyl and ethyl esters, and some of the more common triglycerides.

(3) Sugar solutions

There are a whole range of sugar solutions available to the food processor. The viscosity characteristics of single sugars depend upon the temperature and the concentration. As the temperature decreases and the solids content increases, the viscosity will increase. For corn syrups, high-fructose corn syrups and invert sugar solutions, an extra factor affecting the viscosity is the degree of conversion or inversion. Most of these fluids were pseudoplastic at high concentrations. There is now interest in glucose-galactose syrups, obtained from hydrolysis of lactose.

(4) Hydrocolloids

Hydrocolloids are polymeric materials that are soluble or dispersible in water. They are usually added to food formulations to increase their viscosity or to obtain a gelled consistency. Many of them form gels at relatively low concentrations. They are derived from a wide variety of plant or animal sources, or by the process of fermentation. Many of these hydrocolloids can be modified chemically or enzymatically to control their thickening action and are available in a wide variety of grades. The hydration time can be quite significant for some materials; for example, a 1% guar gum solution will take over 24 h to reach its

maximum or near-maximum viscosity. The viscosity of many hydrocolloids may be affected by the pH of the medium and the presence of substances such as salts, sugars and proteins. The quantity of hydrocolloid required to obtain a viscosity of 100 CP. The gelling behaviour of compounds such as agar, pectins, alginates and starches. Proteins form a special class of polymeric material. The flow behaviour of dilute and concentrated proteins in solution depends upon pH, ionic strength and temperature (as is the case for many of the hydrocolloids).

Some Sensory Aspects

It becomes necessary to distinguish between solid and liquid food. For liquids and semi-liquids describe mouth-feel sensation in terms of viscosity or consistency, whereas for solids use the term texture. It has been suggested that a convenient division is the force due to gravity. If an object flows under the influence of gravity, it is a liquid; if not, it is a solid. This does raise a difficulty with a plastic material, for which it will be necessary to classify it both below and above its yield shear stress. Many forms of viscosity measurement are used as a quality control checks for different products. If the consumer cannot distinguish between the mouth feel of two batches of a product that appear to give different instrumental readings, the instrumental measurement loses some of its validity as a quality assurance measurement. A wide variety of fluids with known shear stresses and shear rate characteristics and used these with sensory assessors to see whether they are capable of distinguishing between the fluids by testing, pouring and stirring. People can distinguish between different fluids, by a sensory measurement, if the flow characteristics are known.

Objective Texture Measurement: Empirical Testing

The two major types are force- and distance-measuring equipment. Force-measuring equipment measures the force required to puncture, crush, deform or extrude a food. Distance-measuring equipment, the material is subjected to a constant force and the deformation is measured. One of the most widely used instruments in this category is the cone penetrometer.

(1) Penetrometer

The penetrometer is a reasonably simple device for measuring the distance that a cone or rod penetrates into a food, in a fixed time. In its simplest form the cone C is positioned on the surface S of the food and is then released for a fixed time. At the end of the time the probe is clamped C1 and the penetration depth is measured using a dial gauge D. The penetration depth will depend upon the weight of the cone and the angle, the type of the material, its temperature and the penetration time. Experimental conditions should be uniform throughout. For materials such as butter and margarine, several readings should be taken at different positions on the surface of the sample to minimize deviations which arise because the samples are not homogeneous. The penetrometer has been found to be extremely useful for assessing the yield stress of plastic materials, such as butter, margarine and similar spreads.

(2) Extrusion and extruders

In extrusion, the force required to extrude a material through a small orifice or an annulus is determined. The thrust required to extrude the material is recorded on a moving chart throughout the test, and this chart serves as a record of the firmness and various other rheological properties of the material. The force required to extrude the material is measured by a series of interchangeable leaf springs. When the instrument is switched on, the carriage starts to move and causes a deflection of the spring via the thrust rod. This produces a gradual linear increase in the thrust on the piston, which is shown as a sloping straight line. Thrust is a sum of the forces required to overcome the frictional resistance between the plug of material and the wall of the sample cylinder and the pressure required to force the material through the orifice. For edible fats the extruder thrust has been found to correlate very closely with subjective assessments by a

skilled taste panel of the 'spreadability' of the fat and to correlate inversely with the subject assessment of firmness. Extruder friction can be regarded as a measure of 'stickiness' and will be a useful measure for some materials. Many of the more sophisticated instruments, such as the Instron machine also have extrusion units as one of the test principles.

(3) General Foods texturometer

The instrument is designed to simulate the mastication process. The food is compressed twice, simulating the first two bites, by pushing a plunger a standard distance, usually 35 mm into the food and measuring the force exerted. There are two mastication speeds, and bite-size objects are used. The major parameters measured are hardness, cohesiveness, adhesiveness and crispness. Typical response curves for a perfect elastic food, a retarded elasticity and a brittle and fracturable food.

(4) Instron universal testing machine

The Instron machine is used for a wide variety of materials for studying stress-strain relationships by either compressing or stretching. It can also be used for more sophisticated tests, such as hysteresis stress relaxation, stress recovery, strain rate sensitivity and rupture, and to assess the energy required for deformation. With food materials it is usually used in the compressive mode. It consists of a drive unit, which drives a horizontal cross-unit in a vertical direction, and a force-sensing and recording system consisting of a series of interchangeable load cells, the output from which is fed to a chart recorder. The load cell can be attached either to the moving cross-head or to the fixed base. A wide variety of test principles are available, e.g. puncture, snap, extrusion and deformation. When the load cell is attached to the moving cross-head, the moving part of the test cell is also attached to the cross-head and the fixed part of the test cell to the base. The use of the Instron machine for a wide variety of foods, together with the most appropriate testing conditions, in a very comprehensive table. The most important parameter used for characterization was the maximum plateau force. Bananas were measured using deformation, apple slices using puncture and chocolate bars using snap. All these conditions could be recorded, together with environmental conditions such as temperature and relative humidity (for hygroscopic materials).

(5) Other instrumental methods

Texture profile analysis involves quantifying a number of different parameters from the stress-strain curves obtained in one test. The general foods texturometer has been used to evaluate hardness, fracturability, cohesiveness and the Instron machine to assess fracturability, hardness, stringiness and springiness. A wide variety of empirical equipment is available, which makes use of the basic test principles of penetration, shear, compressing extrusion, flow and mixing. One instrument worthy of note is the tender-ometer. This measures the force required to crush peas and similar agricultural produce and is widely used to determine the maturity of the crop. The tender-ometer reading affects whether the peas are used for freezing, canning and dehydration and also the price paid to the producer by the food processor.

Size Reduction and Grinding

Size reduction is a very important operation in food processing, its main effect being to reduce the size and to increase the surface-area-to-volume ratio. This will help to increase the rate of diffusion processes which occur in dehydration and solvent extraction. It is commonly used as a pre-treatment operation for raw materials prior to canning, freezing and dehydration or for the production of finer powders which are more easily handled or transported. The effectiveness of a size reduction operation can be assessed by particle size analysis, using sieves, microscopy or more recently a Coulter counter which detects a change in impedance due to the small particles. Results are normally presented as a distribution of particle sizes. It may be necessary to define criteria for the grinding process. A combination of grinding and some separation technique may be necessary to achieve the final objective. Air classification is a technique which is currently being investigated for separating powders, based on their particle size and density. The type of equipment used will depend upon the nature of the material, particularly its rheological properties, and the size reduction required. The cost of the grinding operation will depend very much on the final particle size.

Expression

Expression is the act of expelling a liquid from a solid, either by squeezing or by compaction. It is used for a variety of purposes such as recovering fruit and vegetable juices, recovering oil from seeds and consolidating cheese by removal of the whey. Expression processes can be either batch or continuous, and their efficiency is monitored by the yield and solids content of the liquid obtained. Expression can be divided into an induction period, during which the air is expelled from the press cake pores and the pores gradually fill with exuded liquid and an outflow period. Some of the factors which affect the rate of expression, such as the properties of the cake, e.g. its particle size distribution and degree of compaction, and the pressure drop over the cake which depends upon the applied pressure.

Temperature Effects

The surface tensions of most liquids decrease as the temperature increases and, at temperatures not too near the critical temperature, the relationship is almost linear. In the region of the critical temperature, the surface tension value becomes very low, as the intermolecular cohesive forces approach zero. Some surface tension values for ethyl alcohol and water over the temperature range 0-30°C. An almost linear relationship between surface tension and temperature for most oils and fatty acids, with surface tension decreasing as temperature increases. One relationship, known as the Ramsay-Shields equation is as follows:

$$\gamma \frac{M}{\rho} = k (T_c - T - 6)$$

where γ is the surface tension; M is the molecular weight; T is the experimental temperature; ρ is the density; k is the Eotvos constant and T_c is the critical temperature.

Methods for Measuring Surface Tension

There are many methods for determining surface tension.

- Direct measurement of capillary pull
- Capillary rise, in single tubes, differential tubes, parallel or inclined plates.
- Bubble pressure
- Size of drops (volume or weight).
- Shape of drops or bubbles.
- Dynamic methods (ripples, etc).

'Scrupulous cleanliness is essential in surface tension work; aqueous solutions in particular are highly susceptible to contamination by minute traces of grease or detergent with large reduction in their surface tension.

(1) Capillary rise

When a capillary tube is immersed in water vertically, with one end touching the water, the water rises in the tube to a height above the surface, the narrower the tube, the greater is the height h to which the water rises. This phenomenon is known as capillarity; it is commonly observed in most porous materials, e.g. ink soaking into blotting paper, or water soaking into porous solids as in the reconstitution of freeze-dried foods. The angle between the tangent to the surface of a liquid at the point of contact with a surface, and the surface itself, is known as the angle of contact. For water in contact with clean glass the angle of contact is 0° ; for dirty glass it may be as high as 8° . The angle of contact between clean glass and most other aqueous fluids and alcohol is also 0° . When equilibrium is achieved, the upward forces of surface tension acting round the circumference of the fluid balance the downward forces due to the height of the column of liquid.

(2) Bubble methods

The forces acting on air bubbles in a liquid, it can be seen that contraction or enlargement is prevented by the forces acting on the bubble, which are due to the liquid pressure P_1 plus the surface tension forces acting to reduce the size of

the bubble, whereas the force due to the internal pressure P_2 acts to increase the size of the bubble. There is an excess pressure within the air bubble. The magnitude of the excess pressure depends directly upon the surface tension and inversely on the size of the bubble. Such forces are important in foaming and aeration of liquids. If the bubble is in the form of a film e.g. a soap bubble. Water is supplied to a large container C, thereby slowly displacing air from that container. This air is directed to a piece of glass capillary tubing T, that is immersed below the surface of the test liquid. A manometer M is incorporated into the air line (normally rubber tubing) to measure the pressure of the air (i.e. the pressure in the bubble during its formation and bursting). The water rate is regulated to give a slow but steady stream of air bubbles. The maximum pressure is recorded just as the bubble breaks away from the tubing (it should be noted that the manometer reading will fluctuate; it should not be too difficult to read the maximum pressure recorded). The theory applies to a static situation rather than to a dynamic situation, as occurs during bubble formation. The largest source of error will be in the measurement of the internal bubble pressure. The use of an inclined-tube manometer or pressure transducer may help to improve this. It is an extremely useful technique for comparing the surface tension of liquids or examining the effect of temperature on the surface tension.

(3) Drop weight techniques

The simplest drop-weight technique relies upon measuring the volume or mass of a droplet as it forms at the end of a capillary tube. The mass of the drop is directly related to the surface tension of the liquid. The drops should be allowed to form very slowly and normally five, ten or twenty drops are collected and their masses determined, on the assumption that the drop has a cylindrical form, i.e. no spreading takes place when it is about to break away. The drop will spread over the tube and there may be advantages in measuring the external radius, particularly if the tube wall is thick. The use of very simple equipment but, provided that sufficient care is taken, accurate results can be obtained for the surface tension of liquids.

(4) Direct measurement of capillary pull

The surface tension of a liquid can be determined quickly and with sufficient accuracy by measuring the force F required to detach a horizontal platinum wire ring or a microscope slide from the surface of a liquid. The force F required to tear the slide from the surface is determined by using masses. If the length of the slide is l and its width is b and the force required is mg , then $mg = 2\gamma(l+b)$. For tearing a ring from the surface of a liquid, the force should be equal to twice the perimeter of the ring multiplied by the surface tension.

Heat or Energy Balances

The law of conservation of energy will be used in the form of a heat or energy balance. If steam is being used to heat water, the energy balance states that

$$\text{heat lost by the steam} = \text{heat gained by the water}$$

Such balances enable the quantity of steam, hot water, chilled water, hot air or refrigerant to be evaluated. Other thermal properties of importance, such as specific heat, latent heat, thermal conductivity and thermal diffusivity.

Energy Value of Food

Food contains energy which is utilized by the body for performing useful work, keeping it warm and producing further cell and body tissue to replace that which is lost. This energy is released during the oxidation of food as it is broken down in the body. The energy content of food, which is currently of great concern to people, is expressed in terms of its calorific value. The gross energy value of a food can be determined using an adiabatic bomb calorimeter. The food is burnt in oxygen in a container of constant volume, and all the heat liberated is adsorbed by water; the heat losses to the surroundings are zero. The amount of heat q evolved is determined from the product of the mass of water, its temperature rise and its specific heat. This value is also called the heat of combustion or the internal

energy change. The maximum temperature is used as a measure of the heat evolved and the bomb is calibrated with standards of known energy content, such as butter fat, benzoic acid, sucrose and urea. The amount of energy available for use by the body is known as the metabolizable energy. It is less than the gross energy value because certain substances are not adsorbed and are excreted in the faeces, e.g. some unavailable carbohydrate, or even when adsorbed are not completely converted to carbon dioxide and water and are excreted in the urine.

$$\begin{aligned} (\text{Metabolizable energy}) = & (\text{gross energy intake}) - (\text{energy excreted in faeces}) - \\ & - (\text{Energy excreted in urine}) \end{aligned}$$

The basal metabolic rate is a measure of the energy requirement of the body at rest and is the energy required for maintaining the body at 37 °C and for the activity of internal organs. The basal metabolic rates for different species of animals are the same, when calculated on the basis of body surface area. The basic laws of energy conservation apply in nutrition. If energy intake exceeds energy utilization, the excess energy will accumulate and be stored as fat. For a person of stable weight, energy expenditure will equal energy supplied by the food.

Energy Conservation in Food Processing

Most sectors of the food industry to examine energy utilization, with a view to saving energy because most processing operations are energy intensive. Energy conservation starts even at the design stage in terms of both selecting the process and ensuring that energy recovery systems are incorporated. There is an approximate inverse relationship between capital costs and energy costs, i.e. the more money invested, the lower are the energy requirements. For a given flow rate, the energy costs decrease as the pipe diameter increases but capital costs increase. The economic pipe diameter is calculated as the size which minimizes the total pumping costs (capital plus energy), over the plant operating life. Such economic balances are commonplace in most food engineering operations.

Equipment should be properly installed, all heating and cooling systems should be correctly lagged, and provision should be made to recycle steam condensate and to re-use waste heat. In heating and cooling operations, it is far more energy efficient to use continuous rather than batch processes. Modern continuous heat exchangers operate at high regeneration efficiencies (up to 95%), resulting in savings in heating and refrigeration. In canning processes, considerable heat is lost as non-condensed steam during retorting. Savings can be made by using recirculating hot water as the heating medium and by insulating the retorts. Heat transfer rates may be slightly reduced compared with steam. The thermal efficiency is improved by increasing the inlet air temperature. This is limited as high temperatures may scorch the product. The outlet temperature is controlled at about 95 °C. If it falls below this, the final powder becomes too wet. If it rises too much above this, energy is wasted. The exit air temperature should be as low as possible, commensurate with the product being sufficiently dry. Efficiency can be increased by recovering the heat from the air, either by an indirect exchanger (used to heat incoming air) or by wet scrubbing, where the air is contacted with the incoming concentrate. This serves two functions: it prewarms the concentrate and removes fine powder from the air stream. Energy economy in low-temperature processes is attained by ensuring that the compression conditions are correct and by regular maintenance and inspection, e.g. checking the insulation, avoiding the build-up of ice in the evaporator. The cost of storing frozen foods for long periods should be taken into account when comparing the economics of freezing with canning or dehydration. Heat pumps are used widely for abstracting waste heat and provide a means for utilizing 'low-grade' energy. They are extremely useful when both heating and cooling are required. The energy removed when foods are chilled or frozen is used for space heating or producing hot water. Alternatively, warm chilled water leaving a cooler can be re-cooled and the energy removed used for heating purposes elsewhere. The energy costs involved in cleaning and sanitizing need attention with particular reference to operating temperatures, flow rates, times and detergent strengths. Energy can be recovered from agricultural waste products by fermentation, e.g. the production of protein from a wide variety of low-grade carbohydrate sources, or by production of methane by anaerobic fermentation of organic matter. A wide variety of literature is available in food and agricultural biotechnology. Alternative or 'free' energy sources have been widely investigated; sun drying has been

practiced for centuries. Solar energy is now widely used for domestic heating, cooking, evaporation and dehydration processes. Other 'free' energy sources include wind, tidal and hydroelectric power.

Thermodynamic Terms

Some of the terms used in food-processing operations are discussed below.

Systems and surroundings: One common system encountered in thermodynamics is that of a gas enclosed in a cylinder by a piston. The gas itself is the system; anything external to the system is termed the surroundings. This implies the existence of a boundary, separating the system from the surroundings; in this case the boundary is the cylinder wall. The gas contained within the system will have certain fixed thermodynamic properties, i.e. temperature, pressure, volume, internal energy, etc.

Adiabatic and isothermal processes: If the temperature of the system is kept constant (consider the gas in the cylinder), the process is known as isothermal. If the gas is being compressed, i.e. gaining internal energy, then heat will need to be removed to keep the temperature constant. An isothermal compression will result in the transfer of energy across the boundary. If no energy crosses the boundary, the process is known as adiabatic. All the work of compression goes towards increasing the internal energy of the system.

Reversible and irreversible processes: Most simple thermodynamics are concerned with reversible changes. A reversible change can be defined as a 'change taking place such that the properties hardly change by more than an infinitesimal amount from one instance to another'. This implies a very slow compression or expansion. In practice, most changes are irreversible. Any changes involving the loss of frictional heat are irreversible.

Entropy and the Second Law of Thermodynamics

Entropy is one of the most difficult of the thermodynamic properties to understand. It can be regarded as a measure of the order or disorder of a system and is based on statistical mechanics. A system is regarded as being highly ordered if it is possible to predict the exact location of individual molecules comprising that system. As this becomes more difficult to do, the system becomes more disordered. From the solid state through the liquid state to the vapour state, the disorder increases and the entropy is said to increase:

solid \longrightarrow liquid \longrightarrow gas

Most solids have a regular rigid structure. As the solid melts, the molecules become more mobile and their position less easily predictable. The liquid remains confined within its boundaries or surfaces. A further input of energy will convert the liquid into a gas; here there are no boundaries and it has become extremely difficult to predict the location of an individual molecule.

Evaporation Design

In an evaporator, steam is used to bring a liquid to its boiling point and then to vaporize the water. The heat exchange section is known as the calandria A. The mixture of liquid and vapour passes into a separator B where water vapour is withdrawn at the top and condensed. The evaporation may well operate under vacuum conditions, and the concentrate is either removed or evaporated further in the same or another unit. The total heat requirement Q is given by

$$Q = \begin{array}{l} \text{(heat required to bring feed} \\ \text{to boiling point)} \end{array} + \begin{array}{l} \text{(heat required to cause} \\ \text{evaporation)} \end{array}$$

The sensible heat change is generally low compared with the latent heat change, and particularly so on modern evaporators where the feed is generally pre-heated, almost to its boiling point, prior to entering the main evaporation section. Heat is provided by the steam described by the heat balance:

$$\text{heat lost by steam} = \text{heat required for evaporation}$$

Therefore, a simple evaporator requires approximately 1 kg of steam for every 1 kg of water removed. Energy economy is achieved by multiple-effect evaporation and recompression of the exhaust steam, by either steam ejectors or mechanical compression. Other examples involving evaporation or condensation are in the use of refrigerants for abstracting heat from foods. One problem encountered when concentrating fruit juices is the loss of volatile components which contribute to the flavour. These volatile components would be lost if only a water condenser is used. They can be recovered by a refrigerated condensing system operating at much lower temperatures; they form the basis of natural fruit flavours and can be added back to the concentrate. There are many types of evaporator design available. The quality of the product will depend upon the evaporation temperature and the residence time. Temperatures range from 40 °C to 100 °C whereas residence times can be as short as several seconds to several hours for some batch processes.

Heat Transfer by Radiation

The nature of this radiation will depend upon the nature of the substance and its temperature. This radiation will travel through a vacuum at the speed of light; on contacting a further object, this radiation will be reflected, transmitted or absorbed. Only radiation that is absorbed will impart its energy and cause a temperature change.

Characteristics of electromagnetic radiation: Electromagnetic radiation consists of an electric and magnetic field mutually at right angles; these are normally in phase although they may be out of phase at the source. Both fields vary sinusoidally with time and distance. All electromagnetic radiation travels at the speed of light in a vacuum. The type of radiation is characterized by its wavelength λ or its frequency f . The relationship between these is

$$\text{frequency} \times \text{wavelength} = \text{velocity of light}$$

$$f \lambda = c$$

As the frequency increases, the energy per photon increases and the radiation becomes more harmful and dangerous to health. Electromagnetic radiation consists of a stream of photons, which are considered to have zero rest mass but

contain energy and momentum. These photons interact with matter and may possess sufficient energy to be lethal to living tissue, to break chemical bonds, to give rise to fluorescence or to eject electrons.

Radiation Emitted from Heated Surfaces

The amount of energy emitted at a whole series of discrete wavelengths is measured. The total energy emitted at a particular temperature is given by the area under the curve. As the temperature is raised, two important things happen: firstly, more energy is emitted and, secondly, the distribution of energy about its wavelength changes, with a shift of the maximum f_{max} towards the ultraviolet. This is also the temperature on the surface of the Sun with the Sun providing us with our major source of radiant energy. The radiant energy from the Sun consists approximately of 48% infrared, 40% visible and 12% ultraviolet. Much of the ultraviolet is filtered out in the ozone layer in the upper atmosphere. Solar heating is now becoming a very important source of 'free' energy. Solar energy is converted to thermal energy (hot water) by means of a collector. Collection efficiencies greater than 50% are now commonplace. Solar energy is used for evaporation, drying, cooking and many other operations.

RADIO-FREQUENCY WAVES

(1) Microwave and dielectric heating

The heating effects brought about by microwaves and macrowaves. Both these are types of electromagnetic radiation of long wavelength, in the radio-frequency range. To avoid interfering with the radio network, it has been agreed that manufacturers of commercial equipment are permitted to use the frequencies. The distinction between macrowave and dielectric heating is solely in the wavelength of the incident radiation (note that the frequency multiplied by the wavelength equals the velocity of light). Radio-frequency waves are generated in a device known as an applicator by means of a magnetron. The waves are transferred to the food which is placed in a cavity (oven) by means of waveguides. These waveguides are aluminium tubes along which the waves are internally

reflected. The food is placed within the cavity, and energy that is actually adsorbed by the food brings about a rise in temperature. If the electric field within the cavity is not uniform, uneven heating may occur. A more even distribution of the field is achieved either by using a metal fan which reflects the radiation randomly or by moving the food through the variable field by putting it on a turntable. Radiation is reflected by the walls of the cavity which do not rise in temperature, making the oven very efficient. Since microwaves are very effective at heating biological tissue, leaking radiation can be hazardous to the operators; particularly vulnerable are the eyes since the blood supply is too low to provide sufficient cooling. Microwave ovens should be checked periodically to ensure that there is no leakage, although microwave ovens which are currently available are safe and reliable.

(2)Absorption of microwave energy

It is necessary to examine how microwave radiation is adsorbed by a food material. Microwave radiation which is incident on one surface only. As the wave passes through the food, it is attenuated, i.e. it loses energy. It is this energy which is converted to heat, at the point where the energy is lost. Any temperature gradients that develop within the food are eliminated by normal processes of conduction and/or convection. Firstly, hardly any of the power is absorbed, with no consequent heating effect (this is almost typical of the reaction between microwaves and frozen food). Conversely, all the energy is absorbed very near the surface. In this situation, surface heating effects will predominate and the wave will hardly penetrate the food; this is the situation with most infrared heaters and conventional cooking processes. For uniform even heating throughout the food, there should be a linear decrease in power as the wave penetrates into the food. The mechanism by which energy is produced depends very much on the presence of polar molecules, particularly water, within the food. The water molecule contains a dipole moment, i.e. one end is positively charged and the other end negatively charged. Thus, in a rapid oscillating field, the molecule will vibrate in an attempt to align itself with the field; the dipole rotation results in the formation of frictional heat which, together with some electrical resistance heating, produces a rise in temperature. The presence of liquid water within the food will be conducive towards such a heating effect. The rate of heating for any substance will depend upon the amount of energy absorbed and its specific heat value. The

amount of power absorbed by a food will increase as the frequency of the radiation, the field strength and the loss factor increase. Normally the field strength and the frequency are fixed in a microwave heater. The dielectric loss factor is the important physical property of the food which will affect the amount of radiation adsorbed. Materials with a high dielectric loss factor are termed lossy materials and are very suitable for microwave heating. The loss factor has in turn been found to be dependent upon the frequency of the radiation and the temperature. The dielectric loss factor for three foods at different temperatures. Above the freezing point the loss factor for cooked ham increases as temperature increases, for raw beef there is no change, whereas the value for distilled water decreases as temperature increases. The dielectric loss factor is affected by moisture content. This will be important when using microwaves in dehydration processes. Frozen foods absorb microwave energy poorly and, when one defrosts food too quickly, run-away heating may occur. This happens when parts of the food which melt first then preferentially absorb energy and get very hot, whilst other areas remain frozen. To a limited extent, this can be overcome by subjecting the food to intermittent doses of energy, thereby giving the food time to equilibrate during the rest period. Microwaves offer a rapid means of heating and cooking materials and their use has been suggested in a wide range of food-processing operations, being extremely useful for catering operations. The principles and uses of microwaves and their effects on micro-organisms and food quality.

Irradiation

One way of preserving the shelf-life of foods is to subject the food to high frequency radiation, namely X-rays and γ -rays or an electron beam. As well as killing organisms, such radiation will kill insects, prevent over-ripening of fruits and inhibit sprouting. Undesirable side reactions may take place, such as free radical reactions, oxidation, reduction and the darkening poly (vinyl chloride) and Cellophane films. Some of these reactions can lead to the production of substances that may be toxic or carcinogenic, and for this reason the safety of foods sterilized by irradiation has been questioned. There may well be consumer resistance to any food that is associated with radiation treatment, particularly

from the thought that the food might still be radioactive after treatment. The severity of the radiation treatment is expressed in terms of the number of radiological units ('rads') that the food is exposed to. As with heat treatment, the reduction in organisms follows first-order reaction kinetics, and so irradiation treatment is not an absolute form of sterilization. A dosage is selected to give a suitable reduction of the principle spoilage organisms (usually 12 decimal reductions for *Clostridium botulinum*). The potential advantage of irradiation sterilization of food is that the heating effect is negligible. Irradiation can be used to treat packaged materials, e.g. cans and flexible pouches, and there should be none of the heat transfer problems associated with viscous materials. *Clostridium botulinum* is very resistant to irradiation conditions. Although it is not the most heat resistant of the food spoilage organisms, it has been claimed to be one of the most resistant to radiation. A dosage of 4.8 Mrad has been recommended for achieving 12 decimal reductions for this organism. Such a dosage would adversely affect the flavour of the food and make it organoleptically unacceptable.

Dosage (Mrad)	Applications and Examples
2-6	Sterilization of foods in sealed containers
1	Decontamination of food ingredients, e.g. spices and powders
0.3-1.0	Pasteurization, extension of shelf-life, destruction of surface moulds, e.g. meat, poultry, fish and egg products, often combined with refrigeration
0.01-0.2	Extended storage of fruit, prevention of over-ripening, e.g. strawberries, mangoes and papaya
0.01-0.2	Control of insects, e.g. disinfection of grain
0.01-0.3	Inhibition of sprouting or growth, e.g. onions, potatoes, and carrots

Applications for irradiation treatment

Water in Food

The amount of water in food can be expressed on either a wet weight basis or a dry-weight basis as follows.

On a wet-mass basis,

$$\text{Moisture content } m = \frac{\text{mass of water}}{\text{mass of sample}} \times 100$$

The mass of sample can be made up of water and dry matter or solids.

$$\text{Moisture content } m = \frac{\text{mass of water}}{\text{mass of water} + \text{solids}} \times 100$$

On a dry-weight basis, moisture is calculated as

$$\text{Moisture } M = \frac{\text{mass of water}}{\text{mass of solids}}$$

A food with a moisture content of 80% will have a moisture value of 4 (or 4000%, as a percentage). Imagine that half the water originally present in this food is removed during a dehydration process. Moisture content (wet-weight basis) is most used in food composition tables, whereas moisture (dry-weight basis) is more often encountered with sorption isotherms and drying curves. The amount of water in a food is most easily determined by taking a representative sample of the food and drying it in an oven to constant mass. During dehydration processes, considerable moisture gradients will be established within the food.

Water Activity in Food

Water plays a very important part in the stability of fresh, frozen and dried foods; it acts as a solvent for chemical, microbiological and enzymatic reactions. Water activity a_w is a measure of the availability of water to participate in such reactions. The water in a food will exert a vapour pressure. The amount of pressure will depend upon the amount of water present, the temperature and the composition of the food. Food components will lower the water vapour pressure

to different extents, with salts and sugars being more effective than larger molecules such as starch and proteins. Therefore, two different foods with similar moisture contents may not necessarily exert the same vapour pressure and have the same water activity. Water activity is the ratio of the vapour pressure exerted by the food to the saturated vapour pressure of water at the same temperature.

$$a_w = \frac{\text{vapour pressure of water exerted by food}}{\text{saturated vapour pressure of water at the same temperature}}$$

The sorption isotherm is extremely useful because it also gives the relationship between the water activity and the water content. Thus, in a drying application, it is possible to evaluate the lowest possible moisture content attainable at specified conditions of temperature and relative humidity and the water activity of the dehydrated product. Oxidation reactions, browning reactions and enzymatic activity will occur at low moisture contents; the rate of oxidation goes through a minimum at an a_w value of 0.4, whereas the maximum browning rate occurs at about 0.6 a_w . Although most enzymes are inactive below 0.8 a_w , enzymatic activity can be observed down to very low water activity values. Most food systems are too concentrated for this to occur and a_w depressions are determined experimentally. Such compounds are known as humectants; examples of humectants are salt, sugar and polyhydric alcohols such as glycerol and sorbitol. Growth of micro-organisms can be inhibited by adding such substances to foods or by formulating foods with these ingredients, i.e. salting, curing and sugar preserves. Substances with strong water binding properties are useful in this respect. The water activities of foods containing various levels of sugar and salt. Foods with water activities in the range 0.6-0.9; such foods have been termed intermediate-moisture foods. Intermediate-moisture foods have a much reduced moisture content and a reasonably long shelf-life but are palatable without the need to rehydrate them.

Some typical water activity values for foods

aw	Food
0.98-1.00	Fresh vegetables, fruit, meat, fish, poultry, milk, cottage cheese
0.93-0.96	Cured meats, most cheese varieties
0.86-0.93	Salami, some dry cheeses
0.8-0.87	Flour, cakes, rice, beans, cereals, sweetened condensed milk
0.72-0.88	Intermediate moisture foods, jams, old salami
0.6-0.66	Dried fruits
0.6	Dehydrated foods

Hysteresis

In the determination of a sorption isotherm, different results may arise, depending on whether the test material is dry or fresh; such a phenomena is known as hysteresis. An adsorption isotherm (the starting material is dry food) and a desorption isotherm (the starting material is fresh or wet food) for raw chicken at 5 °C. For most foods the water content is higher when a particular a, value is achieved by desorption than absorption. If hysteresis does occur, the sorption isotherm most relevant to the situation should be selected. For example, for determining the equilibrium moisture content for a dehydrated food, the desorption isotherm should be selected. Another interesting deviation occurs with some sugars. Crystalline sucrose has a completely different sorption isotherm from that for amorphous sugar, with the equilibrium moisture content being much lower for the crystalline form at any water activity value. The amorphous form

often results when the food is dried quickly, e.g. spray drying. During storage, it may slowly revert to the crystalline form. If crystallization occurs during determination of the isotherm, a broken isotherm may result.

Frozen foods

When a food freezes, the ice which separates exerts a vapour pressure which depends only on its temperature. This is in equilibrium with the unfrozen water within the food. The water activity of the frozen food is as follows :

$$a_w = \frac{\text{vapour pressure of ice (or solution)}}{\text{saturated vapour pressure of water}}$$

The vapour pressures of ice and water at various temperatures below 0 °C.

SIMULTANEOUS HEAT AND MASS TRANSFER

In many processes, heat and mass transfer occur at the same time. One example is the evaporation of water from a free moisture surface. Energy is supplied from the air stream to provide latent heat energy for evaporation. Eventually the system comes to equilibrium and at steady state the rate of heat transfer to the surface and the rate of mass transfer away from the surface balance. It is assumed that the air is saturated with water vapour at the surface and the temperature at the surface equilibrates at the wet-bulb temperature. The rate of heat transfer can be a major resistance in operations where latent heat values are high, particularly in dehydration processes.

(1) Hot-air drying

During hot-air drying, if the drying rate is measured at constant conditions and plotted against time. There are two distinct periods, namely a constant-rate period AB and falling-rate period BC; the moisture corresponding to the transition is known as the critical moisture. During the constant-drying-rate period, the controlling resistance is due to the stagnant air film. The surface of the food behaves like a free moisture surface and the surface temperature approximates to the wet-bulb temperature. The drying rate is controlled by the rate of heat

transfer and can be increased by increasing either the temperature driving force or the air velocity. In the situation where air blows over the surface of a food, the heat film coefficient h is proportional to the mass flow rate of air, raised to the power 0.8. The rate Q' of heat transfer and the rate M' of mass transfer are:

$$Q' = hA (T_a - T_s)$$

$$m' = kA (P_s - P_a)$$

Both the heat film coefficient and the mass transfer coefficient increase as turbulence increases. The vast majority of the water in the food is removed during the constant-drying-rate period. The critical moisture content in terms of the mass transfer and heat transfer characteristics. The break point in the drying curve may also be determined experimentally. At the critical moisture content the surface of the food begins to dry out and the dry layer advances into the food. The surface temperature rises and the drying rate becomes to a greater extent independent of the surface conditions and more strongly influenced by the movement of water within the food. Most texts on drying deal with the drying of hygroscopic and non-hygroscopic materials. A hygroscopic material is one whose partial pressure P_w of water vapour is dependent upon the moisture-content. A non-hygroscopic material, exerts the same water vapour pressure at all moisture contents.

(2) Spray drying

One special form of hot-air drying is the spray drier. Hot air at 150-300 °C is blown into the drying chamber and comes into contact with the liquid feed which has been broken into a fine spray by a centrifugal atomizing device; alternatively, two-fluid or pressure nozzles can be used. Drying takes place extremely quickly and the dry powder is conveyed by the air to a system of cyclones where the fine particles are separated from the air stream. The product feed rate is controlled to give an outlet air temperature of between 90 °C and 100 °C. If it falls much below 90 °C, the resulting product is too wet, whereas energy is wasted if it exceeds 100 °C. The corresponding wet-bulb temperature is between 40 °C and 50 °C. Powder temperatures will not exceed the wet-bulb temperature provided that the system is designed to avoid a long hold-up of dry powder in the conveying system. Spray drying is widely used for milk and cheese whey, egg, coffee and other beverages and powdered potato.

(3) Freeze drying (lyophilization)

Freeze drying is a two-stage process. In the first stage the food is frozen, a number of techniques being available. The size of the ice crystals will be affected by the rate of freezing, smaller crystals being produced at faster freezing rates. The size of the ice crystals will affect the subsequent drying rate as smaller ice crystals will produce a smaller pore size, which will decrease the permeability of water vapour. Evaporative cooling methods can also be used for freezing most solid foods; this is of benefit because there is a significant reduction in the moisture content. The food is placed into a vacuum chamber and the pressure is quickly reduced to below the triple-point pressure. If the water vapour pressure is maintained below 4.6 torr, sublimation will occur, as long as sufficient energy is supplied to provide the latent heat of sublimation. The metal trays containing the frozen food are placed onto heating shelves which are heated by electricity or by circulating hot water. Water vapour is removed by a combination refrigerated condenser and a vacuum pump, the two systems being required because of the very high specific volume of water vapour at low pressures. The reverse process to sublimation occurs and water freezes out on the surface of the condenser, residual water vapour being removed by the vacuum pump. If the water vapour pressure rises above 4.6 torr, the ice will melt rather than sublime, and liquid phase drying will occur. The heat and mass transfer processes taking place are as follows:

- Heat transfer from the heater through the dry layer.
- Sublimation at the interface.
- Diffusion of water vapour through the dry layer to the surface.
- Movement of water vapour from the food surface to the condenser.

The heat transfer process is inherently slow, because of the extremely low thermal conductivity of the dried food, and most freeze-drying processes are heat transfer controlled. To decrease the drying time by putting heat in through the frozen layer. The main mechanism of drying is by conduction, and contact between the food and the heating plates is improved by applying a slight pressure; this is known as accelerated freeze drying. Some of the advantages of freeze drying are improved product quality due to the mild heat treatment, better volatile retention due to selective diffusion of water vapour through the dry layer and no case hardening or

shrinkage. The major disadvantages are the high capital and running costs, which has meant that the major commercial successes for freeze-dried products have been restricted to relatively expensive products, for which the consumer is willing to pay a higher price for the superior-quality product produced. Examples are coffee, shrimps, prawns, chickens and mushrooms and some dehydrated complete meals. Microbiological cultures are also often preserved by freeze drying.

Packaging Materials

One of the main functions of packaging material is to provide adequate barrier properties. These include reducing the amount of light that enters the product, preventing the entry of micro-organisms and other environmental contaminants and reducing the transmission of water vapour, oxygen or other gases, as the situation demands. Metal packaging materials in the form of foil or cans provide a complete barrier, as does glass, except for its light transmission properties. A wide variety of plastics have been developed in the form of films or rigid containers, and one important property of these materials is their permeability, particularly when used in films. Materials differ widely in their permeabilities towards oxygen, carbon dioxide and water vapour. Composite packaging materials are now widely available and total resistance can be dealt with in a similar way to thermal resistances.

Membrane Processes

Polymeric materials are used to fabricate semipermeable membranes for use in processes such as reverse osmosis (hyperfiltration), ultrafiltration, dialysis and electrodialysis. The membranes are permeable to some components but not to others, discrimination being based on the molecular shape, size and charge of the component. In both reverse osmosis and ultrafiltration, the liquid is placed on one side of the membrane and subjected to a pressure; the material which passes through the membrane is known as the permeate. The major differences between ultrafiltration and reverse osmosis are summarized.

Distinction between reverse osmosis and ultrafiltration

	Reverse osmosis	Ultrafiltration
Operating pressure	Greater than 50 bar	Between 1 and 10 bar
Membrane characteristics	Small pores; 100% rejection of all components	Larger pore size; low rejection of low-molecular-weight solutes; high rejection of proteins and other high-molecular weight components
Nature of permeate	Water, perhaps with traces of low-molecular weight components	Low-molecular-weight components, present at similar concentration to that in the feed
Selection mechanism	Diffusion activated	Sieving process

Reverse osmosis is used for concentrating liquids such as milk, cheese whey, fruit juices and other beverages. Operating temperatures are low and there is no phase change and a smaller loss of volatiles compared with evaporation. It has been used for removing alcohol from beer and lager. Ultrafiltration is used for concentrating high-molecular-weight components under mild operating conditions. This is useful for proteins including enzymes, polysaccharides and fermentation products.

Specific Heat

The specific heat of a material is a measure of the amount of energy required to raise unit mass by unit temperature rise. Specific heat is temperature dependent. The purpose of many engineering calculations, these variations are small and an average specific heat value is used for the temperature range considered. Latent heat changes which are involved in phase changes will be considered later; examples of these are the conversion of water to ice, other crystallization reactions particularly of fats, the vaporization of water or the condensation of steam, and the sublimation of ice, as in freeze-drying operations. Liquid water has an extremely high specific heat value, much higher than most other liquids. It is widely used as a cooling medium. The addition of ethylene glycol (antifreeze) will lower the specific heat and consequently the cooling efficiency. When water freezes, the specific heat capacity is drastically reduced. Since water has a much higher specific heat than most other food constituents, the specific heat of a food is significantly affected by the amount of water present and the physical state of the water. Frozen foods with high water contents will have specific heat values approximately half that of their fresh counterparts. Less energy is required to reduce food from -1°C to -30°C than is required from 28°C to -1°C (most foods will commence freezing at about -1°C). Freezing is not a sharp process, i.e. the water does not freeze at a constant temperature. During processes such as evaporation, and dehydration the specific heat of the food will fall. Water vapour has a specific heat value approximately equal to that of ice. Metals have very low specific heat values compared with those of foods. Oils and fats again have specific heats about half that for water. Dried grain and food powders also have very low specific heat values. Specific heats are temperature dependent; for most substances, there is a slight increase in the specific heat as the temperature rises. Since specific heats are dependent on moisture content and temperature.

Latent Heat

Sensible heat changes, i.e. changes that can be detected by a rise or fall in temperature. In many food-processing operations, associated with these phase changes are energy changes. The phases involved are the solid, liquid and vapour

phases. Water can exist as a solid, a liquid, a vapour or a combination of these phases in equilibrium. If the pressure and temperature are fixed, it is possible to predict what state the water will be in. At one particular pressure and temperature, the three phases solid (S), liquid (L) and vapour (V) are in equilibrium. The latent heat of vaporization is approximately seven times higher than that for fusion. The latent heat of vaporization for water is extremely high. Thus, energy costs for evaporation and dehydration are potentially high in comparison with processes involving only changes in sensible heat. Steam is also a very useful heat transfer fluid because it gives out large quantities of energy when it condenses as well as having a high heat film coefficient value. When a food freezes, it gives out substantial amounts of energy which has to be removed by the refrigerant.

Enthalpy-Composition Data

For processes taking place at a constant pressure, heat changes can be associated with enthalpy changes. If the enthalpy of the food is known at two temperatures, e.g. +25 °C and -20 °C, the amount of heat removed is simply obtained from the difference in values. Such enthalpy changes will account for both sensible and latent heat values. Microbial activity also ceases at temperatures below -10 °C. This type of data is also useful for interpreting changes in the structure of frozen foods during conditions of storage at fluctuating temperatures. Substantial proportions of the water will be changing state. These effects will be much more pronounced if the temperature is allowed to rise above -10 °C, and so storage temperatures above this must be avoided, to prevent deterioration of product quality. Thermodynamically, it can be shown that small ice crystals melt in preference to large ice crystals. During this process the small ice crystals will melt and form larger pools of water; when the temperature is subsequently reduced, these pools form larger ice crystals, which may disrupt the cell structure. This phenomenon is known as 'recrystallization'. Many foods can be stored almost indefinitely at temperatures below -30 °C without any noticeable loss in quality. Temperatures of -30 °C are used for freezing and storing foods at the processing factory, whereas the storage temperature in most supermarket and domestic freezers is between -18 °C and -20 °C. Containing high quantities of fat or salt, which are subject to oxidation reactions, often exert a maximum reaction rate at a temperature of from -10 °C to -15 °C.

Freezing and Thawing Times

If a slab of food is being frozen, the surface of the food is subjected to a low temperature and heat is removed from the food to the cold source. The food will start to freeze at the surface. The situation part of the way through the freezing process as the frozen zone advances into the food and energy is being removed through the frozen layer. When a food which is partially frozen is dissected, such a sharp interface between the two layers is observed. This provides an alternative method for measuring freezing rates, namely the speed of advancement of the frozen layer into the food. In contrast, thawing or defrosting a frozen food is an intrinsically slower process than freezing. The surface of the food is subjected to the thawing medium and melting proceeds from the surface. During this process, heat is transferred through the melted (fresh) food, which has a much lower thermal conductivity than the frozen food. In addition, the temperature of the thawing medium is limited as the food surface will be close to this temperature for the duration of the process. This may cause microbiological or other problems when thawing times are long. This also puts a limit on the temperature driving force available. The rate of heat transfer during freezing and thawing foods of different geometries was first considered by Planck. The following were amongst the most important assumptions made by Planck.

- Foods have a sharp freezing point.
- Heat transfer from the freezing front in the food to the cooling medium is in steady state, i.e. freezing takes place relatively slowly.
- Freezing starts with all the food at the freezing temperature; the pre-freezing and tempering stages are not accounted for.
- The freezing medium remains at a constant temperature, and the thermal conductivity and density of the food are independent of temperature.

Because of the nature of the assumptions made, calculated freezing times are not always in agreement with experimentally determined times. Freezing time depends upon product-related properties such as density, thermal conductivity, shape and enthalpy change, where scope for change is limited, and upon process-related variables, such as type of packaging, refrigeration temperature and type of refrigeration system, where there may be more scope for change. Thawing times can be evaluated by using the thermal conductivity of the fresh food. Sensible

heat changes can be accounted for by substituting the total enthalpy change from start to finish.

Refrigeration Methods

Refrigeration involves the production of temperatures below the ambient temperature, the main areas of interest being freezing and chilling. Chilling extends from just below the ambient temperature down to -1°C and only sensible heat changes are involved. Freezing commences at -1°C and involves the conversion of water to ice, with the removal of the latent heat associated with this phase change. Virtually all microbial activity ceases below -10°C . Most domestic food freezers operate at -18°C , whereas some commercial cold-storage units are much lower (between -25°C and -30°C). Some chemical and enzymatic reactions may still take place below -18°C , albeit at a very low rate. It is very important to ensure that chilled and frozen foods are maintained at their optimum storage temperature at all points between their production and point of sale. Freezing and chilling processes can be divided into direct and indirect processes in a similar fashion to heating processes. The use of refrigerants for obtaining low temperatures in a vapour compression refrigeration cycle.

Plate Freezers

Food such as fish, meat and vegetables are arranged in trays to a maximum thickness of 4-5 cm. The trays are loaded between metal plates (usually aluminium alloy) which are hollow and through which passes an evaporating refrigerant at a temperature between -30°C and -40°C . It is essential to get good contact between the food and the plates to improve conductive heat transfer; to ensure this, a slight pressure is applied. Freezing times range between 30 min and 60 min and are affected by the thickness of the product and the thermal properties of the food. At the end of the process the trays are removed and the products are 'knocked out' as a slab. This is quickly broken into pieces or cut to the desired shape. For example, fish is sawed into fish-shaped pieces or fish fingers. Freezers are labour intensive but are also extremely useful for freezing food in thin

regularly shaped packages, such as hamburgers and pre-cooked meals, or for hardening ice-cream blocks.

Cold-Air Freezing

Air is reduced in temperature by passing it over coils containing evaporating refrigerant. In a deep-freeze cabinet, the air is stagnant, resulting in very low heat film coefficients. In a blast freeze the air is circulated around the freezing compartment using a fan, thereby increasing the heat film coefficient. Energy costs are slightly higher and the heat energy produced by fan also needs to be removed. Factors affecting the freezing time are the air velocity, the air temperature and the thermal properties and dimensions of the foods. Freezing times can range from several minutes for small samples to several days for large carcasses of meat. One problem that may occur is surface dehydration or freezer burn. It is most likely to occur when the food is relatively warm as there will be a large water vapour pressure gradient between the surface of product and the bulk air. This can be reduced by ensuring that the cold air is saturated and by more rapid freezing methods. Freezing times can be further reduced for particulate matter by fluidizing the particles using higher air velocities. This is suitable for peas, sliced beans, diced vegetables and foods of similar dimensions. The energy requirements are much higher, but the products are 'individually quick frozen'.

Immersion Freezing

Cold liquids can be used for freezing rather than air, resulting in higher heat film coefficients. The lowest temperature attainable with chilled water is about 0 °C. It is suitable for chilling and is so used in batch and continuous heat exchangers. For freezing applications, the temperature is reduced by adding substances such as inorganic salts, sugars or ethylene glycol. The freezing point of a sodium chloride solution is affected by salt concentration. The presence of salt reduces the freezing point, as freezing proceeds, ice separates out and is in equilibrium with the solution. Temperatures of - 23.8 °C and - 51.2 °C, respectively, can be achieved by using 40% and 60% ethylene glycol solutions. These solutions can be chilled and used with either batch or continuous heat

exchangers, e.g. ice-cream freezers. In certain cases, products can be immersed in the solution, e.g. fish in a sodium chloride solution, but usually the product would need to be packaged before immersion, e.g. frozen chicken in a plastic bag. Eutectic bricks are used in insulated cool-boxes. They are taken from the freezer, in their frozen form, when required and placed in the box with the food. Strong sugar solutions can also be used for immersion freezing, but they may be very viscous at low temperatures. Sugar-water systems have been used for modelling fruit juices.

Cryogenic Freezing

A cryogenic freezant usually refers to a fluid whose boiling point is well below the normal freezing point of the food. When the food is immersed in the fluid, evaporation of the freezant takes place on the surface of the food, thereby improving the surface heat film coefficient. Liquid nitrogen has a boiling point of -196°C at atmospheric pressure. When a food is immersed in liquid nitrogen, heat is rapidly transferred from the surface of the food to the liquid nitrogen and the liquid evaporates at the surface. The surface heat film coefficient is high and this, combined with a large temperature driving force, makes it a rapid method for freezing foods. The size of the food increases, conduction within the food becomes the controlling mechanism and many of the advantages incurred by liquid nitrogen are lost. As liquid nitrogen is expensive to date, it is used commercially mainly with small high-quality delicate foods where the advantages of the high quality produced by rapid freezing outweigh the higher costs incurred by the process, e.g. shrimps, prawns, raspberries and strawberries. Cryogenic fluids used for direct contact refrigeration must be non-toxic and not leach any of the food components. Solid carbon dioxide (Cardice) is widely used for transporting frozen foods.

Vacuum Cooling and Freezing

If a food is placed in a vacuum chamber and the pressure is reduced, a point will be reached when the chamber pressure reaches the saturated water vapour pressure of the food material. At this point the water will evaporate from the surface of the food; this requires energy which is supplied by the food and will result in a localized cooling effect. If the pressure is further reduced, evaporation proceeds and further cooling results. An estimate of the amount of water removed can be obtained from the equation:

$$\text{heat lost by food} = \text{heat required to evaporate water}$$

Therefore,

$$\text{mass food} \times \text{specific heat} \times \text{temperature fall} = \text{mass evaporated} \times \text{latent heat}$$

If the pressure is reduced below about 4.6 Torr, the food will reach 0 °C and start to freeze. The latent heat term can be added to the right-hand side of the equation. For most foods a temperature fall involving sensible heat changes results in only a small loss of water. Much larger quantities are lost as the food starts to freeze. This method has found use in the quick cooling of horticultural products taken straight from the field. Evaporative freezing is a very useful preliminary step for freeze drying, as between 20% and 25% of the water is lost during the freezing process. It is an extremely useful method for freezing foods prior to the sublimation process in freeze drying. It is not suitable for liquids or soft fruit and vegetables. The extent of cooling or freezing can be controlled by regulating the vacuum conditions. For example, if a product temperature of 5 °C is required, the pressure is adjusted to a value corresponding to the saturated water vapour pressure at that temperature, thereby ensuring that the temperature will not fall below that value.

Chilling

Chilling involves reducing the temperature to below the ambient temperature, but above - 1 °C. Microbial reaction rates are retarded, and it is used in combination with pasteurization for extending the shelf-life of 'fresh' products. chilled storage of perishable produce, namely fruit and vegetables, meat, poultry, eggs, fishery products, dairy products, cut flowers and seeds.

Assignment for FTech 308 Food Biochemistry and Food Processing

Food Biochemistry

Many biochemical reactions and their products are the basis of much of food science and technology. For example, in the development of food packaging materials, one must consider microbiological, environmental, biochemical (flavour/nutrient) and economic questions in addition to material/polymer science. An ideal food product would promote healthy gut microflora, contain 20 g of vegetable protein with no limiting amino acids and have 25% of the daily fibre requirement. It would be lactose-free, nut-free, trans-fat-free, antibiotic- and pesticide-free, artificial colour-free, no sugar added and contain certified levels of phytosterols. The product would contain tasteless, odourless, mercury-free, cold-pressed, bioactive omega 3-rich fish oil harvested using animal-friendly methods. It would be blood sugar-stabilizing and heart disease-preventing, boost energy levels, not interfere with sleep, be packaged in minimal, compostable packaging and manufactured using 'green' energy, transported by biodiesel-burning trucks and be available to the masses at a reasonable price. At their most fundamental levels, growing crops and raising food animals, storing or ageing foods, processing fermentation, developing food products, preparing and/or cooking, and finally ingesting food are all ways of bringing about, or preventing, biochemical changes. Methods to combat both pathogenic and spoilage organisms are based upon biochemical effects, including acidifying their environments, heat denaturing their membrane proteins, oxygen depriving, water depriving and/or biotin synthesis inhibiting. The basic mechanisms behind food losses and food poisoning begun to be unravelled. Food biochemistry has followed developments in food processing technology and biotechnology, resulting in improved nutrition and food safety. For example, milk-intolerant consumers can ingest nutritious dairy products that are either lactose-free or by taking pills that contain an enzyme to reduce or eliminate lactose. People can decrease gas production resulting from eating healthy legumes by taking α -galactosidase supplements with meals.

Changes in Carbohydrates in Cheese Manufacturing

Action, Enzyme or Enzyme System	Reaction
Formation of lactic acid <ul style="list-style-type: none"> Lactase (EC 3.2.1.108) Tagatose pathway Embden–Meyerhoff pathway 	$\text{Lactose} + \text{H}_2\text{O} \rightarrow \text{D-Glucose} + \text{D-Galactose}$ $\text{Galactose-6-P} \rightarrow \text{Lactic acid}$ $\text{Glucose} \longrightarrow \text{Pyruvate} \longrightarrow \text{Lactic acid}$
Formation of pyruvate from citric acid <ul style="list-style-type: none"> Citrate (pro-3S) lyase (EC 4.1.3.6) Oxaloacetate decarboxylase (EC 4.1.1.3) 	$\text{Citrate} \longrightarrow \text{Oxaloacetate}$ $\text{Oxaloacetate} \longrightarrow \text{Pyruvate} + \text{CO}_2$
Formation of propionic and acetic acids <ul style="list-style-type: none"> Propionate pathway 	$3 \text{ Lactate} \longrightarrow 2\text{-Propionate} + 1 \text{ Acetate} + \text{CO}_2 + \text{H}_2\text{O}$ $3 \text{ Alanine} \longrightarrow \text{Propionic acid} + 1 \text{ Acetate} + \text{CO}_2 + 3 \text{ Ammonia}$
Formation of succinic acid <ul style="list-style-type: none"> Mixed acid pathway 	$\text{Propionic acid} + \text{CO}_2 \longrightarrow \text{Succinic acid}$
Formation of butyric acid <ul style="list-style-type: none"> Butyric acid pathway 	$2 \text{ Lactate} \longrightarrow 1 \text{ Butyrate} + \text{CO}_2 + 2\text{H}_2$

Formation of ethanol <ul style="list-style-type: none"> Phosphoketolase pathway Pyruvate decarboxylase (EC 4.1.1.1) Alcohol dehydrogenase (EC 1.1.1.1) 	<p>Glucose \longrightarrow Acetylaldehyde \longrightarrow Ethanol</p> <p>Pyruvate \longrightarrow Acetylaldehyde + CO₂</p> <p>Acetylaldehyde + NAD + H⁺ \longrightarrow Ethanol + NAD⁺</p>
Formation of formic acid <ul style="list-style-type: none"> Pyruvate-formate lyase (EC 2.3.1.54) 	<p>Pyruvate + CoA \longrightarrow Formic acid + Acetyl CoA</p>
Formation of diacetyl, acetoin, 2,3-butylene glycol <ul style="list-style-type: none"> Citrate fermentation pathway 	<p>Citrate \longrightarrow Pyruvate \longrightarrow Acetyl CoA \longrightarrow Diacetyl \longrightarrow Acetone \longrightarrow 2,3-Butylene glycol</p>
Formation of acetic acid <ul style="list-style-type: none"> Pyruvate-formate lyase (EC 2.3.1.54) Acetyl-CoA hydrolase (EC 3.1.2.1) 	<p>Pyruvate + CoA \longrightarrow Formic acid + Acetyl CoA</p> <p>Acetyl CoA + H₂O \longrightarrow Acetic acid + CoA</p>

Locations and Major Functions of Myofibrillar Proteins Associated with Contractile Apparatus and Cytoskeletal Framework

Location	Protein	Major Function
Contractile apparatus		
A-band	<ul style="list-style-type: none"> • Myosin • c-Protein • F-, H-, I-Proteins 	<ul style="list-style-type: none"> • Muscle contraction • Binds myosin filaments • Binds myosin filaments
M-line	<ul style="list-style-type: none"> • M-Protein • Myomesin • Creatine kinase 	<ul style="list-style-type: none"> • Binds myosin filaments • Binds myosin filaments • ATP synthesis
I-band	<ul style="list-style-type: none"> • Actin • Tropomyosin • Troponins T, I, C • β-, γ -Actinins 	<ul style="list-style-type: none"> • Muscle contraction • Regulates muscle contraction • Regulates muscle contraction • Regulates actin filaments
Cytoskeletal framework		
GAP filaments	<ul style="list-style-type: none"> • Connectin (titin) 	<ul style="list-style-type: none"> • Links myosin filaments to Z-line
N2-line	<ul style="list-style-type: none"> • Nebulin 	<ul style="list-style-type: none"> • Unknown
By sarcolemma	<ul style="list-style-type: none"> • Vinculin 	<ul style="list-style-type: none"> • Links myofibrils to sarcolemma
Z-line	<ul style="list-style-type: none"> • α-Actinin • Eu-actinin, filamin • Desmin, vimentin • Synemin, Z-protein, Z-nin 	<ul style="list-style-type: none"> • Links actin filaments to Z-line • Links actin filaments to Z-line • Peripheral structure to Z-line • Lattice structure of Z-line

Proteases in Animal Tissues and Their Degradation

Enzyme	Reaction
Aspartic proteases <ul style="list-style-type: none"> • Pepsin A (pepsin, EC 3.4.23.1) • Gastricsin (pepsin C, EC 3.4.23.3) • Cathepsin D (EC 3.4.23.5) 	<ul style="list-style-type: none"> • Preferential cleavage, hydrophobic, preferably aromatic, residues in P1 and P'1 positions • More restricted specificity than pepsin A; high preferential cleavage at Tyr bond • Specificity similar to, but narrower than that of pepsin A
Serine proteases <ul style="list-style-type: none"> • Trypsin (a- and b-trypsin, EC 3.4.21.4) • Chymotrypsin (Chymotrypsin A and B, EC 3.4.21.1) • Chymotrysin C (EC 3.4.21.2) • Pancreatic elastase (pancreato-peptidase E, pancreatic elastase I, EC 3.4.21.36) • Plasmin (fibrinase, fibrinolysin, EC 3.4.21.7) • Enteropeptidase (enterokinase, EC 3.4.21.9) • Collagenase 	<ul style="list-style-type: none"> • Cleavage to the C-terminus of Arg and Lys • Preferential cleavage: Tyr-, Trp-, Phe-, Leu- • Preferential cleavage: Leu-, Tyr-, Phe-, Met-, Trp-, Gln-, Asn- • Hydrolysis of proteins, including elastin. Preferential cleavage: Ala • Preferential cleavage: Lys > Arg; higher selectivity than trypsin • Activation of trypsinogen by selective cleavage of Lys6-Ile7 bond • Hydrolysis of collagen into smaller molecules
Thio/cysteine proteases <ul style="list-style-type: none"> • Cathepsin B (cathepsin B1, EC 3.4.22.1) • Papain (EC 3.4.22.2) • Fiacin (ficin, EC 3.4.23.3) • Bromelain (EC 3.4.22.4) • γ-Glutamyl hydrolase (EC 3.4.22.12 changed to 3.4.1.99) • Cathepsin H (EC 3.4.22.16) • Calpain-1 (EC 3.4.22.17 changed to 3.4.22.50) 	<ul style="list-style-type: none"> • Broad specificity, Arg-Arg bond preference in small peptides • Broad specificity; preference for large, hydrophobic amino acid at P2; does not accept Val at P1 • Similar to that of papain • Broad specificity similar to that of pepsin A • Hydrolyses γ-glutamyl bonds • Protein hydrolysis; acts also as an aminopeptidase and endopeptidase (notably cleaving Arg bond) • Limited cleavage of tropinin I, tropomyosin, myofibril C-protein, cytoskeletal proteins;

	activates phosphorylase, kinase, and cyclic-nucleotide-dependent protein kinase
Metalloproteases <ul style="list-style-type: none"> • Procollagen N-proteinase (EC 3.4.24.14) 	<ul style="list-style-type: none"> • Cleaves N-propeptide of pro-collagen chain $\alpha 1(I)$ at Pro+Gln and $\alpha 1(II)$, and $\alpha 2(I)$ at Ala+Gln

FOOD LIPID BIOCHEMISTRY

Fatty Acids: Lipids are organic compounds characterized by little or no solubility in water and are the basic units of all organisms' membranes, the substituent of lipoproteins and the energy storage form of all animals. The basic units of lipids are fatty acids (FAs), simple hydrocarbon chains of varying length with a carboxylic acid group at one end. $\text{CH}_3 - (\text{CH}_2)_n - \text{COOH}$

Selected Commercial Biotechnology-Derived Food Enzymes

Enzyme	Application
Acetolactate decarboxylase (EC 4.1.1.5)	Beer aging and diacetyl reduction
α -Amylase (EC 3.2.1.1)	High-fructose corn syrup production
Amylo-1,6-glucosidase (EC 3.2.1.33)	High-fructose corn syrup production
Chymosin (EC 3.4.23.4)	Milk clotting in cheese manufacturing
Lactase (EC 3.2.1.108)	Lactose hydrolysis
Glucan-1,4- α -maltogenic α -amylase (EC 3.2.1.133)	Anti-stalling in bread

Triglycerides and Phospholipids: In foods, most lipids exist as triglycerides (TGs), making up 98% of food lipids. The name triglyceride refers to its biochemical structure consisting of a glycerol having three FAs bound at its hydroxyl groups. TGs are the primary energy storage form in animals, seeds and certain fruits (e.g. avocado and olive).

Phospholipids: Another class of lipids are phospholipids (PLs), most of which consist of a glycerol backbone with two FAs and the third back-bone position containing various substituents such as serine, choline and ethanolamine. An example of a PL used in food is lecithin, a natural emulsifier and surfactant.

Food Lipid Degradation: Hydrolysis and oxidation reactions are the principal ways in which TGs are degraded in foods. Lipolysis refers to the hydrolysis of the ester linkage between the glycerol backbone and FAs, thereby releasing free FAs. Lipases are enzymes that release FAs from the outer TG positions by hydrolysis. Free FA's are more susceptible to oxidation and they are more volatile compared to FAs within TGs.

Lipid Analysis

Compared to most other food components, lipids are a group of relatively small, naturally occurring molecules containing carbon, hydrogen, and oxygen atoms, but with much less oxygen than carbohydrates. This large group of organic molecules includes fats, waxes, cholesterol, sterols, glycerides, phospholipids, etc. The most simplistic definition of a lipid is based on its solubility, that is, it is soluble in organic solvents (e.g., alcohol) but insoluble in water. Lipid molecules are hydrophobic, but this generality is sometimes not totally correct as some lipids are amphiphilic, that is, partially soluble in water and partially soluble in organic solvents. Lipids are widely distributed in nature and play many important biological roles, including signaling (e.g., cholesterol), acting as structural materials in cellular membranes, and energy storage. The amphiphilic nature of some lipids gives them the ability to form cellular structures such as vesicles and liposomes within cellular aquatic environments. Analytically, lipid insolubility in

water becomes an important distinguishing characteristic that can be maximally exploited in separating lipids from other nutritional components in the food matrix such as carbohydrates and proteins. Lipids are divided into two groups based upon the types of bonding between the carbon atoms in the backbone, which influences the lipid's physical characteristics. Fats having a greater number of fatty acids with single carbon to carbon bonds (saturated fatty acids) cause it to solidify at 23°C (room temperature). The fatty acids in oils have a greater proportion of one or more double bonds between the carbon atoms (unsaturated fatty acids) and are liquid at room temperature. Structurally, glycerides are composed primarily of one to three fatty acids (a mixture of saturated and unsaturated fatty acids of various carbon lengths) bonded to the backbone of a glycerol molecule, forming mono-, di-, and triglycerides (the most predominant), respectively. Animal fats in the milk (from mammals), meat, and from under the skin (blubber), including pig fat, butter, ghee, and fish oil (an oil), are generally more solid than liquid at room temperature. Plant lipids tend to be liquids (i.e., they are oils) and are extracted from seeds, legumes, and nuts (e.g., peanuts, canola, corn, soybean, olive, sunflower, safflower, sesame seeds, vegetable oils, coconut, walnut, grape seed, etc.). Margarine and vegetable shortening are made from the above plant oils that are solidified through a process called hydrogenation. This method of solidifying oils increases the melting point of the original substrate but produces a type of fat called trans-fat, whose content can be as high as 45% of the total fat content of the product. Trans fats are so detrimental to human health that the amount of trans fat in food. The total lipid content of a food is commonly determined using extraction methods using organic solvents, either singularly or in combinations. Unfortunately, the wide relative hydrophobicity range of lipids makes the choice of a single universal solvent for lipid extraction and quantitation nearly impossible. In addition to various solvents that can be used in the solvent extraction methods, non-solvent wet extraction methods and other instrumental methods also exist, which utilize the chemical and physical properties of lipids for content determination.

ENZYMATIC ANALYSIS OF FOOD QUALITY

While enzymes generally exert positive influence on food quality, the activities of some enzymes need to be controlled postharvest or postprocessing to avoid compromising the quality of food products. For instance, protease activity is desirable for meat tenderization during ageing, but left uncontrolled, meats become mushy and overtenderized. Similarly, excessive lipase and oxidase activities in foods during storage, especially under temperature-abuse conditions, may cause rancidity and impact quality attributes such as color, flavor, and texture. Therefore, a number of preservation techniques developed through the years have been aimed at controlling such undesirable postharvest enzymatic as well as microbial activities to ensure extended shelf life of food products. The activities of a number of enzymes as well as the content of certain food components and secondary metabolites resulting from postharvest or postprocessing biochemical and microbial activities have been recognized as quality indices for various foods and consequently monitored. An example is the milk endogenous alkaline phosphatase, which is inactivated following heat treatment at 60°C for 5 seconds. With milk generally subjected to pasteurization or ultra-high-temperature treatment, residual alkaline phosphatase activity following such treatment provides a good indication of efficacy of the treatment. The phosphatase test is based on hydrolysis of disodium phenyl phosphate to liberate phenol, which reacts with dichloroquinone chloroimide to form a blue indophenol. In most seafoods, freshness is rapidly compromised postharvest, particularly when handled under temperature-abuse conditions that promote endogenous enzyme activity. ATP breakdown in postmortem fish muscle has been very well investigated, and the relative amounts of the different intermediates are generally accepted as fish freshness indicator. These key freshness indicators such as ornithine, amines, and hypoxanthine, which rapidly build up in fresh seafoods, have been analyzed by various enzymes. These include ornithine carbamoyl transferase, nucleoside phosphorylase, xanthine oxidase, and diamine oxidase for ornithine and amines; and xanthine oxidase for hypoxanthine. In meats, lactic acid levels tend to increase postmortem, and thus their levels have been monitored as freshness indicators using xanthine oxidase, diamine oxidase, and polyamide oxidase. In addition to the indirect indicators of food quality or safety described, there are other enzymatic methods for direct detection of contaminating

microflora. Detection or binding of the enzyme label is conducted by an electrochemical system using tetramethylbenzidine dihydrochloride as electron transfer mediator and hydrogen peroxide as substrate.

Browning Reactions

Browning is one of the most important reactions taking place during food processing and storage. Both, enzymatic and nonenzymatic browning can affect the quality of food in either positive or negative ways, depending on the type of food. Browning reactions are some of the most important phenomena occurring in food during processing and storage. They represent an interesting research for the implications in food stability and technology as well as in nutrition and health. The major groups of reactions leading to browning are enzymatic phenol oxidation and so-called nonenzymatic browning.

Enzymatic Browning

Enzymatic browning is one of the most important color reactions that affect fruits, vegetables, and seafood. It is catalyzed by the enzyme polyphenol oxidase (PPO; 1,2 benzenediol; oxygen oxidoreductase, EC 1.10.3.1), which is also referred to as phenoloxidase, phenolase, monophenol oxidase, diphenol oxidase (DPO), and tyrosinase. Phenoloxidase enzymes (PPOs) catalyze the oxidation of phenolic constituents to quinones, which finally polymerize to colored melanins. Significant advances have been made on biochemistry, molecular biology, and genetics of PPO. Enzymatic browning reactions may affect fruits, vegetables, and seafood in either positive or negative ways. These reactions may contribute to the overall acceptability of foods such as tea, coffee, cocoa, and dried fruits (raisins, prunes, dates, and figs). Products of enzymatic browning play key physiological roles. Melanins, produced as a consequence of PPO activity, may exhibit antibacterial, antifungal, anticancer, and antioxidant properties. PPOs impart remarkable physiological functions for the development of aquatic organisms, such as wound healing and hardening of the shell (sclerotization), after molting in insects and in crustaceans such as shrimp and lobster. The mechanism of wound healing in aquatic organisms is similar to that which occurs in plants in which the compounds produced as a result of the polymerization of quinones, melanins, or

melanoidins exhibit both antibacterial and antifungal activities. In addition, enzymatic reactions are considered desirable during fermentation. Despite these positive effects, enzymatic browning is considered one of the most devastating reactions for many exotic fruits and vegetables, in particular tropical and subtropical varieties. Enzymatic browning is especially undesirable during processing of fruit slices and juices. Lettuce, other green leafy vegetables; potatoes and other starchy staples, such as sweet potato, breadfruit, and yam; mushrooms; apples; avocados; bananas; grapes; olive; peaches; pears and a variety of other tropical and subtropical fruits and vegetables are susceptible to browning. Crustaceans are also extremely vulnerable to enzymatic browning. Since enzymatic browning can affect color, flavor, and nutritional value of these foods, it can cause tremendous economic losses. The mechanism of enzymatic browning in fruits, vegetables, and seafood; the properties of the enzymes involved; and their substrates and inhibitors may be helpful for controlling browning development, avoiding economic losses, and providing high-quality foods.

Water Chemistry and Biochemistry

Water, the compound H_2O , is the most common food ingredient. It's rarely used chemical names are hydrogen oxide or dihydrogen monoxide. So much of this compound exists on the planet earth that it is taken for granted. Water is present in solid, liquid, and gas forms in the small range of temperatures and pressures near the surface of the earth. Moreover, natural waters always have substances dissolved in them, and only elaborate processes produce pure water. The chemistry and physics of water are organized studies of water: its chemical composition, formation, molecular structure, rotation, vibration, electronic energies, density, heat capacity, temperature dependency of vapor pressure, and its collective behavior in condensed phases (liquid and solid). Water includes interactions of water with atoms, ions, molecules, and biological matter. The knowledge of water forms the foundation for biochemistry and food chemistry. Biochemistry and food chemistry has something to do with water, because water is intimately linked to life, including the origin of life. Biochemistry studies the chemistry of life at the atomic and molecular levels. Living organisms consist of

many molecules. Even simple bacteria consist of many kinds of molecules. The interactions of the assembled molecules manifest life phenomena such as the capacity to extract energy or food, respond to stimuli, grow, and reproduce. The interactions follow chemical principles, and water chemistry is a key for the beginning of primitive life forms billions of years ago. The properties of water molecules give us clues regarding their interactions with other atoms, ions, and molecules. Water remains important for human existence, for food production, preservation, processing, and digestion. Water is usually treated before it is used by food industries. After usage, wastewaters must be treated before it is discharged into the ecological system. Foods, water helps us to digest, dissolve, carry, absorb, and transport nutrients to their proper sites. It helps hydrolyze, oxidize, and utilize the nutrients to provide energy for various cells, and eventually, it carries the biological waste and heat out of our bodies. Oxidations of various foods also produce water.

Water Vapor Chemistry and Spectroscopy

Spectroscopy is the study of the absorption, emission, or interaction of electromagnetic radiation by molecules in solid, liquid, and gaseous phases. The spectroscopic studies of vapor, in which the H_2O molecules are far apart from each other, reveal a wealth of information about individual H_2O molecules. Electromagnetic radiation (light) is the transmission of energy through space via no medium by the oscillation of mutually perpendicular electric and magnetic fields. Max Planck theorized that a bundle of energy converts into a light wave. Small systems can be only at certain energy states called energy levels. Due to quantization, they can gain or lose only specific amounts of energy. Spectroscopy is based on these theories. Water molecules have quantized energy levels for their rotation, vibration, and electronic transitions. Transitions between energy levels result in the emission or absorption of photons. The electromagnetic spectrum has been divided into several regions. From low energy to high energy, these regions are long radio wave, short radio wave, microwave, infrared (IR), visible, ultraviolet (UV), X rays, and gamma rays. Visible light of various colors is actually a very narrow region within the spectrum. IR and UV regions are very large, and both are divided into near and far, or A and B, regions. Water molecules vibrate,

and there are some fundamental vibration modes. The three fundamental vibration modes of water are symmetric stretching ν_1 , bending ν_2 , and asymmetric stretching ν_3 . Vibration energy levels are represented by three integers, ν_1 , ν_2 , and ν_3 , to represent the combination of the basic modes. The frequencies of fundamental vibration states differ in molecules of other isotopic species. Water molecules that have energy levels corresponding to very high overtone vibrations absorb photons of visible light, but the absorptions are very weak. Thus, visible light passes through water vapor with little absorption, resulting in water being transparent. The absorption gets progressively weaker from red to blue. Thus, large bodies of water appear slightly blue. Because visible light is only very weakly absorbed by water vapor, more than 90% of light passes through the atmosphere and reaches the earth's surface. The water droplets in clouds (water aerosols) scatter, refract, and reflect visible light, giving rainbows and colorful sunrises and sunsets. Ultraviolet photons have sufficiently high energies to excite electrons into higher molecular orbitals. Combined with vibrations and rotations, these transitions give rise to very broad bands in the UV spectrum. As a result, gaseous, liquid, and solid forms of water strongly absorb UV light. The absorption intensities and regions of water vapor are different from those of ozone, but both are responsible for UV absorption in the atmosphere. Incidentally, both triatomic water and ozone molecules are bent.

FOOD CHEMISTRY OF WATER

Water ingestion depends on the individual, composition of the diet, climate, humidity, and physical activity. A non-exercising adult loses the equivalent of 4% of his or her body weight in water per day. Aside from ingested water, water is produced during the utilization of food. It is probably fair to suggest that food chemistry is the chemistry of water, since we need a constant supply of water as long as we live. Technical terms have special meanings among fellow food scientists. Food scientists deal with dynamic and nonequilibrium systems, unlike most natural scientists who deal with static and equilibrium systems. There are special concepts and parameters useful only to food scientists. The fundamental properties of water discussed above lay a foundation for the food chemistry of water. With respect to food, water is a component, solvent, acid, base, and

dispersing agent. It is also a medium for biochemical reactions, for heat and mass transfer, and for heat storage. Food chemists are very concerned with water content and its effects on food. They need reliable parameters for references, criteria, and working objectives. They require various indicators to correlate water with special properties such as perishability, shelf life, mobility, smell, appearance, color, texture, and taste.

(1) Water as a Common Component of Food

Water is a food as well as the most common component of food. Even dry foods contain some water, and the degree of water content affects almost every aspect of food: stability, taste, texture, and spoilage. Most food molecules contain OH, C=O, NH, and polar groups. These sites strongly interact with water molecules by hydrogen bonding and dipole-dipole interactions. Furthermore, dipole-ion, hydrophilic, and hydrophobic interactions also occur between water and food molecules. The properties of hydrogen-bonded water molecules differ from those in bulk water, and they affect the water molecules next to them. There is no clear boundary for affected and unaffected water molecules. It is convenient to divide them into bound water and free water. The concept is useful, because it helps us understand the changes that occur in food when it is heated, dried, cooled, or refrigerated. When water is the major ingredient, interactions with other ingredients modify the properties of the water molecules.

(2) Water Activity

Interactions of water and food molecules mutually change their properties. Water in food is not pure water. Water molecules in vapor, liquid, and solid phases or in solutions and food react and interchange in any equilibrium system. Both water activity and relative humidity are fractions of the pure-water vapor pressure. Water activity can be measured in the same way as humidity. If the water vapor in the atmosphere surrounding the food is greater than the water activity of the food, water is adsorbed; desorption takes place. Water activity reflects the combined effects of water-solute, water-surface, capillary, hydrophilic, and hydrophobic interactions. Water activity is a vital parameter for food monitoring. Desorption and adsorption isotherms are different because this is a

nonequilibrium system. Water in food may be divided into tightly bound, loosely bound, and non-bound waters. Crisp crackers get soggy after adsorbing water from moist air, and soggy ones can be dried by heating or exposure to dry air. Water activity affects the growth and multiplication of microorganisms. Every type of organism is a component and a phase of the system, due to its cells or membranes. If the water activity of an organism is lower than that of the bulk food, water will be absorbed, and the species will multiply and grow. If the water activity of the organism is higher, the organism will dehydrate and become dormant or die. It is not surprising that water activity affects the growth of various molds and bacteria. Humidity will have the same effect on microorganisms in residences and buildings. Little packages of drying agent are placed in sealed dry food to reduce vapor pressure and prevent growth of bacteria that cause spoilage.

(3) Aquatic Organisms and Drinking Water

Life originated in the water or oceans eons ago, and vast populations of the earliest unicellular living organisms still live in water today. Photosynthesis by algae in oceans consumes more CO_2 than the photosynthesis by all plants on land. Fungi, Plantae, and Animalia live in water, ranging from single-cell algae to mammals. All life requires food or energy. Some living organisms receive their energy from the sun, whereas others get their energy from chemical reactions. For example, the bacteria *Thiobacillus ferro-oxidans* derive energy by catalyzing the oxidation of iron sulfide, FeS_2 , using water as the oxidant. Chemical reactions provide energy for bacteria to sustain their lives and to reproduce. Many organisms feed on other organisms, forming a food chain. Factors affecting life in water include minerals, solubility of the mineral, acidity (pH), sunlight, dissolved oxygen level, presence of ions, chemical equilibria, availability of food, and electrochemical potentials of the material, among others. Water used directly in food processing or as food is drinking water, and aquatic organisms invisible to the naked eye can be beneficial or harmful. Drinking Water Quality for water used in food services and technologies. Wastewater from the food industry needs treatment, and the technology is usually dealt with in industrial chemistry. When food is plentiful, beneficial and pathogenic organisms thrive. Pathogenic organisms present in drinking water cause intestinal infections, dysentery, hepatitis, typhoid fever, cholera, and other diseases. Pathogens are usually present in waters that contain human and animal wastes that enter the water

system via discharge, runoffs, flood, and accidents at sewage treatment facilities. Insects, rodents, and animals can bring bacteria to the water system. Testing for all pathogenic organisms is impossible, but some organisms have common living conditions. These are called indicator bacteria, because their absence signifies safety.

(4) Water and State of Food

When a substance and water are mixed, they mutually dissolve, forming a homogeneous solution, or they partially dissolve in each other, forming solutions and other phases. At ambient pressure, various phases are in equilibrium with each other in isolated and closed systems. The equilibria depend on temperature. Food and biological systems are open, with a steady input and output of energy and substances. Due to time limits and slow kinetics, phases are not in equilibrium with each other. The changes follow a definite rate, and these are steady states. Temperature against the composition, showing the existences of states (phases), are called state diagrams. They indicate the existence of various phases in multicomponent systems. Sucrose (sugar, $C_{12}H_{22}O_{11}$) is a food additive and a sweetener. Solutions in equilibrium with excess solid sucrose are saturated, and their concentrations vary with temperature. The eutectic point is the lowest mp of water–sugar solutions. However, viscous aqueous sugar solutions or syrups may exist beyond the eutectic point. These conditions may be present in freezing and tempering (thawing) of food. Dry sugar is stable, but it spoils easily if it contains more than 5% water. The changes that occur as a sugar solution is chilled exemplify the changes in some food components when foods freeze. Ice I_h forms when a 10% sugar solution is cooled below the freezing point. As water forms I_h , leaving sugar in the solution, the solution becomes more concentrated, decreasing the freezing point. When cooled, this solution may not reach equilibrium and yield sugar crystals at the eutectic point. Part of the reason for not having sucrose crystals is the high viscosity of the solution, which prevents molecules from moving and orienting properly to crystallize. The viscous solution reaches a glassy or amorphous state at the glass transition temperature (T_g). The glass state is a frozen liquid with extremely high viscosity. In this state, the molecules are immobile. The temperature, T_g , for glass transition depends on the

rate of cooling. The freezing of sugar solution may follow different paths, depending on the experimental conditions. The water-sucrose binary system illustrates that the states of food components during freezing and thawing can be very complicated. Freshly made ice creams have wonderful texture, and the physics and chemistry of the process are even more interesting.

Scheme of Classification and Numbering of Enzymes

A system for the classification of enzymes are:

1. The first number shows to which of the six divisions (classes) the enzyme belongs.
2. The second figure indicates the subclass.
3. The third figure gives the sub-subclass.
4. The fourth figure is the serial number of the enzyme in its sub-subclass.

The main classes are as follows:

- Class 1: Oxidoreductases (dehydrogenases, reductases, or oxidases).
- Class 2: Transferases.
- Class 3: Hydrolases.
- Class 4: Lyases.
- Class 5: Isomerases (racemases, epimerases, cis-trans-isomerases, isomerases, tautomerases, mutases, cycloiso-merases).
- Class 6: Ligases (synthases)

Biocatalysis, Enzyme Engineering and Biotechnology

Enzymes are biocatalysts evolved in nature to achieve the speed and coordination of nearly all the chemical reactions that define cellular metabolism necessary to develop and maintain life. The application of biocatalysis is growing rapidly, since enzymes offer potential for many exciting applications in industry. The advent of whole genome sequencing projects enabled new approaches for biocatalyst development, based on specialized methods for enzyme heterologous

expression and engineering. The engineering of enzymes with altered activity, specificity and stability, using site-directed mutagenesis and directed evolution techniques are now well established. Enzyme immobilization has become important in industry. New methods and techniques for enzyme immobilization allow for the reuse of the catalysts and the development of efficient biotechnological processes. The techniques and strategies used for enzyme production, engineering and immobilization.

Enzyme Engineering

Enzyme technology is enzyme engineering. New enzyme structures may be designed and produced in order to improve existing ones or create new activities. The advent of protein engineering, molecular biotechnology has permitted not only the improvement of the properties of these isolated proteins, but also the construction of 'altered versions' of these 'naturally occurring' proteins with novel or 'tailor-made' properties. Enzyme Engineering are:

- (1) Tailor-Made Enzymes by Protein Engineering
- (2) Rational Enzyme Design
- (3) Directed Enzyme Evolution

Immobilized Enzymes

The term 'immobilized enzymes' describes enzymes physically confined, localized in a certain region of space or attached on a support matrix. There are at least four main areas in which immobilized enzymes may find applications, that is industrial, environmental, analytical and chemotherapeutic. Environmental applications include waste water treatment and the degradation of chemical pollutants of industrial and agricultural origin. Analytical applications include biosensors. Biosensors are analytical devices, which have a biological recognition mechanism (most commonly enzyme) that transduce it into a signal, usually electrical, and can be detected by using a suitable detector. Immobilized enzymes, usually encapsulated, are also being used for their possible chemotherapeutic applications in replacing enzymes that are absent from individuals with certain genetic disorders.

Advantages of Immobilized Enzymes

1. Repetitive use of a single batch of enzymes.
2. Immobilization can improve enzyme's stability by restricting the unfolding of the protein.
3. Product is not contaminated with the enzyme. This is very important in the food and pharmaceutical industries.
4. The reaction is controlled rapidly by removing the enzyme from the reaction solution (or vice versa).

Enzymes Involved in Xenobiotic Metabolism and Biochemical Individuality

The term xenobiotic metabolism refers to the set of metabolic pathways that chemically modify xenobiotics, which are compounds foreign to an organism's normal biochemistry, such as drugs and poisons. The term biochemical individuality of xenobiotic metabolism refers to variability in xenobiotic metabolism and drug responsiveness among different people. Biochemical individuality is a significant factor that can improve public health, drug therapy, nutrition and health impacts such as cancer, diabetes and cardiovascular disease. Most xenobiotics are lipophilic and able to bind to lipid membranes and be transported in the blood. The enzymes that are involved in xenobiotic metabolism. One of the first defense mechanism against environmental carcinogens and xenobiotic compounds. Xenobiotic metabolism follows mainly three phases (I, II, III). In Phase I, the original compound obtain increased hydrophilicity and constitute an adequate substrate for phase II enzymes, by the introduction of a polar reactive group ($-\text{OH}$, $-\text{NH}_2$, $-\text{SH}$ or $-\text{COOH}$). In Phase II, the products of Phase I can be conjugated to substrates such as GSH, which result in a significant increase of water solubility of xenobiotic, promoting its excretion. The ATP-dependent transporters that facilitate the movement of the polar conjugates (by phase I and II) across biological membranes and their excretion from the cell constitute Phase III proteins. The enzymes that are involved in xenobiotic metabolism are genetically polymorphic, affecting the individual delicacy to environmental pollutants.

Phase I: Human cytochrome P450, is one of the most important enzymes that takes part in xenobiotic metabolism; its genetic polymorphisms. Genetic polymorphisms of this gene impact smoking behaviour. Example of genetic polymorphism's impact of this enzyme came that CYP1A1 phenotype AA showed association with increased risk of developing papillary thyroid cancer.

Phase II: Polymorphisms of human UGT correlate with diseases and side effects of drugs, for example the isoform UGT1A1 is associated with diseases of bilirubin metabolism. N-Acetyltransferases (NAT) are important enzymes that participate in metabolic activation of carcinogenic aromatic and heterocyclic amines that are present in cigarette smoke. Smokers with MnSOD AA genotype and prostate cancer risk, especially in case of rapid NAT1 subjects. The AA genotype of MnSOD in women smokers have an elevated risk for breast cancer. Tobacco smoke as well as smoked foods, cereals, leafy green vegetables and fossil fuels combustion by-products are the sources of exposure to polycyclic aromatic hydrocarbons (PAHs). PAHs have been considered as potential carcinogens for human. The lack of dose–response relationship of PAHs and breast cancer may be due to genetic differences in metabolic activation and detoxification of PAHs.

Phase III: The proteins of phase III are membrane transporters. These proteins seem to be significantly implicated in the absorption, distribution and discard of drugs. There are genetic polymorphisms of drug transporters, which appear to have clinical impact and have been detected in multiple clinical and in vitro studies.

Chemical Composition of Enzymes

For many enzymes, protein is not the only component required for its full activity. On the basis of the chemical composition of enzymes, they are categorized into several groups, as follows:

1. Polypeptide, the only component, for example, lysozyme, trypsin, chymotrypsin, or papain.
2. Polypeptide plus one to two kinds of metal ions, for example, α -amylase containing Ca^{2+} , kinase containing Mg^{2+} , and superoxide dismutase having Cu^{2+} and/or Zn^{2+} .

3. Polypeptide plus a prosthetic group, for example, peroxidase containing a heme group.
4. Polypeptide plus a prosthetic group and a metal ion, for example, cytochrome oxidase (a + a₃) containing a heme group and Cu²⁺.
5. Polypeptide plus a coenzyme, for example, many dehydrogenases containing NAD⁺ or NADP⁺.
6. Combination of polypeptide, coenzyme, and a metal ion, for example, succinate dehydrogenase containing both the FAD and nonheme iron.

Biochemistry of Fruits

Fruits are major ingredients of human diet and provide several nutritional ingredients including carbohydrates, vitamins and functional food ingredients such as soluble and insoluble fibers, polyphenols and carotenoids. Biochemical changes during fruit ripening make the fruit edible by making them soft, changing the texture through the breakdown of cell wall, converting acids or stored starch into sugars and causing the biosynthesis of pigments and flavour components. Fruits are processed into several products to preserve these qualities. The fruits have developed various organoleptic (stimulatory to organs) characteristics that include attractive colour, flavour and taste. The biochemical characteristics and pathways in the fruits are developmentally structured to achieve these goals. The nutritional and food qualities of fruits arise as a result of the accumulation of components derived from these intricate biochemical pathways. In terms of production and volume, tomato, orange, banana and grape are the major fruit crops used for consumption and processing around the world.

Lipid Metabolism

Among fruits, avocado and olive are the only fruits that significantly store reserves in the form of lipid triglycerides. In avocado, triglycerides form the major part of the neutral lipid fraction, which can account for nearly 95% of the total lipids. Palmitic, palmitoleic, oleic and linoleic acids are the major fatty acids of triglycerides. The oil content progressively increases during maturation of the fruit, and the oils are compartmentalized in oil bodies or oleosomes. The

biosynthesis of fatty acids occurs in the plastids, and the fatty acids are exported into the endoplasmic reticulum where they are esterified with glycerol-3-phosphate by the action of a number of enzymes to form the triglyceride. The triglyceride-enriched regions then are believed to bud off from the endoplasmic reticulum as the oil body. The oil body membranes are different from other cellular membranes, since they are made up of only a single layer of phospholipids. The triglycerides are catabolized by the action of triacylglycerol lipases with the release of fatty acids. The fatty acids are broken down into acetyl-CoA units through β -oxidation. With the decline in phospholipid content, there is a progressive increase in the levels of neutral lipids, primarily diacylglycerols, free fatty acids and fatty aldehydes. Membrane lipid degradation occurs by the tandem action of several enzymes, one enzyme acting on the product released by the previous enzyme in the sequence.

Fruit Juice Processing

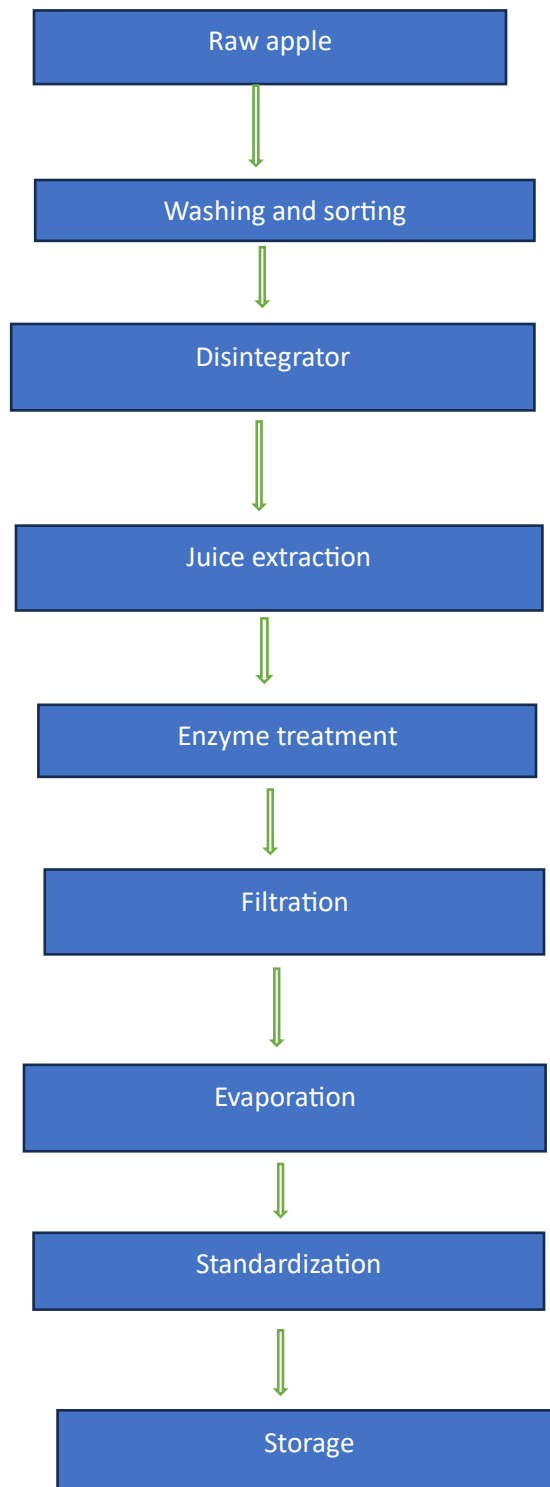
The quality of the juice depends on the quality of the raw material, regardless of the process. The quality of the fruit is dependent on the stage of maturity or the stage of ripening. The major physicochemical parameters used in assessing fruit ripening are sugar content, acidity, starch content, and firmness. The main steps involved in the processing of most type of juice include the extraction of the juice, clarification, juice deaeration, pasteurization, concentration, essence add-back, canning or bottling, and freezing (less frequent). Juice extractors for oranges and grapefruits, whose peel contain bitter oils, are designed to cause the peel oil to run down the outside of the fruit and not enter the juice stream. Since apples do not contain bitter oil, the whole apples are pressed. Juice extraction should be done as quickly as possible, in order to minimize oxidation of phenolic compounds in fruit juice by naturally present enzymes.

Apple Juice Processing

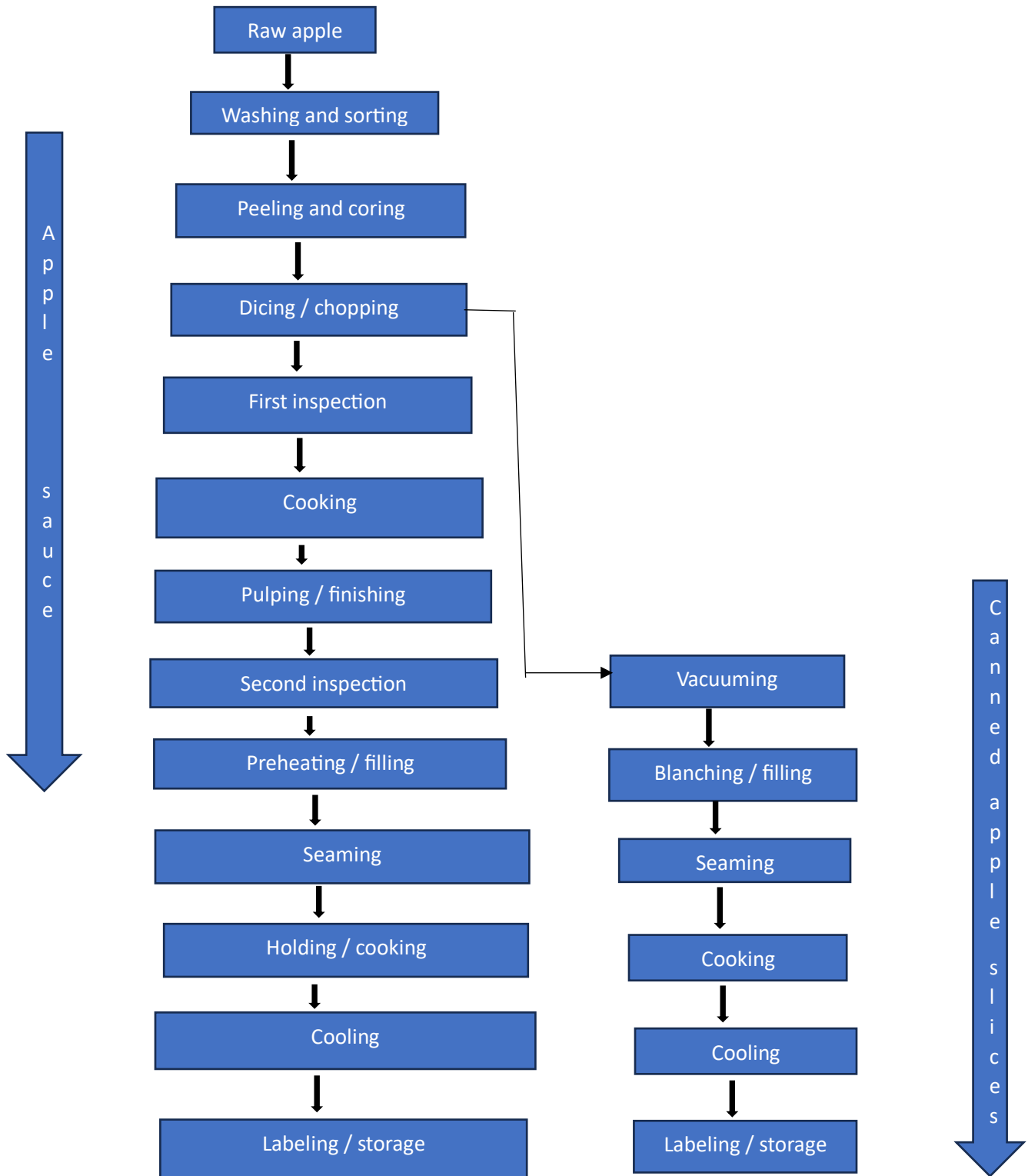
The processing of apple juice starts with washing and sorting of the fruit in order to remove soil and other foreign material as well as decayed fruits. Any damaged or decayed fruit should be removed or trimmed in order to keep down the level of patulin in the finished juice. Patulin is an indicator, which tells if the juice was produced from windfalls or spoiled apples. The acceptable level of patulin in most countries is less than 50 ppb. Patulin is carcinogenic and teratogenic. Various methods are currently used to reduce the levels of patulin in apple juice, namely, charcoal treatment, chemical preservation (sulfur dioxide), gamma irradiation, fermentation, and trimming of fungus-infected apples. The pressing followed by centrifugation resulted in an average toxin reduction of 89%. Total toxin reduction using filtration, enzyme treatment, and fining were 70, 73, and 77%, respectively, in the finished juice. Patulin reduction was due to the binding of the toxin to solid substrates such as the filter cake, pellet, and sediment. Prior to pressing, apples are ground using disintegrators, hammers, or grating mills. The effectiveness of the pressing operation depends on the maturity level of the fruits, as more mature fruits are often difficult to press. A wide range of presses is used in juice extraction including hydraulic, pneumatic, and screw/basket type. The vertical hydraulic is a batch-type press and requires no press aid. The main disadvantage is that the press is labor intensive and produces juice with low solids content. Hydraulic presses are the oldest type of press and are still used worldwide. The newer versions are automated and require press aid such as up to 1–2% paper pulp or rice hulls or both in order to reduce spillage and increase juice channel in the mash. The apple mash has many natural enzymes. Pectinolytic enzyme products contain the primary types of pectinases, pectinmethylesterase (PME), polygalacturonase (PG), pectin lyase, and pectin transeliminase (PTE). PME deesterifies methylated carboxylic acid moieties of pectin, liberating methanol from the side chain, after which PG can hydrolyze the long pectin chains. Enzymatic mash treatment has been developed to improve the pressability of the mash and, therefore the throughput and yield. An amount of 80–120 mL of enzyme per ton is added to the apple mash in order to break down the cell structure. High-molecular weight constituents of cell walls, like protopectin, are insoluble and inhibit the extraction of the juice from the fruit and keep solid particles suspended in the juice. Pectinase used in the apple juice

processing is extracted from the fungus. Pectinase developed for apple mash pretreatment acts mainly on the cell wall, breaking the structure and freeing the juice. Also, the viscosity of the juice is lowered, and it can emerge more easily from the mash. The high content of pectin esterase (PE) causes the formation of deesterified pectin fragments, which has a low water-binding capacity and reduces the slipperiness. These pectins consist of chains of galacturonic acid joined by alpha-glycoside linkage. In addition, polymers of xylose, galactose, and arabinose (hemicelluloses) form a link with the cellulose. The entire system forms a gel that retains the juice in the mash. The extraction is easier, even if the pectins are partially broken by pectinesterase. The pomace acts like a pressing aid, when used with mash predraining. The application of enzyme treatment can increase the press throughput by 30–40% and the juice yield by over 20%. Mash pretreatment also increases the flux rate of ultrafiltered apple juice by up to 50%. An important by-product of apple juice industry is pectin. Therefore, overtreatment of mash with pectinolytic enzymes could render the pomace unsuitable for the production of pectin. Inactivation of the enzyme after reaching the appropriate level of pectin degradation is an important step in the production of apple juice. Residual pectic enzymes in apple juice concentrate could cause setup problems, when used for making apple jelly. There is a recent development in apple juice extraction with the process of liquefaction. Liquefaction is a process of completely breaking down the mash by using an enzyme preparation, temperature, and time combination. The liquefied juice is extracted from the residual solid by the use of decanter centrifuges and rotary vacuum filters. The addition of cellulose enzyme to the mash to further degrade the cellulose to soluble solids, increasing the juice Brix nearly by 5°. The commercially available enzyme preparations contain more than 120 substrate specific enzyme components. The principle of the system is as follows: the mash is heated, predrained, and counterwashed with water and recycled hot juice. A 90–95% recovery is possible when the throughput is about 3 tons per hour. The main disadvantage of the system is the lower soluble solids content of the obtained juice. Juice yield from different types of extraction varies from 75% to 95%, and depends on many factors including the cultivar and maturity of the fruit, the type of extraction, the equipment and press aids, the time, temperature, and the addition and concentration of the enzyme to the apple mash.

Apple juice and concentrate flow chart



A flow chart depicting steps in apple processing



Apple Sauce

Diced or chopped apples with added sugar, preferably a sugar concentrate, are cooked at 93–98°C for 4–5 minutes in order to soften the fruit and inactivate polyphenol oxidase. Sauce with a good texture, color, and consistency is produced with high quality raw apples and a good combination of time and temperature treatment. Cooked applesauce is passed through a pulper of 1.65–3.2 mm finishing screen to remove unwanted debris and improve the texture. Applesauce is then heated to 90°C and immediately filled in glass jars or metal cans. The filled apple sauce is seamed or capped at 88°C and cooled to 35–40°C after 1–2 minutes. There are various types of apple sauce that include natural, no sugar added, “chunky”, cinnamon applesauce, and mixture of applesauce and other fruits such as apricot, peach, or cherry.

Chemical Composition of Vegetables

Fresh vegetables contain more than 70% water, and very greater than 85%. Beans and other dry crops are exceptions. The protein content is often less than 3.5% and the fat content less than 0.5%. Vegetables are also important sources of digestible and indigestible carbohydrate, as well as of minerals and vitamins. They contain the precursor of vitamin A, beta-carotene, and other carotenoids. Carrots are one of the richest sources of beta-carotene (provitamin A).

Vitamins: Vegetables are major contributors to our daily vitamin requirements. The nutrient contribution from a specific vegetable is dependent on the amount of vitamins present in the vegetable, as well as the amount consumed. The approximate percentage that vegetables contribute to daily vitamin intake is: vitamin A-50%, thiamine-60%, riboflavin-30%, niacin-50%, and vitamin C-100%. Vitamins are sensitive to different processing conditions including; exposure to heat, oxygen, light, free water, and traces of certain minerals. Trimming, washing, blanching, and canning can cause loss in vitamin content of fruits and vegetables.

Minerals: The amount and types of minerals depend on the specific vegetable. Not all minerals in plant materials are readily available and are mostly in the form of complexes. An example is calcium found in vegetables as calcium oxalate. Green leafy vegetables are rich in magnesium and iron.

Dietary Fiber: The major polysaccharides found in vegetables include starch, and dietary fiber such as cellulose, hemicellulose, pectic substances, and lignin. Cell walls in young vegetables are composed of cellulose. As the produce ages, cell walls become higher in hemicellulose and lignin. These materials are tough and fibrous and their consistency is not affected by processing. Some vegetables such as potato also contain varying amounts of starch resistant to hydrolysis (resistant starch). Resistant starch is not digested as efficiently as regular starch, and reaches the colon where they undergo microbial fermentation. The short chain fatty acids liberated during the digestion of resistant starch is considered to be beneficial to the health. Roots of vegetables such as endive are rich in fructo-oligosaccharides such as inulin, which are considered to possess health regulatory function.

Proteins: Most vegetables contain less than 3.5% protein. Soybeans are an exception. In general, plant proteins are major sources of dietary protein in places where animal protein is in short supply. Plant proteins are deficient or limiting in one or more essential amino acids. Wheat protein is limiting in lysine, while soybean protein is limiting in methionine. Leafy green vegetables are also rich in proteins, especially photosynthetic proteins such as ribulose-bis-phosphate carboxylase oxygenase and other chloroplast proteins. Multiple sources of plant proteins are recommended in the diet because of the absence of key amino acids.

Lipids: The lipid content of vegetables is less than 0.5% and primarily found in the cuticles, as constituents of the cell membrane, and as a part of the internal cell structure (oleosomes). Even though lipids are a minor component of vegetables, they play an important role in the characteristic aroma and flavor of the vegetable. The characteristic aroma of cut tomato and cucumber results from components released from the lipoxygenase pathway, through the action of lipoxygenase upon linoleic and linolenic acids and the hydroperoxide lyase action on the peroxidized fatty acids to produce volatile compounds. This action is accentuated, when the tissue is damaged. The results of the action of

lipoxygenase are sometimes deleterious to the quality—for example, the action of lipoxygenase on soybean oil leads to rancid flavors and aromas.

Volatiles: The specific aroma of vegetables is due to the amount and diversity of volatiles they contain. Volatiles are present in extremely small quantities.

Characteristic flavors and aromas are a combination of various compounds, mainly short chain aldehydes, ketones, and organic acids. Of more than 400 volatiles identified in tomato, the following have been reported to play important roles in fresh tomato flavor: hexanal, trans-2-hexenal, cis-3-hexenal, cis-3-hexenol, trans-2-trans-4 decadienal, 2-isobutylthiazole, 6-methyl-5-hepten-2-one, 1-penten-3-one, and β -ionone.

Water: Water is the most abundant single component of most vegetables (up to 90% of total weight). The maximum water content of vegetables varies between individuals due to structural differences. Agricultural conditions also influence the water content of plants. As a major component of vegetables, water impacts both on the quality and the rate of deterioration. Harvest should be done during the cool part of the day in order to keep the turgidity to its optimum. Loss of turgor under post harvest storage is a major quality-reducing factor in vegetables.

Organic Acids: Organic acids are important contributors to the taste and flavor of many vegetables (tomato). Total titratable acidity, the quantity and specificity of organic acids present in vegetables influence the buffering system and the pH. Acid content decreases during maturation, because of its use for respiration and transformation into sugars through gluconeogenesis. Certain fruits are used as vegetables when immature. For example, immature mango fruits, which are rich in organic acids, are used as vegetables.

Pigments: Pigments are mainly responsible for the skin and flesh colors in vegetables. The vegetables undergo changes during maturation and ripening of vegetables, including loss of chlorophyll (green color), synthesis and/or revelation of carotenoids (yellow and orange) and development of anthocyanins as in eggplant (red, blue and purple). Vegetables such as carrots are especially rich in beta-carotene, and red beets owe their red color to beta-cyanins. Tomatoes are a rich source of the red carotenoid lycopene. Anthocyanins belong to the group of flavonoids, occur as glycosides, and are water-soluble. They are unstable and

easily hydrolyzed by enzymes to free anthocyanins. The latter are oxidized to brown products by phenol-oxidases. The colors of anthocyanins are pH dependent. In basic medium, they are mostly violet or blue, whereas in acidic medium they tend to be red. Several exotic new vegetables with different colors have been introduced recently, that include purple carrots and tomatoes containing anthocyanins, yellow, and green cauliflower (broccoflower).

Phenolic Components: Phenolic compounds found in vegetables vary in structure from simple monomers to complex tannins. Under most circumstances they are colorless, but after reaction with metal ions, they assume red, brown, green, gray, or black coloration. The various shades of color depend on the particular tannins, the specific metal ion, pH, and the concentration of the phenolic complex. Phenolics, which are responsible for the astringency in vegetables, decrease with maturity, because of the conversion of astringent phenolics from soluble to insoluble form.

Carbohydrates: The carbohydrate content of vegetables is between 3% and 27%. Carbohydrates vary from low molecular weight sugars to polysaccharides such as starch, cellulose, hemicellulose, pectin, and lignin. The main sugars found in vegetables are glucose, fructose, and sucrose. Vegetables contain higher amount of polysaccharides (starch). Root vegetables are rich in starch (e.g., taro and colocasia, various yams, tapioca, sweet potato, potato). Plantains are also rich in starch. Fruits of the Artocarpaceae family (jack fruit, bread fruit) are also rich in starch prior to their ripening, when they are used as vegetables.

Turgor and Texture: The predominant structural feature of vegetables is the presence of parenchyma cells that are assembled into metabolically and functionally important regions for their function. In leaf tissues, the parenchymal cells are organized to obtain photosynthetic efficiency. In root tissues, the cells are loaded with starch granules. The texture of vegetables is largely related to the elasticity and permeability of the parenchyma cells. Cells with high content of water exhibit a crisp texture. The cell vacuoles contain most of the water of plant cells. The vacuolar solution contains dissolved sugars, acids, salts, amino acids, pigments and vitamins, and several other low-molecular-weight constituents. The osmotic pressure within the cell vacuole, and within the protoplast against the cell walls, causes them to stretch slightly in accordance with their elastic properties.

These processes determine the specific appearance and crispness of vegetables. Damaged vegetables lose their turgor after processing and tend to become soft unless precautions are taken in packaging and storage.

Bread

Many different types of bread are produced in the world. Bread formulations and technologies differ both within and between countries due to both traditional and technological factors including: (1) which cereals are traditionally grown in a country and their suitability for bread baking, (2) the status of bread in the traditional diet, (3) changes in lifestyle and living standards, (4) globalization of eating habits, and (5) economic possibilities for investing in new types of bread-making equipment. The basic production of most bread involves the addition of water to wheat flour, yeast, and salt. Other cereal flours may be blended into the mixture, and other optional ingredients include sugar, fat, malt flour, milk and milk products, emulsifiers, and gluten. The mixture is worked into an elastic dough that is then leavened by the yeast to a soft and spongy dough that retains its shape and porosity when baked. An exception to this is the production of bread containing 20–100% rye flour, where the application of sourdough and low pH are required.

Bread Formulation

The formulation of bread is determined by several factors. In a simple bread, the baking properties of the flour are of vital importance in determining the characteristics of the loaf using a given technology. In addition, the bread obtained from using poor bread flour or suboptimum technology may be improved by using certain additives. The major methods used to prepare bread are summarized. In the straight dough method, all the ingredients are added together at the start of the process, which includes two fermentation steps and then two proofing steps. In the sponge and dough method, only part of the dry ingredients are added to the water, and this soft dough undergoes a fermentation of about 5 hours before the remainder of the ingredients are added and the dough is kneaded to develop the structure. Although these processes are time

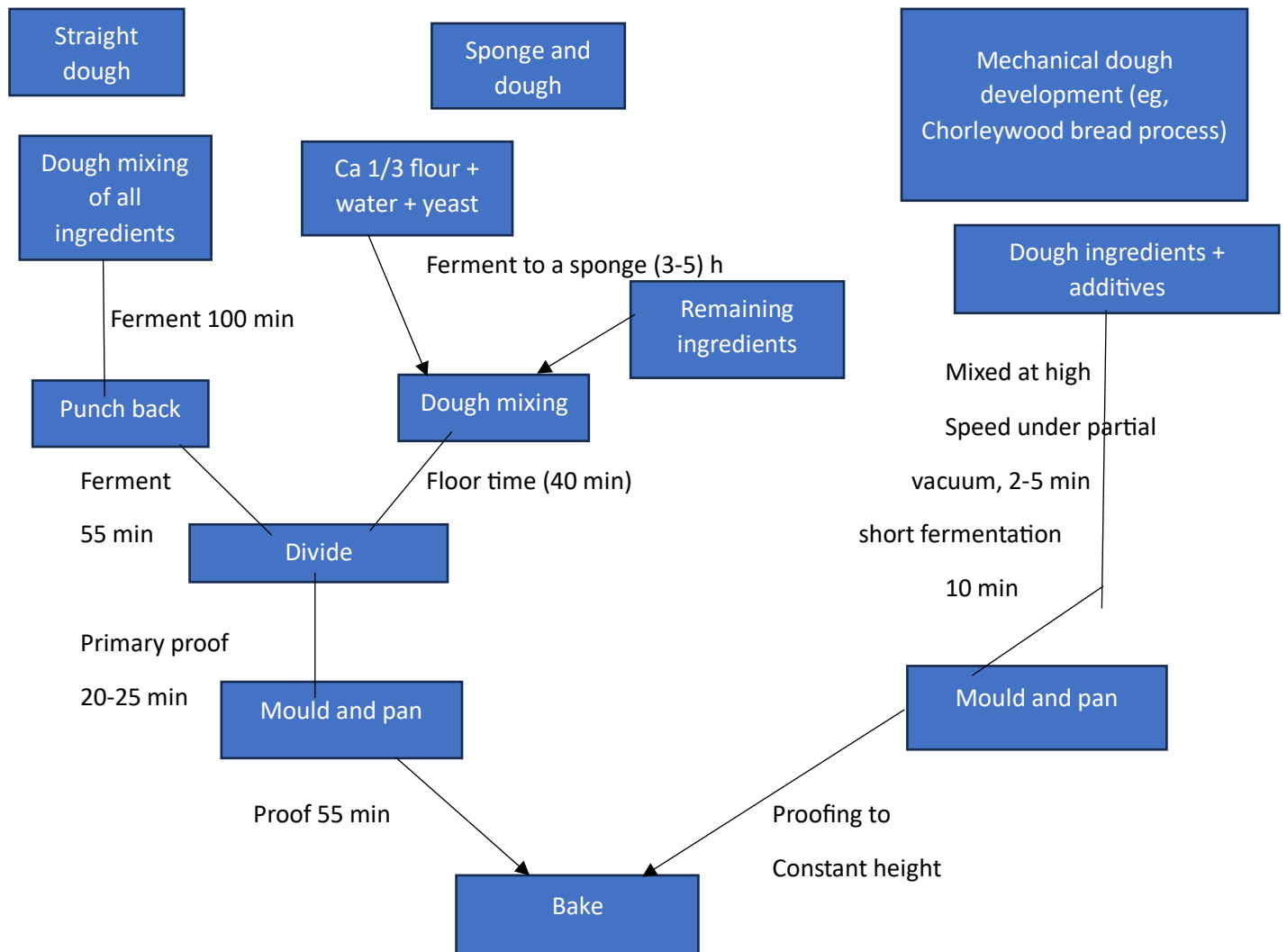
consuming, their advantages are that they develop a good flavor in the bread and that the timing and technology of the processes are less critical. The fermentation step is virtually eliminated, and dough formation is achieved by intense mechanical mixing and by various additives that hasten the process. The resulting loaf has a high volume and a thin crust but lacks flavor and aroma. The trend is now away from this kind of process due to customer demand for more flavorful bread and reduced use of additives.

Bread Additives

Dough Additive	Role
Cysteine. Sodium sulphite and metabisulphite	Reducing agent. Aids optimal dough development during mixing by disrupting disulphide ($-S-S-$) bonds. A “dough relaxer.”
Amylase	Releases soluble carbohydrate for yeast fermentation and Maillard browning reaction. Reduces starch retrogradation.
Ascorbic acid	Oxidizing agent. Strengthens gluten and increases bread volume by improving gas retention.
Potassium iodate, calcium iodate; calcium peroxide; azodicarbonamide	Fast-acting oxidants; oxidizes flour lipids, carotene and converts sulphydryl ($-SH$) groups to disulphide ($-S-S-$) bonds.

Potassium and calcium bromates	Delayed-acting oxidants: Develops dough consistency, reduces proofing stage.
Emulsifiers, strengtheners/conditioners and crumb softeners	Dispersion of fat in the dough. Increase dough extensibility. Interact with the gluten-starch complex and thereby retard staling.
Soy flour	Increases nutritional value, bleaches flour pigments, increases in loaf volume, increases crumb firmness and crust appearance, promotes a longer shelf life.
Vital wheat gluten and its derivatives	Increases gluten content, used especially when mixing time or fermentation time is reduced. Water adsorbant. Improves dough and loaf properties.
Hydrocolloids: Starch-based products from various plants	Regulates water distribution and water-holding capacity and thereby improves yield. Strengthens bread crumb structure and improves digestibility
Cellulose and cellulose-based derivatives	Source of dietary fiber.
Salt	Enhances flavor (ca. 2% based on flour weight) and modifies mixing time for bread and rolls. Increases dough stability, firmness and gas retention properties. Raises starch gelatinization temperature

Bread-processing methods



The Beer Brewing Process

The principal raw materials used to brew beer are water, malted barley, hops and yeast. The brewing process involves extracting and breaking down the carbohydrate from the malted barley to make a sugar solution (called “wort”), which also contains essential nutrients for yeast growth, and using this as a source of nutrients for “anaerobic” yeast growth. During yeast fermentation, simple sugars are consumed, releasing heat and producing ethanol and other flavoring metabolic by-products. The major biological changes, which occur in the brewing process, are catalyzed by naturally produced enzymes from barley (during malting) and yeast. The rest of the brewing process largely involves heat exchange, separation, and clarification, which only produces minor changes in chemical composition when compared to the enzyme catalyzed reactions. Barley is able to produce all the enzymes that are needed to degrade starch, β -glucan, pentosans, lipids, and proteins, which are the major compounds of interest to the brewer.

Schematic overview of the brewing process



Biochemistry and Probiotics

Probiotics are live microorganisms which, when administered in sufficient quantity, confer a health benefit to the host. Many health effects have been suggested: improved carbohydrate digestion in the gastrointestinal (GI) tract, reduction of the incidence of diarrhoea, immune system enhancement, blood cholesterol reduction. From a technological and biochemical standpoint, this definition of probiotics implies two important features: (1) the cells must be viable, and (2) a certain quantity must be maintained.

Biochemical processes

Many biochemical processes are critical in the functionality of probiotic bacteria. From a technological perspective, it can be foreseen that cells will be adapted to enhance a specific enzymatic activity that will promote their growth or their stability during storage. Minor acid, osmotic, and thermal stresses have been proposed for this purpose. As knowledge of the enzymatic systems involved in health functionality of probiotics increases, the requirement for viable cells might gradually be reduced. The critical element for the health effect may be limited to the enzymatic components, for example, the quantity of the pro-bioactive. The use of pure enzymes might eventually be considered in substitution to probiotics, but only if the enzymes are stable in the matrix and if they survive passage to the GI conditions.

Biochemistry and Growth of Probiotic Cultures in Foods

Several different metabolic pathways explain the biosynthetic functions of microorganisms that could maintain their life. Each metabolic pathway consists of many reactions that are regulated by different enzyme systems, and so the level of enzymes and their activity sustain and control the functions of the microbial cell. Breakdown of nutrients (carbohydrates, proteins, lipids, and other minor constituents) present in the growth medium results in the production of smaller molecules that are subsequently consumed for buildup and division of the microbial cells as well as energy requirements for survival. In lactic acid bacteria

(LAB) (i.e., the lactococci, leuconostoc, lactobacilli, streptococci, and bifidobacteria), energy is mainly supplied by the fermentation of carbohydrates. Hundreds of enzymes are required to sustain life in microorganisms. The two most important biochemical reactions are carbohydrate assimilation and protein metabolism. This justifies the focus that will be made of these particular enzymatic activities.

Prebiotics and Other Foods

Prebiotics are nondigestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the GI system. This definition overlaps with the definition of dietary fiber, with the exception of its selectivity for certain bacterial species and a wider range of health effects. Peptides, proteins, and lipids contain prebiotics characteristics, but some carbohydrates have received the most attention, including lactulose, inulin, and a range of oligosaccharides that supply a source of fermentable carbohydrate for the beneficial bacteria in the colon. The nutritional composition of pulses such as complex carbohydrates, protein, vitamins, and minerals as well as antioxidants, and only very small amounts of unsaturated fats made this ingredients as a very good source of prebiotic components for human body as well as yogurt and probiotics bacteria. Enriching milk with prebiotic supplements enhances the stability of probiotics in yogurt, but very few studies have been conducted with soy or pulses. Addition of soy protein isolates in yogurt does not improve stability during storage but some pulses do. Food fermentations with probiotics have mainly been conducted on dairy and soy substrates. Pulses contain many of the carbohydrates of soy but there are also various other oligosaccharides. Therefore, from a carbohydrate perspective, growth of probiotics in pulses should require similar enzymatic profiles to those required in soy; a wider range of cultures can theoretically develop in some pulses due to the presence of verbascose or other oligosaccharides. Cereal-based products also offer many possibilities for the development of probiotic-based. Cereals mainly have starch. Assimilation of starch typically requires amylases and maltases. Vegetables are also frequently used as substrates for lactic acid fermentations and are thus potential matrices for probiotic cultures. Sucrose is found in these

matrices, but a wide variety of substrates are encountered. For example, mannitol is the main carbon-based substrate but original polysaccharides are discovered.

To examine each plant-based matrix for the required enzymes. Following are the points that must be emphasized:

- Carbohydrate substrates vary as a function of the food matrix and enzymatic requirements vary accordingly.
- There is variability in the ability of probiotic bacteria to use the carbohydrates; a strain selection process is required.

BIOCHEMISTRY AND HEALTH FUNCTIONALITY

Survival to Gastric Acidity

Many bacteria do not survive passage to the conditions of the GI tract and, as mentioned previously, one of the most important criteria for functionality of probiotic bacteria is the survival to acid conditions of the stomach. Proton-translocating ATPases are the enzymes that are involved in maintaining a high pH_i , as they contribute to excrete protons outside the cell. Acid resistance of probiotic cells in the stomach can also be linked to the presence of a fermentable sugar in the medium. This shows that numerous enzymatic systems interact to prevent a big drop in pH_i , when the bacteria produce lactic acid during their fermentation or when the cells are exposed to an exocellular environment having a low pH. Cells can be adapted to enhance their resistance to acid. This ATR has been shown to be effective on subsequent short-term acid stresses such as those that occur when cells are exposed to gastric solutions. As a result, enzymatic adaptations (H^+ -ATPases or others) improve the survival of probiotics to passage in the GI tract. It can be assumed that survival of probiotics to passage in the stomach requires at least two sets of enzymes: (1) those that can assimilate sugar or amino acid substrates and generate ATP and (2) those that excrete protons outside the cell to help maintain an acceptable pH_i .

Lactose Maldigestion

Lactase insufficiency indicates that the concentration of the β -gal in the cells of the small intestine mucosa is very low. As a result, hypolactasia causes insufficient digestion of lactose in the GI tract. This phenomenon is alternatively called lactose malabsorption, lactose maldigestion, or lactose intolerance. In addition to the intrinsic intestinal lactase activity and its determinants, other parameters that affect lactose digestion include ethnic origin and age. Lactase activity is high at birth, decreases in childhood and adolescence, and remains low in adulthood. The symptoms of lactose intolerance are increased breath hydrogen, flatulence, abdominal pain, and diarrhoea. The benefit of yogurt in lactose digestion in the GI tract has been granted and evidence points toward a reduction of symptoms of intolerance in lactose maldigesters. The synthesis of β -gal by the yogurt starter culture is considered as the pro-bioactive component involved in the positive effects on intestinal functions and colonic microflora, and reduced sensitivity to symptoms. Unbroken bacterial cell walls act as a mechanical protection of lactase during gastric transit and also affect the discharge of the enzyme into the small intestine; they consequently influence the efficiency of the system. It must also be mentioned that reduced amounts of lactose are often found in cheeses due to lactose utilization by starter microorganisms. Lactose catabolism mainly occurs by β -gal derived from the yogurt starters in fermented milk processing. The optimum activity of streptococcal β -gal is at a neutral pH and at 55°C in presence of buffer. Activity of β -gal is stimulated in presence of Mg^{2+} and oxgall (0.15 mL/100mL), while ethylenediaminetetraacetic acid (EDTA) causes inhibition. Thermal denaturation occurs at 60°C, although stability can be enhanced by the addition of bovine serum albumin. It can be expected that yogurt drinks heated at high temperatures to enable storage at room temperature would not contain active β -gal and not present the enzymatic functionality. In comparison with yogurt cultures, other probiotic bacteria usually promote lactose digestion in the small intestine less efficiently. Some probiotic bacteria may act by preventing symptoms of intolerance in the large intestine in addition to (or rather than) by improving lactose digestion in the small intestine. Yogurt cultures are not included in lists of probiotic bacteria presumably because they generally do not highly survive the gastric transit nor grow in the intestines.

Blood Cholesterol Level

High cholesterol in serum is associated with the incidence of human cardiovascular diseases. One of the health-promoting benefits of probiotics is their ability to reduce blood cholesterol, which was observed in humans and animals. This points to a specific biological activity that is variable between cultures. Bile salt hydrolase (BSH) in probiotics renders them more tolerant to bile salts, and it is believed that this activity also helps to reduce the blood cholesterol level of the host. The higher BSH activity can be acquired. It is unknown if cells that are suddenly exposed to bile salts upon entrance to the duodenum can increase their BSH level and increase their functionality. Thus, BSH activity in the GI tract can potentially be enhanced by culture preparation methodologies prior to consumption. The production of secondary deconjugated bile salts through BSH activity may have undesirable effects. Contradictory data suggest that colon cancer could be enhanced, while another study suggests that *Lactobacillus reuteri* could have protective properties through precipitation of the deconjugated bile salts and a physical binding of bile salts by the bacterium, thereby making the harmful bile salts less bioavailable.

Gas Discomforts

The oligosaccharides that are not broken down by the human GI enzymes may be responsible for gas production in the GI tract. Since they are not assimilated in the small intestine, these oligosaccharides end up in the colon where they are fermented by the microbiota. Unfortunately, the consumption of beans has been associated with gas production in the GI tract. Legumes can be good substrates for the growth of probiotics but strain selection is required. Although some probiotic cultures only use the short-chain carbohydrates in legumes, the prospect of introducing probiotics into a high-fiber bean product is a very promising one. It is unknown at the present time, if the carbohydrates in beans can indeed have a positive impact on survival and growth in the GI tract. In addition to the health benefits, probiotics may also have the potential of reducing problems associated with digestibility. This benefit of probiotics on sugar metabolism in the GI tract through α -gal resembles that of β -gal for lactose

mal digestion mentioned previously. It is unknown to what extent live cells are required for the health benefit to occur.

Other Benefits

For probiotic bacteria, the main purpose of proteases is for nutrition. By hydrolysing proteins in the medium, the cells gain access to peptides and amino acids for the synthesis of their own proteins. Milk proteins contain peptidic angiotensin I-converting enzyme (ACE) inhibitors, which can be released by proteolysis during milk fermentation by some strains of *L. helveticus*. An ACE inhibition activity recorded in fermented milk may unfortunately not extend to fermented fruits or vegetables low in proteins. The production of peptides is not the only way lactic cultures can affect blood pressure. Foods naturally contain antioxidants and bioactive compounds, but some are linked to sugars or proteins. When combined with sugars or other food ingredients, some of these bioactive compounds have less biological activity. Antioxidants are bioactive compounds that are quite varied in chemical. In foods, examples include carotenoids, terpenes, anthocyanins, isoflavones, and flavonoids like quercetin. Quercetin is of interest because of its high antioxidant capacity, that is, 229% higher than that of ascorbic acid. In onions, quercetin is mainly found in three forms: (1) quercetin diglucoside (Qdg), (2) quercetin mono-glucoside (Qmg), and (3) free quercetin. The enzymes responsible for this useful bioconversion in onions are glucosidases. These enzymes contribute to enhancing the biological value of other foods as well. Many enzymatic activities of lactic cultures contribute to the synthesis, or simply to the release, of probioactives in foods.

Color and Shelf Life of Muscle-Based Foods

Meat and meat products are susceptible to degradation during storage and throughout the retail process. Color is one of the most important quality attributes for indicating the state of preservation in meat. Any energy received by food can initiate its degradation, the rate of any reactions depending on the exact composition of the product, environmental factors (light, temperature, presence of oxygen), or the presence of additives. Transition metals, such as copper or iron,

are very important in the oxidative/antioxidative balance of meat. When the free ions of these two metals interact, they reduce the action of certain agents, such as cysteine, ascorbate and α -tocopherol, oxidizing them and significantly reducing the antioxidant capacity in muscle. The iron in meat is 90% heme iron (HI), which is several times more absorbable than nonheme iron (NHI) present in other foods. Although the mechanism for heme iron release in meat has not been determined, oxidation of the porphyrin ring and denaturation of Mb are involved. When a meat product is exposed to light or is stored in darkness, the use of ascorbic acid or its salts may help stabilize the product's color. When sodium iso-ascorbate or erythorbate is used in "longaniza" production, color stability is much reduced during the retail process.

Microorganisms and Color

Although the real limiting factor in the shelf life of fresh meat is the microbial load, the consumer chooses it according to its color. The bacterial load is usually the most important cause of discoloration in fresh meat and meat products (sausages and other cooked products), so slaughter, cutting, and packaging must be strictly controlled. Bacterial contamination decisively affects the biochemical mechanisms responsible for the deterioration of meat. Another variable affecting color stability in meat is the quantity of microorganisms present, a concentration in excess of 10^6 per gram having a strong effect. Although antioxidants, such as ascorbic acid, slow down lipid oxidation and consequently improves color stability, they (antioxidants) do not alter color changes caused by bacterial growth.

BIOCHEMISTRY OF CULTURED DAIRY PRODUCTS

Composition of Milk

The quality of the cultured dairy products is influenced by the composition and quality of the raw milk. Species, breed, nutritional status, health, and stage of lactation of the cow can have an impact on the fat, protein, and calcium content and overall composition and quality of the milk. Good microbiological quality of

the raw milk is also essential to the production of safe, high-quality cultured dairy products. The predominant sugar in milk is lactose, a disaccharide of glucose and galactose. The fermentation of lactose by lactic acid bacteria in cultured dairy products provides the flavor and textural attributes that are desirable in cultured dairy products. The fat is present in the milk in the form of fat globules, which are surrounded by a polar milk fat globule membrane (MFGM). Triacylglycerols are the predominant lipid fraction in milk, accounting for 98% of the total lipids. Diacylglycerols, monoacylglycerols, fatty acids, phospholipids, and sterols account for the remaining lipid fraction. The phospholipids are integral components of the MFGM. Approximately 65% of the fatty acids in milk fat are saturated, including 26% palmitic acid and 15% stearic acid. A significant amount of short- and middle-chain fatty acids, including 3.3% butyric acid are present. These fatty acids and the breakdown products of these fatty acids are important contributors to the flavor of many cultured dairy products. Two major classes of milk proteins are caseins and whey proteins. The caseins, which make up 80% of the total protein in cow milk, are insoluble at a pH of 4.6, but are stable to heating. The whey proteins remain soluble at pH 4.6 and are heat sensitive. Fresh cow's milk is characterized as having a distinctive subtle flavor. Classes of volatile flavor compounds that have been shown to have the greatest impact on milk flavor include nitrogen heterocyclics, linolenic acid oxidation products, γ -lactones, phenolics and phytol derivatives; many of these compounds are found in foods of plant origin. Differences in the milk flavor from cows fed different diets have been attributed to concentration differences of these flavor compounds rather than the presence of different compounds.

Lactic Acid Bacteria

The lactic acid bacteria used in the development of cultured dairy products include *Streptococcus*, *Lactococcus*, *Leuconostoc*, and *Lactobacillus* genera. These bacteria are gram-positive bacteria and belong to either the Streptococcaceae or Lactobacillaceae families, depending on the morphology of the bacteria as cocci or rods, respectively. These bacteria also differ in their optimal temperature for growth, with 20–30°C the optimal temperature for mesophilic bacteria and 35–45°C the optimal temperature for thermophilic bacteria. Although the lactic acid bacteria are quite diverse in growth requirements, morphology, and physiology, they all have the ability to metabolize lactose to lactic acid and reduce the pH of

the milk to produce specific cultured dairy products. The heat treatment the cultured dairy products receive following inoculation is one of the factors that influences the selection of lactic acid bacteria for specific cultured dairy products.

Engineering Aspects of Separation Processes

The separation of valuable components from natural materials has been directed toward high value-added products. For the recovery of valuable components from raw materials, applications of separation technologies to recover major or minor components from agricultural commodities is usually a solid–liquid contacting operation. The successful and effective development of separation technologies is a critical issue in the chain of value added processing of agricultural materials such as developments in functional food ingredients, nutrients, and nutraceuticals. Separation operations are interphase mass transfer processes because they involve certain heat, mass, and phase transfers, as well as chemical reactions among food components. The engineering properties of the targeted food components via separation systems include separation modeling, simulations, optimization control studies, and thermodynamic analyses. The following issues of engineering properties are important for process optimization and simulation.

1. Chemical equilibration—binary, ternary, and multicomponent systems in solid–liquid contacting operation,
2. Diffusivity (pressure diffusion, thermal diffusion, gaseous diffusion) and convection,
3. Solubility of targeted components under different separation operating conditions,
4. Iso-electric points and charge dependence on pH,
5. Chemical interaction kinetics (colloid formation and affinity),
6. Physical properties of particles of the food material,
7. Flux and fouling properties in membrane separation processes,
8. Solvent selection, recycling, and management,

9. Nature of solvents, optimum composition of mixed solvents for certain nutrient separations, and solvent residues in food products are factors to be optimized.
10. Some solvent treatments such as evaporation, concentration, de-watering, de-coloring, toxicological analyses, waste minimization, recycling, and disposal are necessary.

Shelf Life of Foods and Food Ingredients and Food Safety

The shelf life of a food product generally refers to the keeping quality of the food. An estimated 25% of the food supplies world-wide are lost as a result of spoilage; it is economically beneficial to maintain the quality of food products at various stages of food production and storage. There are two categories of foods in relation to shelf life: shelf stable and perishable. Whether a particular food product is shelf stable or perishable depends on the intrinsic properties of the food (e.g., pH, water activity, and structure). Shelf-stable foods usually have low water activity, low pH, or a combination of both, while perishable foods tend to have high water activity and high pH. The structure or texture of the food is also an important factor in shelf stability. Extrinsic factors such as storage temperature, gaseous atmosphere, and relative humidity also determine the shelf stability of food products. These intrinsic and extrinsic factors influence the survival and growth not only of spoilage organisms but also of pathogenic organisms in foods. Food spoilage occurs as a result of physical or chemical changes in the food or of the by-products of spoilage microorganisms growing in the food product.

Pathogens present in low levels may not produce identifiable changes in the food; the presence of pathogens cannot be determined using noticeable changes in the food as an indicator. Although shelf-stable foods are less likely to be implicated in foodborne illness than perishable foods, cross-contamination of shelf-stable or perishable foods by pathogens can be a source of foodborne illness. A number of preservation applications used in the food industry are designed to extend the shelf life of the food product by reducing microbial growth; pathogens that are able to survive or even grow under preservation techniques such as refrigeration can cause foodborne illness. Effective strategies for controlling the presence of spoilage and foodborne pathogens in foods should include elimination of sources of contamination combined with food preservation technologies such as drying,

freezing, smoking, curing, fermenting, refrigeration and modified-atmosphere packaging.

Four Simple Steps for Consumers to Ensure Food Safety

Clean: Wash hands and surfaces often

- Wash your cutting boards, dishes, utensils, and counter tops with hot soapy water after preparing each food item and before you go onto the next food
- Use plastic or other nonporous cutting boards
- Consider using paper towels to clean up kitchen surfaces

Separate: Don't cross-contaminate

- This is especially true when handling raw meat, poultry, and seafood
- Never place cooked food on a plate that previously held raw meat, poultry, or seafood

Cook: Cook to proper temperatures

- Use a clean thermometer that measures the internal temperatures of cooked foods to make sure meat, poultry, casseroles, and other foods are cooked all the way through
- Cook roasts and steaks to at least 145°F. Whole poultry should be cooked to 180°F for doneness
- Cook ground beef, where bacteria can spread during processing, to at least 160°F
- Don't use recipes in which eggs remain raw or only partially cook

Chill: Refrigerate promptly

- Refrigerate or freeze perishables, prepared foods, and leftovers within 2 hours or sooner
- Never defrost at room temperatures. Thaw food in the refrigerator, under cold running water, or in the microwave. Marine foods in the refrigerator
- Divide large amounts of leftovers into small, shallow containers for quick cooling in the refrigerator

Food Allergens

The management of allergens along the food value chain and the diagnosis of food allergic diseases continue to pose serious challenges to the food industry as well as health care professionals. These priority allergens include milk, eggs, soya beans, peanuts, tree nuts (e.g. almonds, walnuts, pecans, cashews, Brazil nuts, hazel nuts, pistachios, pine nuts, macadamia nuts, chestnuts and hickory nuts), seafood such as fish (i.e. both saltwater and freshwater finfish), crustaceans (e.g. shrimp, prawns, crab, lobster and crayfish) and molluscs (e.g. snails, oysters, clams, squid, octopus and cuttlefish), gluten-containing cereals (i.e. wheat, rye, barley and their hybridised strains and products), sesame and mustard. Symptoms of food allergic reactions and the threshold dose required to provoke allergic reaction markedly vary among sensitised individuals. Food production practices, processing conditions and matrix effects can also modify the molecular structure of food allergens and their potential immunogenic properties which can make allergens difficult to detect even when present in foods. Food allergy is emerging as a growing public health problem. Unfortunately, the management of food allergens along the food value chain and the diagnosis of food allergic diseases continue to pose a challenge to the food industry as well as health care professionals. Food allergy is an immunological reaction resulting from the ingestion, inhalation or atopic contact of food. Immunological reactions can be mediated by IgE antibodies or other immune cells such as T cells. Some workers define food allergy specifically as being those immunological responses mediated by immunoglobulin E (IgE) antibodies, whereas others use the broader definition of immunological response, which include T-cell mediated responses as well. Any protein-containing food can elicit an allergic response in sensitised individuals. Allergenic proteins in foods may be enzymes, enzyme inhibitors, structural proteins or binding proteins with varied biological functions. The pathogenesis of food allergy begins with a sensitisation phase during which time the body recognises one or more proteins in a particular food source as a foreign invader and begins to mount an immune-defensive response. Subsequent consumption of the offending food can result in an allergic response that is, immediate or delayed response.