CHAPTER 1

Overview of Food Constituents and their Role in Food Chemistry & Nutrition

1.1 Definition and Importance of Food Chemistry

Food chemistry is a division of food science that evaluates how foods are processed, prepared and distributed. This science is closely related to biochemistry in that, its principles are based on knowledge of the main components of life such as water, carbohydrates, lipids (fats), proteins, minerals and vitamins. Food chemistry is the study of chemical processes and interactions of all biological and non-biological components of foods. The biological substances include items such as meat, poultry, milk, vegetables, and fruits etc. Food is made up of non-biological chemicals that include primarily water, proteins, lipids, carbohydrates, vitamins and minerals. It is similar to biochemistry in its main components such as carbohydrates, lipids, protein, water, vitamins, minerals, enzymes, but it also includes areas such as food additives, flavors, and colors. This discipline also encompasses how food materials change under certain food processing techniques and describes the ways either to enhance or to prevent these changes. An example of enhancing a process would be to encourage fermentation of dairy products with microorganisms that convert lactose to lactic acid. An example of preventing a process would be stopping the browning reaction on the surface of freshly cut red delicious apples using lemon juice or other acidulated water.

The chemical nature of foods is important in two ways in respect to food processing:

(a) Food chemicals are altered by processing and these changes result in changes in the characteristics of the food and consumer acceptance of the product.

(b) Because of the lability of some food chemicals, the parameters used in food processing such as temperature and shear, are limited to achieve minimal changes in the characteristics of the food and to maximize consumer acceptance. Minimal processing of the food results in least changes in the chemical composition and interactions of the food constituents and provides the food with good nutritional quality. However, this type of processing results in a food product with a very short shelf life.

As processing is performed to extend the shelf life of the product by subjecting the food to processes such as drying and canning, more chemical changes may occur resulting in changes in nutritional quality of products.

Food chemistry focuses on the chemistry of foods, their deterioration and the principles underlying the improvement of foods for consumers. It applies chemistry to developing, processing, packaging, preserving, storing and distributing foods and beverages to obtain safe, economical and aesthetically pleasing food supplies.

1.2 Chemistry and Nutrition of Food Constituents

The major food constituents are water, carbohydrates, proteins, lipids, minerals and vitamins.

1.2.1 Water

A major component of food is water, which can encompass anywhere from10% in grains to 50% in meat products to around 70-80% in fruit and vegetable products. It is also an excellent place for bacterial growth and food spoilage, if it is not properly processed. It influences textural properties and the extent to which the food may be subjected to microbial spoilage. One way by which this is measured in food is by water activity which is very important in the shelf life of many foods during processing. One important aspect of food preservation is to reduce the amount of water or alter the water's characteristics to enhance shelf life. Such methods include dehydration, freezing, refrigeration etc.

Removing water through concentration, drying or freezing reduces the "free" water and prevents microbial growth. Water activity is a measure of free (unbound) water available for chemical and biological activity. Generally bacteria require a water activity of > 0.9 to grow and most yeasts and molds are inhibited by a water activity of < 0.7. Materials that are water soluble are called hydrophilic and those that are not water soluble are called hydrophobic. Food chemistry can manipulate a factor as seemingly insignificant as water to design and develop food products. Apart from the actual water content of food products that can be catered for during mixing, water is also used to create varieties that can affect the taste, texture and color of finished food products.

1.2.2 Carbohydrates

The carbohydrates in foods are mixtures of carbon, hydrogen and oxygen and can be classified as simple and complex carbohydrates. Carbohydrate, as it relates to food chemistry, is a general term used for a group of chemical compounds present in both plants and animals that are essentially carbon and water molecular combinations. Simple carbohydrates are sugars and complex carbohydrates are starches and fibers.

***Simple carbohydrates*:** These are classified as monosaccharides, disaccharides, trisaccharides etc. Monosaccharides generally may have 3-6 carbons and are called as trioses, tetroses, pentoses and hexoses depending on the number of carbon atoms. Glucose (sometimes called dextrose), fructose and galactose are three common hexoses. Ribose and deoxyribose are two common pentoses. Two monosaccharides may be linked together to form a disaccharide by a glycosidic linkage. There are two general types of carbohydrates: (a) reducing and (b) non-reducing sugars. Examples of these are glucose (reducing) and sucrose (non-reducing). Reducing sugars contain a reactive aldehyde (CHO) or keto (C=O) group that is absent in non-reducing sugars. Thermal processing can cause reactions between reducing sugars and the amino group of proteins, causing browning and altering color and flavor of the products. This reaction is termed as the Maillard reaction. Heat processing at high temperatures in a low water environment can cause caramelization (polymerization) of sugars and can result in browning reaction. Sucrose is the most common disaccharide and is made of one molecule each of glucose and fructose. Sucrose is commonly referred to as sugar. Lactose is the major sugar in milk and is made up of one molecule of glucose and one of galactose. Maltose is a disaccharide made from two molecules of glucose.

***Complex carbohydrates*:** These carbohydrates have a number of monosaccharide units linked by glycosidic linkages. Starch, cellulose, hemicellulose, pectin etc are examples of these complex carbohydrates. Starch is made up of a number of glucose units linked by α-1-4 and α-1-6 glycosidic linkages that can be digested by humans. In plants, starch is an energy reserve. Starches, commonly used as thickening agents in food, are plant storage polysaccharides that are either branched (amylopectin) or unbranched (amylose). The proportion of these two components of starch varies from plant to plant and influences the processing of the foods in which starches are used, as well as the characteristics of the food. Starches with 100% amylopectin (waxy starch) are clear with a long texture and do not form films. Starches that have >20% amylose have a pudding like short texture, are cloudy and do form films. Regular starches require heating to replace the hydrogen bonds between starch molecules with starch-water bonds, which causes gelatinization and creates the thickening effect.

In animals, small amount of energy is stored in liver and muscle as glycogen, a highly branched polymer of glucose. In glycogen also, the glucose units are linked by α-1-4 and α-1-6 glycosidic linkages.

Cellulose is the most common polysaccharide and the major component of plant cell walls. Cellulose is a polymer of glucose molecules linked together by β1-4 linkages and cannot by digested by humans. Thus, cellulose is a major component of dietary fiber.

Pectin is a polymer of galacturonic acid and is not digested by humans. In plants, pectin cements cells together. Polysaccharides may be added to foods for a variety of reasons. Nutritionally, they are generally added to increase the dietary fiber content. Functionally, polysaccharides are added to thicken, to form gels, to bind water, and to stabilize proteins. Starch is the most common polysaccharide added to food products. For some uses, starch may be chemically modified to improve stability or to alter its functional properties. Cellulose and cellulose derivatives are also added to a number of food products. The term, gum, is used to describe some of the naturally occurring polysaccharides added to food. Polysaccharides commonly added to foods include Agar, Gum tragacanth, Alginates, Locust bean gum , Carrageenan, Pectin, Guar gum, Xanthan gum, Gum Arabic, Starch, Cellulose etc.

1.2.3 Proteins

Proteins are polymers of amino acids linked together through a peptide bond. They are mainly composed of carbon, nitrogen, hydrogen, oxygen, and some sulfur, and sometimes may also contain iron, copper, phosphorus, zinc etc. They play a fundamental role in the structure and function of cells.The function of a protein is determined by the sequence of its amino acids. Proteins are essential to the nutritional well being of the human. There are twenty amino acids that are found in proteins out of which 10 are called as essential amino acids because the body cannot produce these amino acids and they have to be provided through the diet. Food chemistry explains how proteins can change their structure through many methods of food processing. Proteins in foods add texture to foods, contribute to odor and taste, form gels, stabilize foams and emulsions etc. The food sources of proteins are grains and animal foods. However, the quality of protein is superior from animal foods compared to plant foods because of amino acid composition.

Generally the conditions used in food processing are adjusted to optimize the effects of the processing on the proteins and subsequent characteristics of the food. In bread, for example, the brown crust is related to the Maillard reaction and the final structure of the bread is caused by the thermal gelation of the protein gluten.

1.2.4 Lipids

The term lipid comprises a diverse range of molecules such as water-insoluble or non polar compounds of biological origin, including triglycerides, fatty acids, phospholipids, sphingolipids, glycolipids terpenoids, waxes, retinoids and steroids. A triglyceride contains three fatty acids that are esterified to the three hydroxyl groups of glycerol. Triglycerides that contain mostly unsaturated fatty acids are oils and triglycerides that contain mostly saturated fatty acids are fats. Generally oils, because of the higher level of unsaturated fatty acids will oxidize over time. Hydrogenation (addition of hydrogen and removal of double bonds) is used to convert vegetable oils into semi-solid or solid fats to be used as ingredients in baked/processed foods. These partially hydrogenated products are less susceptible to oxidation than the original oils. Some lipids, such as phospholipids and mono and di glycerides are used as emulsifiers.

Most lipids have some polar character in addition to being largely non polar. Generally, the bulk of their structure is non polar or hydrophobic ("water-fearing"), meaning that it does not interact well with polar solvents like water. Another part of their structure is polar or hydrophilic ("water-loving") and will tend to associate with polar solvents like water. This makes them amphiphilic molecules (having both hydrophobic and hydrophilic portions).

Lipids in food include the oils of grains such as ground nuts, soybean, sunflower, corn and from animal fats such as milk, cheese, ghee, and meat. They also act as vitamin carriers. Lipids serve as energy sources, organ cushioning, insulation and are an important part of cell composition.

1.2.5 Vitamins

Vitamins are nutrients required in small amounts for essential metabolic reactions in the body. Fourteen different vitamins have been shown to be essential for normal growth and health in humans. The vitamins as a class have no particular chemical structure in common, but they can be divided into the fat soluble and water soluble vitamins. Vitamins are required in the diet because the body is either unable to synthesize them or unable to produce adequate amounts of them. By themselves vitamins do not provide chemical energy, although they may participate as coenzymes in chemical reactions which release energy from other molecules. Increasing the amount of vitamins in the diet does not necessarily increase the activity of those enzymes for which the vitamins function as coenzymes. However, lack of vitamins in the diet causes ill effects, since they are essential for the activity of many enzymes. Vitamins are classified as water soluble or fat soluble vitamins. Water soluble vitamins include B complex vitamins, vitamin C, Pantothenic acid etc. Vitamin A, D, E and K are examples of fat soluble vitamins. As the amount of water soluble vitamins in the diet is increased so is the amount excreted in the urine, with the result that accumulation of these vitamins in the body is limited. On the other hand, in the case of the fat soluble vitamins, the intake of very large quantities is known to produce toxic effects that damage various tissues. These effects are related to the fact that very large quantities of these fat soluble vitamins can accumulate in the body because they dissolve readily in the fat stores in adipose tissue.

1.2.6 Minerals

Minerals are inorganic substances, present in all body tissues and fluids and their presence is necessary for the maintenance of certain physicochemical processes which are essential to life. Although they yield no energy, they have important roles to play in many activities in the body. Minerals may be broadly classified as macro (major) or micro (trace) elements. The macro minerals include calcium, phosphorus, sodium and chloride, while the micro elements include iron, copper, cobalt, potassium, magnesium, iodine, zinc, manganese, molybdenum, fluoride, chromium, selenium and sulfur. The macro–minerals are required in amounts greater than 100 mg/day and the micro minerals are required in amounts less than 100 mg/day. Micronutrient deficiencies are a major public health problem in many developing countries, with infants and pregnant women especially at risk. The micronutrient deficiencies which are of greatest public health significance are iron deficiency, causing varying degrees of impairment in cognitive performance, lowered work capacity, lowered immunity to infections, pregnancy complications e.g. babies with low birth weight, poor learning capacity and reduced psychomotor skills.

1.3 Role of Water and Water Activity in Food

Food production and processing require large amounts of water of varying quality. Awareness of the close association between water and food borne disease is growing and thus there is a need to develop rational water use management plans within the food industry that maximize health protection. Water, like food, is a vehicle for the transmission of many agents of disease and continues to cause significant outbreaks of disease in developed and developing countries world wide. Water can also contaminate food. Contamination of foods during primary production can play a role in the transmission of food borne disease.

In Food Processing and Preservation

Water is an essential natural resource for the food processing industry, as large volumes are needed to meet processing demands. Water is used for cleaning, as carrier for nutrients, as plasticizer, as well as diluent and for food production. It has an important impact on all chemical reactions and physical state changes occurring during various food processing operations.

Water plays many critical roles within the field of food science. Solutes such as salts and sugars found in water affect the physical properties of water. The boiling and freezing points of water are affected by solutes. For example one mole of sucrose per kilogram of water raises the boiling point of water by 0.52 ^{o}C, and one mole of salt per kilogram of water raises the boiling point by 1.04 ^{o}C. Similarly, increasing the number of dissolved particles lowers water's freezing point. Solutes in water also affect water activity which affects many chemical reactions and the growth of microbes in food. Water activity can be described as a ratio of the vapor pressure of water in a solution to the vapor pressure of pure water. Solutes in water lower water activity. This is important to know because most bacterial growth ceases at low levels of water activity. Microbial growth not only affects the safety of food but also the preservation and shelf life of food.

Water hardness is also a critical factor in food processing. It can dramatically affect the quality of a product and plays a role in sanitation. The hardness of water also affects its pH balance which plays a critical role in food processing. For example, hard water prevents successful production of clear beverages. Water hardness also affects sanitation, with increasing hardness, there is a loss of effectiveness for its use as a sanitizer.

The concept of free water as opposed to the total water, including bound water, has gained wide acceptance in the food processing industry. Water activity has been reported to exert a decisive influence on such phenomena as change in color, taste and aroma, food poisoning and spoilage (shelf life), loss of vitamins etc. Total moisture content of the food generally has very little influence on these parameters. Water activity in foods can be controlled by using various additives (e.g., salts, sugars etc.,), by using satisfactory packaging materials and by maintaining favorable storage conditions. Water activity measurements are increasingly being used in food research as well as in food quality control laboratories.

1.4 The Importance of Water Activity in Foods

The importance of water activity in foods is illustrated by the following few examples:

(a) ***Growth of Microorganisms*****:** Water activity indicates the amount of water in the total water content of the food which is available to micro-organisms. Each species of micro–organism (bacteria, yeast and mould) has its own minimum water activity value below which growth is no longer possible. Water activity has its most useful application in predicting the growth of bacteria, yeasts and moulds. For a food to have a useful shelf life without relying on refrigerated storage, it is necessary to control either its acidity level (pH) or the level of water activity or a suitable combination of the two. This can effectively increase the product's stability and make it possible to predict its shelf life under known ambient storage conditions. Food can be made safe to store by lowering the water activity to a point that will not allow dangerous pathogens such as *Clostridium botulinum* and *Staphylococcus aureus* to grow in it. Particular water activity levels can support the growth of particular groups of bacteria, yeasts and moulds. For example, food with a water activity below 0.6 will not support the growth of osmophilic yeasts, which can pose a problem in high sugar products. *Clostridium botulinum*, the most dangerous food poisoning bacterium, is unable to grow at a water activity of 0.93 and below. The risk of food poisoning must be considered in low acid foods (pH > 4.5) with a water activity greater than 0.86. *Staphylococcus aureus*, a common food poisoning organism, can grow down to this relatively low water activity level. Foods which may support the growth of this bacterium include cheese and fermented sausages stored above correct refrigeration temperatures.

(b) ***Chemical stability*****:** Water activity control is an important factor for the chemical stability of foods. Most food stuffs contain carbohydrates and proteins and are therefore subject to non-enzymatic browning reactions (Maillard reaction). The Maillard reaction gets stronger at increasing water activity values and reaches its peak at water activity of 0.6 to 0.7. With further increase of water activity, this reaction gets rapidly weaker. The spontaneous autocatalyctic breaking of the molecular chains of fats is strongly influenced by water activity. This kind of food spoilage increases at high water activity values. Even at low water activity values, foods with a fat content acquire a rancid taste after being stored for some time. Foods in which the action of lipases creates fatty acids with short molecular chains are particularly affected by this kind of spoilage: they produce a strong and disagreeable smell. The conservation of food stuffs is influenced by numerous changes produced by oxidation of food, color change of carotene, oxidation of myoglobin in meat, oxidation of proteins and vitamins etc. The oxidation of fats and other food components decreases sharply at water activity values below 0.2.

(c) ***Enzymatic stability*****:** Most enzymatic reactions are slowed down at water activity values below 0.8. Some of these reactions occur even at very low water activity values. However, as many food stuffs are thermally treated during their processing, enzymatic spoilage is usually of very little importance.

Increased knowledge on the chemistry of constituents of foods and changes that occur in these constituents and interactions among theses constituents on food processing gives an opportunity for controlling the processes so that better quality products with longer shelf life can be manufactured. This information will also help to use the right raw material for the right process and product. In different food industries, food chemistry principles are being used to provide healthier foods, such as margarine made using inter-esterification to give the lowest levels of saturated fats and high levels of essential fats. Typically, such spreads are also fortified with vitamin A and vitamin D. Ideally in future, food products need to be prepared with minimum levels of added sugar, saturated fats and trans fats. Achieving this will not be easy. However, there is ample space for food chemistry to help create that type of food products by changing the chemistry of food constituents and processing conditions.

The big challenge is to make foods healthier whilst at the same time ensuring that they still taste great. Another challenge is to overcome the current consumer trend for 'natural' foods. Nutritionists and food chemists need to alter the perception of the consumers that healthy foods are completely natural foods. Consumers need to be helped to understand that food processing and food chemistry are not techniques to be afraid of but they can be used to improve their health. The consumer of the future will demand healthier products that deliver the enjoyment and convenience. Hence, food chemistry will help to design and develop new food products for the present day consumers. The study of the components of various food substances could be used to initiate an array of chemical reactions that could lead to the formation of either new or improved food products. The improvement could be taste enhancement, new aroma, color, or increased shelf life.