FOOD CHEMISTRY

R. Lasztity
Budapest University of Technology and Economics, Budapest, Hungary

Keywords: food, chemistry, composition, chemical.

Contents

Summary

Food science is an interdisciplinary subject involving chemistry, biology, microbiology, and engineering. ***Food chemistry is the science that deals with the chemical composition and properties of food and the chemical changes it undergoes.***

The subject of food chemistry as an independent branch of science was formed in the19-th century in parallel with growing interest on food quality and suppressing of food adulteration and falsification. New methods of food analysis allowed us to discover and characterize not only the major nutrients (such as proteins, carbohydrates and lipids) but also essential minor components such as vitamins and essential minerals and finally thousands of minor and micro components being natural constituents of food (such as aroma compounds, natural coloring matters, natural antioxidants). The results mentioned above formed the basis of exact evaluation of nutritive value of foods, determination of its quality and detection of adulteration and falsification of foods. Recent activity of food chemistry is primarily connected with food safety with supply of population with healthy food. An important part of this activity is the detection and determination of food contaminants and control of food additives.

In the framework of this chapter the gross chemical composition of main types of foods is overviewed. Chemical properties of proteins and enzymes, lipids, carbohydrates, vitamins, flavors and colorants, minerals and other micro components, food additives and contaminants, occurring in different foods, nutritional requirements, changes during processing and storage will are treated. No chemical formulas are included in this chapter. These are given in the related chapters dealing with individual food components. References are given for readers interested in more detailed study of given topics.

1. Introduction

Food chemistry is the science that deals with chemical composition of foods, with chemical structure and properties of food constituents, and with chemical changes food undergoes during processing and storage. In his work the food chemist relies heavily on knowledge in chemistry. On the other hand, food chemistry is also related to biochemistry (especially in study of chemical changes of food constituents) and science of nutrition (nutritive value of foods, contaminants) and microbiology (spoilage and preservation, food safety).

The material included in the theme food chemistry is divided into chapters according to main groups of food constituents: proteins and enzymes, lipids, carbohydrates, vitamins, flavors and colorants, minerals and other micro components, additives and contaminants. Only some tables giving information about gross chemical composition of main types of foods (cereals, bread, legumes, oilseeds, fruits, meat, milk, and eggs) are included in this topic level chapter.

In every group of compounds their main sources, the nutritional requirements and some food safety aspects are briefly treated. At the beginning a short historical overview is also given.

2. Historical Aspects.

Although food science as a separate science was formed only in the second half of the 19-th century, satisfactory food supply has always been a central problem for governments, since the formation of ancient societies several thousands years ago. Food laws were among the earliest known to humans. Consumer protection in the field of adulteration and falsification of food represents one of the earliest forms of government regulation of commercial enterprises. Food regulations existed in Egyptian, Hebrew, Chinese, Hindu, Greek, Roman, Arab societies.

In the Middle Ages Trade Guilds were formed whose purpose was to provide control and general supervision over the honesty and integrity of their members and the quality of their products. This activity of Trade Guilds continued till the 18-th century when the 1789 revolution in France took away the Guild's authority and hierarchies, and freedom of industry and trade was proclaimed.

The 18-th and the 19-th centuries were a period of big changes in economy and society but also in science. The developments in chemistry in this period laid the foundation of food chemistry as a separate branch of science. The work of French chemist Lavoisier contributed to final rejection of phlogiston principle. With respect to food chemistry, he established the fundamental principles of combustion and organic analysis, made the first attempts to determine the elemental composition of alcohol,, and reported on organic acids of various fruits. Scheele, a Swedish pharmacist, discovered chlorine, glycerol, isolated citric and malic acid from several fruits, and tested twenty common fruits for citric- malic- and tartaric acids. Liebig in addition to discovery newer food components perfected the analytical methods, and first classified the foods as either nitrogenous (albumin, casein, animal flesh, and blood) or non-nitrogenous (fats, carbohydrates and alcoholic beverages). Although this classification was not correct in detail and he had no knowledge about structure of proteins and carbohydrates, and many other food constituents, he published in 1847, what is apparently the first book on food chemistry entitled *Researches on Chemistry of Food.*

Discovery of microorganisms by Pasteur and knowledge of fermentation processes was a further step in development. Till the end of the 19-th century, development of chemical analytical methods, progress in physiology and nutrition made knowledge of the main chemical constituents of foods possible.

The period beginning with the industrial revolution was a time of tremendous expansion in many fields, which had a particular bearing on food quality control. Change from a largely rural society to a largely urbanized society,and from domestic to factory system in food production, with concentration of populations, placed strain on food production and distribution. This period created many public health problems too, due to bad hygienic conditions, low quality of foods, and also adulteration and falsification of food. Such situation stimulated efforts of bigger cities and governments to establish institutions to control chemical composition of foods. For example, in 1858, a municipal service was set up in Amsterdam for the control of food and beverages. Similar institutions appeared in many countries in Europe and Northern America. The regulations regarding food were revised and the first modern food laws were enacted in several countries. The growing importance of food chemistry favored establishment of agricultural experimental stations, food control laboratories, research institutions, foundation of scientific journals dealing with food chemistry and education of specialists in food chemistry.

Although in comparison with food supply and food quality in the 19-th century the present situation in this field, especially in developed countries, seems to be almost perfect, the food quality and food safety remained in the focus of activity of food chemistry. New raw materials, new technologies, new foods, wide use of chemical additives, growing environmental pollution, increased interest in relation to food-health, justifies the efforts of food chemists. The globalization of world food market needs harmonization of food regulations and food laws. That is why international organizations were established in this field. Here only the Codex Alimentarius Commission will be mentioned which was established by member countries of Food and Agriculture Organization (FAO) and World Health Organization (WHO) in 1962.

3. Gross Chemical Composition of Foods.

As a result of investigations of food quality control stations and many other institutions, at present a lot of books, data banks and other facilities are available for obtaining information about chemical composition of foods. Bearing in mind that the structure of topic food chemistry is based on type of constituents and not on different types of foods, here, in this chapter a short review will be given about gross chemical composition and character of these foods.

3.1. Cereals and Cereal Products

Cereals are staple foods in majority of countries and play a central role in nutrient supply. The chemical composition of cereals grains is characterized by a high content of starch, a substance with a relatively significant protein content, and a relatively low lipid content. From minor constituents the vitamins of B-group, potassium and phosphorus and magnesium are the main ones. The gross chemical composition of commercially important cereals is summarized in Table 1.

Cereal grain	Protein	Lipid	Starch	Fiber	Ash
Wheat	12.2	1.9	71.9	1.9	1.7
Rye	11.6	1.7	71.9	1.9	2.0

Triticale	11.9	1.8	71.9	1.9	1.8
Barley	10.9	2.3	73.5	4.3	2.4
Oats	10.2	5.8	55.5	10.9	3.2
Maize	10.2	4.6	79.5	2.3	1.3
Millet	10.3	4.5	58.9	8.7	4.7
Sorghum	11.0	3.5	65.0	4.9	2.6
Rice (brown)	8.1	2.3	75.8	1.8	1.4

Table 1.Gross chemical composition of cereal grains

The various constituents of grain are not uniformly distributed in the kernel; so the ratio of constituents in different botanical parts (embryo or germ, pericarp and hull, aleurone layer, endosperm) of kernel differs significantly.

Embryo is rich in protein (20-35%) and lipids (12-35%). Consequently, their carbohydrate content is lower. Embryo has also a higher content of minerals and some vitamins (for details see *Vitamins and Minerals*). *Endosperm* contains the highest amount of starch and its protein content is somewhat lower than that of whole kernel. Endosperm is the lowest in lipid, vitamin and mineral content. The *pericarp's* (and hull's in covered cereals) main component is cellulose, considerable amounts of hemicelluloses, pentosans and other non-starch polysaccharides and also some lignin are present. No starch was found in hulls, the protein and lipid content is very low. Potassium and phosphorus are the main mineral components. In rice husk silicon is the main mineral component. Waxes, coloring matters are the remaining components. The *aleurone layer* is the outermost layer of the endosperm. From nutritional point of view the high protein (in average 24%), lipid (8%), and mineral (11%) content may be mentioned. The aleuron is rich in vitamins of B-group. A significant component is the phytic acid which is present in the form of granules containing potassium and calcium salts of this compound. About 70-75% of phosphorus in cereals occurs as phytic acid and phytic acid is the main phosphorus store of the seed.

Due to their low moisture content and kernel structure the cereal grains have a good storability and wide variety of cereal based products are used worldwide. The chemical composition of *cereal products* depends mainly on type of milling product used (white flour – based products are lower in vitamins, dietary fiber and minerals than that of whole grain meal based products) and naturally on the type and amount of other ingredients.

3.2. Legumes and Oilseeds.

Grain legumes and oilseeds are the richest in protein among food raw materials (Table (2.). Seeds of leguminous plants have been traditionally consumed by humans, and they constitute an important protein complement to cereals and starchy foods.

Legume (oilseed)	**Moisture**	**Protein**	**Lipid**	**Carbohydrate**
Pea	12.0	23.3	2.0	69.2

Field bean	12.0	30.1	2.2	61.0
Peanut	9.1	25.0	49.9	20.0
Sunflower seed	6.0	30.0	43.5	26.2
Rapeseed	5.2	26.0	33.8	34.9
Soybean	7.0	45.2	25.3	16.0

Table 2. Chemical composition of some legumes and oilseeds

The growing problems connected with supply of food protein to the world population stimulated the search of new protein sources for food purposes. The efforts to increase the food protein production led to growing commercial production of plant protein concentrates and isolates and their use as ingredients in a lot of traditional and new food products. Especially the production of soy protein concentrates was increased due to its favorable chemical composition. After the extraction of oil under mild conditions the non-protein components are removed and concentrates (protein content about 60-70%) and isolates (protein content about 90%) may be obtained.

3.3. Fruits and Vegetables.

The terms fruits and vegetables cover a big number of plants or more precisely edible parts (tissues) of plants. From botanical point of view there are *roots* such as sugar beet, sweet potato, yams, and cassava; *stems* such as potato, onion, asparagus, rhubarb, and kohlrabi; *leaf crops* such as lettuce and spinach; and *fruits*. The edible plant parts are composed from living tissues that are even after harvesting metabolically active. It means that they are more or less constantly changing in composition depending on growing conditions prior to harvest, the physiological role in the plant part, the genetic pool of the cell, and the post harvest environment.

Water generally represents about 70-90% of the fresh weight. The main constituents of solid matter of plant tissues are the *carbohydrates* (Table 3.).

In fruits, the sugars are the dominating carbohydrate component, in potato and other starchy vegetables the starch. In addition to sugars and starch, digestible components of plant tissues, a lot of compounds named *cell wall constituents* are present in fruits and vegetables. The principal cell wall constituents are cellulose, hemicelluloses, pectin and lignin. The relative proportion of these compounds depends on species, degree of maturity at harvest and conditions of storage after harvesting. Although the cell wall constituents, the major components of dietary fiber, are not digestible, there is considerable evidence for the beneficial role played by the fiber in health and disease. (for details see *Carbohydrates).*

Fruit/vegetable	Water	Protein	Carbohydrate	Ash
Apple	90.5	0.4	7.0	0.4
Apricot	86.1	0.9	10.2	0.7
Sour cherry	85.7	0.8	11.0	0.6
Orange	89.6	0.9	7.0	0.5
Banana	74.1	1.3	22.8	0.9
Walnut	8.1	18.6	11.7	1.7

Hazelnut	3.0	15.6	8.7	2.0
Potato	73.0	2.6	21.1	0.9
Green pea	75.1	2.5	13.5	1.0
Tomato	94.1	0.8	3.8	0.6
Carrot	90.1	1.1	7.2	0.8
Spinach	91.5	2.5	1.7	1.6
Lettuce	94.6	1.8	1.2	0.9
Cucumber	96.8	0.6	1.8	0.6
Green pepper	89.5	1.1	5.2	0.6

Table 3.Chemical composition of some fruits and vegetables (%)

The *protein* content of fruits and vegetables varies in different species, however it generally represents only a small percentage of fresh weight and except potato does not play significant role in protein supply of population. Plant tissues may contain considerable amount of non-protein nitrogen such as free amino acids and amines.

Fruits and vegetables are an important source of *vitamins* such as vitamin-C, thiamine, niacin, riboflavin and provitamins of vitamin-A. The total *mineral content* of fruits and vegetables, expressed as ash (residue after incineration) varies in wide range (0.1-5 %). Potassium, calcium, magnesium and phosphorus are the major minerals.

Among other components the *organic acids* (malic-, citric- tartaric acid) of fruits, *aroma compounds* and *pigments* (carotenoids, chlorophylls and flavonoids) may be mentioned.

3.4. Meat, Fish and Their Products.

Meat, fish and their products play a decisive role in providing high quality protein to the world population. From quantitative point of view *water* is the major component of meat and fish (Table 4). Its proportion is primarily dependent on fat content. Generally it may be calculated that the fat + water content is constant (about 70-80 %). *The protein content* of lean portion of meat and fish is 19-23 %.

Type of animal	**Protein**	**Fat**	**Water**
Cattle (lean)	20.6	3.5	74.2
Cattle (fatty)	18.9	24.5	58.3
Pig (lean)	20.1	6.3	78.7
Pig (fatty)	15.1	35.0	49.0
Lamb (lean)	19.0	6.4	72.1
Lamb (fatty)	17.6	26.4	53.5
Broiler	19.8	11.5	67.5
Turkey	19.9	8.2	68.4
Duck	13.0	26.8	51.0
Goose	12.2	32.1	52.1
Carp	20.5	6.1	73.3
Trout	23.1	8.8	67.2

Herring	18.6	3.5	78.0
Codfish	23.9	1.0	76.1

Table 4.Chemical composition of meat (%)

The major part of protein is so called contractile protein (Main constituent myosin) other groups are the soluble proteins (muscle enzymes and red colored myoglobin), and the proteins of connective tissue such as collagen, keratin and elastine.

In mammalians and avians *fat* is located partly in muscle tissue and partly in adipose tissue. Chicken muscles generally contain less fat than those of mammalians. In lean fish fat is carried in the liver. In fatty fish, depot fat apparently occurs as extracellular droplets in the muscle tissue.

Muscle tissue is an important source of *vitamins* particularly vitamins of B-group (thiamin, riboflavin, niacin vitamin B_{12}). Vitamin-C is present in only very low levels in meat. Meat is a good source *of iron and phosphorus* a rather poor source of calcium.

3.5. Milk and Dairy Products

The solid matter of milk, comprising 12-15 % of fresh milk is a complex mixture of proteins, lipids carbohydrates, vitamins, and minerals (Table 5.). Bovine milk contains 3.0-3.5% *high quality protein.* The proteins are classified as casein- and whey proteins. Casein comprises the largest fraction (about 80% of total protein). It may be precipitated with acid or rennet in procedures of production of yogurt and cheese respectively. The average fat content (about 4%) is present in milk in globules of 2-3μm in diameter. It is composed from triacylglycerols and small amounts of phospholipids and sterols (0.1g/l). *Lactose, milk sugar* is the main carbohydrate of milk (50mg/l). Lactose intolerance (lactose malabsorption) is infrequently observed in some individuals. This is connected with lack (or low activity) of a digestive enzyme, lactase splitting lactose to simple sugars. Symptoms of lactose malabsorption are diarrhea, bloating and abdominal cramps. In acid milk products such as yoghurt and kefir the lactose is transformed to lactic acid, so lactose intolerant people can consume such products freely.
Milk is an excellent source of both *water and fat- soluble vitamins* and *minerals*, particularly calcium and iron. Chemical composition of some milk products is shown in Table.5.

Product	**Water**	**Protein**	**Fat**	**Carbohydrate**
Cow milk	87.3	3.6	3.8	4.7
Sheep milk	80.1	5.5	7.4	4.8
Goat milk	87.4	2.9	4.5	4.1
Hard cheese	38-48	22-27	28-36	-
Processed cheese	45-58	18-20	20-25	-
Milk powder	5-6	19	26	36
Butter	16-20	1	78-82	1

Table 5. Chemical composition of milk and some dairy products

4. Chemistry of Food Constituents

4.1. Proteins

4.1.1. Chemistry and Classification

Proteins play a fundamental role in the structure and function of living organisms including plants and animals used directly or indirectly as food. In animal body, proteins are the main constituents of muscles, important components of milk, of blood, skin etc., they occur in cereal seeds dry legumes, and in smaller amount in potato, fruits and vegetables.

From chemical point of view, proteins contain, in addition to carbon atoms, hydrogen, oxygen and also nitrogen and usually sulfur. As minor components they may contain phosphorus, and metals (e.g. iron, copper, zinc). Complex proteins contain considerable amount of non-amino acid constituent such as carbohydrate (glycoprotein) or lipid (lipoproteins). Their molecular mass varies from about 5000 to many million daltons. The hydrolysis (treatment with acid, alkaline compounds or protein degrading enzymes) of proteins results in the degradation of proteins to their building units to amino acids.

Proteins are the most important nutrients for humans. Different values for the average daily protein requirement can be found in the literature. Generally the optimal daily protein supply is calculated to be 0.8 g per body weight (in kg), roughly 56 g for a 70 kg man. Protein requirement is higher for growing children, is dependent on calorie intake. The lower of energy uptake, the higher must be the percentage of protein in diet. Not only the quantity, but also the nutritional quality of protein should be taken in mind. Some of amino acids, the *essential amino acids,* cannot be synthesized in humans, thus these must be supplied in the diet. The nutritive value of a protein depends on its essential amino acid content. A high quality food protein contains essential amino acids in ratios which correspond to the human requirements. Generally the animal proteins are of better nutritional quality in comparison to those of plant origin (except some legume- and oilseed proteins).

4.1.2. Chemistry

In spite of their complexity and immense diversity, all proteins have been found to consists of only about 20 structural units, the so called *amino acids.*

In proteins the various amino acids are linked by *peptide bonds* i.e. the carboxyl group of one amino acid is linked with the amino group of the second amino acid with elimination of H_2O.

When hydrolyzed by strong mineral acids, or with the aid of certain enzymes, proteins can be completely decomposed into their component amino acids (For details concerning amino acids see *Food Proteins and Enzymes*) Due to big variations in size of molecules and amino acid composition and other chemical and physical factors, *the structure of proteins* is highly complicated. Molecular weight, amino acid composition and the linear sequence of amino acids along the peptide chain constitute what is known as *primary structure* of a protein molecule. The spatial arrangement of the various atoms in a molecule is referred to as *conformation.*

The term *conformation* includes both the relative position of neighboring groups (*secondary structure)* and the overall folding of the chain over itself *(tertiary structure).* A fourth level of organization, the *quaternary structure*, involves the non-covalent association of several polypeptide chains to form the protein Two types of tertiary structure are the most common : the *globular conformation* and the *fibrous conformation* Concerning the more deeper knowledge of protein structure, the reader is referred to literature given at the end of this chapter.

Due to its composition, structure and reactivity of its groups, the proteins have a lot of characteristic chemical, physical and biological properties which makes difficult their classification. The first system of classification was based on solubility and proteins were divided into six classes:
Albumins *– soluble in water*
Globulins *– soluble in dilute salt solutions* (but not in water)
Prolamines *– soluble in 50-70% ethanol*
Glutelins – insoluble above but *soluble in alkali and acids*
Histons – proteins of comparatively low molecular weights containing a large number of basic amino acids *soluble in water and acids*
Scleroproteins – *essentially insoluble* proteins with fibrous structure which fulfill structural function in the animals (e.g. proteins of bones, skin, nails, hair etc.).

Despite inadequacies, this old nomenclature is still used particularly in food chemistry. The complex proteins (containing non-amino acid constituent) are classified according to non-amino acid constituent to
Nucleoproteins
Glycoproteins
Lipoproteins
Phophoproteins
Chromoproteins and
Metalloproteins

4.1.3. Denaturation

Heat, strong acids and bases, solvents such as ethyl alcohol, concentrated solutions of some salts, a number of phenolic substances, usually bring about profound changes in the physico-chemical properties of soluble proteins. These changes include generally lower solubility (coagulation, gel forming), higher susceptibility to enzymatic hydrolysis (and therefore better digestibility) and changes in conformation of proteins. It has been customary to group all these changes under one term: *denaturation.* Very often the net result of denaturation of a globular protein is the unfolding of polypeptide chain).

Protein denaturation is a process of primordial importance in food technology. Protein denaturation may contribute to both the texture and flavor of many foods and better digestibility.

-
-
-

Bibliography

Belitz,H., Grosch,W. and Schieberle, P. (2004), *Food Chemistry.* Springer Verlag, Berlin-Heidelberg. [A book written for students and researcherswith topics of particular interest to food technologists]

Cui,W.(2005) *Food Carbohydrates.* CRC Press, Boca Raton [A recent book about basic chemistry and industrial applications of food carbohydrates]

Dombrowski,W.M. and Sikorski,Z. (2005) *Toxins in Food.* CR Press, Boca Raton [A book giving an overview about all important toxic compounds in food including natural toxins and allergenes].

Fennema, O.R.(1985). *Food Chemistry.* Marcel Dekker Inc., New York-Basel.

Hudson, B.J.F. (1981-1991) Developments in Food Proteins 1-7, Elsevier Appl.Sci.Publ. London-New York.

Morton,I.D.and MacLeod, A.J. (1986). *Food Flavors.* Elsevier, Amsterdam-Oxford-New York- Tokyo.[Commodity oriented detailed description of food flavors]

Otles, S. (2005) *Pesticide, Veterinary and other Residues in Food.* CRC Press, Boca Raton. [A recently published book giving an overview about toxicity, risks and control of chemical contaminanats in food].

Sikorski,Z.E. and Kolakowska,A.(2004) *Chemical and Functional Properties of Food Lipids.* CRC Press, Boca Raton.[A recent book about chemistry, processing and health-related concerns of food lipids]

Weidenbörner,M. (2001) *Encyclopedia of Food Mycotoxins.* Springer Verlag, Berlin-Heidelberg [A recent book giving overview of all relevant mycotoxin producing fungi and relating food safety aspects]

Biographical Sketch

Radomir Lasztity D.Sc., Professor of the Department of Biochemistry and Food Technology at Budapest University of Technology and Economics, was born in 1929 in Deszk, Hungary. Dr Lasztity received his M.Sc. degree in Chemical Engineering in 1951 and his D.Sc. degree in Chemical Science in 1968. He is honorary president of International Association for Cereal Science and Technology (ICC) and deputy technical director. He was acting chairman of the Codex Committee on Methods of Analysis and Sampling of the FAO/WHO Food Standard Program in the period 1975 – 1988. Dr Lasztity is a member of the Food Chemistry Division of the Federation of European Chemical Societies, and a member of the editorial boards of several international scientific journals. Among other awards he has received the Bailey and Schweitzer Medal of the ICC, the State Prize of the Hungarian Republic, and the Golden Medal of Czech Academy of Sciences. Dr Lasztity's main research activities are chemistry and biochemistry of food proteins, food analysis and food quality control. He has published more than 800 articles in Hungarian and overseas journals. He is the author/editor of more than twenty books and textbooks [*Chemistry of cereal proteins (1984, second ed. 1996), Amino Acid Composition and Biological Value of Cereal Proteins (1985), Cereal Chemistry (1999), Use of Yeast Biomass in Food Production (1991), Gluten Proteins (1987)*].