Chapter 1
Brief Introduction of Food Processing Methods and Chemical Hazards Formed during Thermal Processing

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1.1 Introduction

Food processing methods are used to convert varieties of raw agricultural materials or ingredients into safe, nutritious, and convenient food products. In the development of food processing, the key issues of improving food quality, safety, and nutrition remain to be addressed. According to the heat input during processing, food processing methods are generally divided into two categories: thermal processing and non-thermal processing. Thermal processing normally requires high temperature generated by heating, whereas non-thermal processing is often conducted by high-pressure, sonication, pulsed electric field, microwave, infrared, and cool plasma.

Thermal processing, which is one of the most important processes in the food industry, usually includes operation processes such as canning, baking, roasting, frying, pasteurization, boiling, and steaming of various food items. Initially, thermal processing is mostly used to inactivate enzymes or kill pathogens and microorganism in raw food materials and products to enhance the safety and preservation of foods. Nowadays, thermal processing techniques are used widely to improve the palatability, flavor, nutrition quality, and shelf-life of finished food products.

Non-thermal processing is an emerging or novel technology for the improvement or replacement of conventional processing technologies, with the aim of delivering higher quality or better consumption-oriented food products. The physical phenomena used in non-thermal processing of foods include pressure waves, sonication, high hydrostatic pressure, and electric/electromagnetic fields [1]. In addition to processing foods, non-thermal processing technologies have been widely used to modify the properties of food components (such as starch and protein) and widen their application.

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During thermal processing, non-enzymatic browning often occurs. The non-enzymatic browning contains three types of reactions: the Maillard reaction, caramelization, and ascorbic acid oxidation. Of these, much attention has been given to the Maillard reaction, since caramelization and ascorbic acid oxidation often occur at special conditions. The Maillard reaction is incredibly complex and important in the generation of reaction flavors and colors in food processing. Nevertheless, many chemical hazards can also be formed in this reaction. In this chapter, food processing methods and chemical hazards formed during thermal processing will be discussed.

1.2 Thermal Processing Methods

Thermal processing, which is referred to as heating foods at a certain temperature for a length of time, exists in many processes of food engineering universally. The increasing demand for enhancing food safety and quality leads to the development of novel thermal processing technologies. According to the heating forms, thermal processing can be divided into two categories: dry-heat process and moist-heat process. The dry-heat process refers to any technique where the heat is transferred to the food items without any moisture. However, the moist-heat method includes any technique that involves heating with moisture.

1.2.1 Dry-Heating Methods

Foods are subjected to dry-heating either using a flame directly or by surrounding foods with hot air or oil indirectly. Both these operations are conducted at higher temperature (up to 300 °C), which leads to a series of organoleptic changes differing from cooking using moist heat [2]. Particularly, surface browning and flavor development due to Maillard reactions, as well as crust variation resulting from denaturation of surface proteins, are important features, especially in roast meat products and baked cereal-based products. There are at least seven common dry-heating methods, such as broiling, grilling, roasting, baking, sautéing, deep-fat frying, and pan-frying [2].

1.2.1.1 Broiling

Radiant heat, which is from an overhead source, is utilized to cook foods in this process. Foods are put on a heated metal grate to produce crosshatch marks, and the radiant heat cooks foods from above. Foods may be placed on a preheated platter on condition that crosshatch marks are not desirable.

1.2.1.2 Grilling

Similar to broiling, this method uses a heat source located either above or beneath the cooking surface. Grills may be electric, gas, or wood- or charcoal-fired to produce a smoky flavor in the food [2].

1.2.1.3 Roasting and Baking

Foods are heated through hot air in a closed environment. The term "roasting" is usually applied to meats and poultry, whereas "baking" is used for fish, fruits, vegetables, breads, or pastries [2]. Heat is transferred by the form of radiation and convection to the food surface and then penetrates the food through conduction. The surface dehydrates and the food browns because of Maillard reactions and caramelization.

1.2.1.4 Sautéing

The method uses the conduction of heat from a hot pan to the food using a small amount of oil heated to its smoke point. Heat penetrates the food by conduction. High temperatures are used to sautéing foods which are usually cut into small pieces to promote uniform cooking. Stir-frying is a variation of sautéing in which a wok is used instead of a sauté pan; the curved sides and rounded bottom of the wok diffuse heat and facilitate tossing and stirring of the food [2].

1.2.1.5 Deep-Fat Frying

The heat is transferred to the food immersed or free-floating in the hot oil by convection at a temperature range of 160–190 °C and cooks the interior of the food by conduction. Foods are characterized by a golden brown color. As with pan-frying, deep-fried foods are often coated in batter or breading to keep moisture into the food and prevent the food from absorbing excessive quantities of oil [2].

1.2.1.6 Pan-Frying

This method is similar to both sautéing and deep-fat frying where heat is transferred from the pan to the food by conduction using a small amount of oil at a lower temperature than that used in sautéing. Pan-fried foods usually contain breadcrumbs, which keep the food moist and prevent hot oil from penetrating into the food to cause the food greasy [2].

1.2.2 Moist-Heating Methods

Moist heating is performed by placing food materials or food products in hot liquid, which can be water, wine, stock, or steam. Compared to dry heating, moist heating employs lower temperatures, ranging from 60 to 100 °C. The commonly used moist-heating methods are poaching, simmering, boiling, steaming, braising, and stewing. Boiling and steaming are used in processing of meat and oriental cereal-based products. Steaming, braising, and stewing are usually applied to process poultry products.

1.2.2.1 Poaching

Poaching involves processing by submerging food in hot water, wine, stock, or milk, and it is different from other moist-heating processing methods, such as simmering and boiling. Poaching usually operates at a relatively low temperature (60–80 °C), which makes it particularly suitable for foods with delicate flavors, such as eggs, fish, poultry, and fruit. Poaching is usually regarded as a healthy way of cooking because it does not make use of fat to cook or flavor the food. According to the amount of liquid used, poaching is also classified into two categories: shallow poaching and deep poaching. Shallow poaching uses a sautoir or other shallow cooking utensils, in which heat is rapidly transferred by conduction from the pan to the liquid and then to the food. Shallow poaching is best suited for single serving size, naturally tender, boneless, diced, or sliced pieces of poultry, meat, or fish. Deep poaching is similar to shallow poaching; but the food is fully submerged in liquid.

1.2.2.2 Simmering

Simmering uses higher temperatures from 80 to 95 °C, at which steam bubbles are visible, but the cooking liquid does not boil. The food is sorrounded by this liquid at a fixed temperature, which results in even cooking. It is a standard method to prepare stocks and soups, and to cook starchy foods such as potatoes or pastas. However, water-soluble vitamins and minerals leached out from the food into the cooking liquid are lost if the liquid is not consumed [2].

1.2.2.3 Boiling

Boiling at 100 °C is utilized less frequently because some foods may be damaged by the violent agitation owing to steam bubbles. There are many foods suitable for boiling, such as vegetables; starchy foods including rice, noodles, and potatoes; stocks; sauces; eggs; soups; and meats. It is simple and fit for large-scale cookery as a cooking method. It takes a long and slow cooking for tough meats or poultry to produce a nutritious stock. There is loss of water-soluble vitamins and minerals during boiling. Polythene sachets are sometimes used to pack commercially prepared foodstuffs, which are sold as "boil-in-the-bag" products.

1.2.2.4 Steaming

Steaming is defined by boiling water continuously to vaporize into steam. Upon steaming, foods are separated from boiling water but in direct contact with steam to give it a moist texture. Steaming is suitable for cooking vegetables, seafood, Chinese bread, and other foods having delicate textures or flavors. It can be cooked quickly, with some losses of water-soluble nutrients owing to leaching. Low-pressure steam cooking is a rapid and efficient process of heating and mixing high-protein liquid products, such as cheese, milk, sauce, or soup. The product can not be burnt as there is no direct contact with the heated surface. High-pressure steam at 110–120 °C is used to produce meat casserole products to reduce the time required to soften the meat, usually from a few hours to a few minutes [2].

1.2.2.5 Pasteurization and Sterilization

Pasteurization and sterilization, to inactivate microorganisms existing in foods, are widely used to ensure food safety and extend the shelf-life of foods in the food industry. Pasteurization is a relatively mild treatment in which liquid foods are mostly heated to below 100 °C. The pasteurization and sterilization techniques are initially used in liquid foods such as milk and fruit juices, and they are also applied to particulate food products recently [3]. Heat sterilization is a unit operation where food is heated at a temperature high enough for a long time to destroy vegetative microbial cells and spores and inactivate enzymes. Therefore, the packaged sterile foods have a shelf-life of more than six months at room temperature.

1.2.2.6 Braising and Stewing

Both methods are a combination of dry-heat and damp-heat cooking. The food is first roasted or sautéed and then partially covered with liquid and simmered at a relatively low temperature in a closed container. This may require the use of a pan heated from the bottom, but an oven, a bratt pan, or a jacketed kettle is better in that the food is heated more evenly from all sides. Braising and stewing, which will dissolve the connective tissues and soften the meat by prolonged heating, are important methods to cook harder pieces of meat. Moisture is absorbed in muscle fibers from the cooking liquid, which can increase juiciness of the meat, and flavors from stock vegetables and any herbs or seasonings included are absorbed as well. Braising and stewing are also utilized to cook vegetables such as cabbage, carrots, and aubergine.

1.2.3 Application of Thermal Processing

Thermal processing methods are generally used for food production and manufacturing in food industry. Heat treatment is still one of the most important methods used in food processing in terms of food safety, nutrition, and organoleptic properties. Thermal processing can not only affect desirably the quality of food consumed (many foods consumed in cooked forms and processed such as baked and grilled flavors cannot be produced by other means), but also have a preservative effect on foods by the destruction of enzymes, microorganisms, insects, and parasites.

1.2.3.1 Meat Products

Since the concept of heat treatment to preserve food proposed by Nicolas Apppert, thermal processing of meat and its products has been greatly developed, which can be used alone or in combination with other novel food processing techniques [4]. The main purpose of heat treatment is to improve food safety and extend the shelf-life of products, and it also provides an opportunity to develop the sensory attributes required for varieties of meat and its products. The thermal processing technology used for meat preservation and development of new products can be classified as dry, wet, novel thermal (microwave or infrared), or a combination of technology with minimal changes in meat quality. Thermal processing of meat can be broadly divided into batch type that heating, holding, and cooling phases are provided using a cooker or steamer, or continuous type with the above operations taking place in series [5, 6].

Although new technologies such as irradiation, high-intensity electric fields, ultra-high pressure, and high-intensity light have been widely used in the food industry, thermal processing is still the preferred method to ensure microbiological safety of poultry products. Heat treatment will continue to be the primary method of imparting safety, flavor, and value to poultry products. The use of hot water or steam pasteurization is an effective method to reduce the pathogenic bacteria content on the surface of poultry meat.

1.2.3.2 Fish Products

Pre-cooking is a severe heat treatment before sterilization. Fishes are usually pre-cooked with steam in a steamer at 100–102 °C, and the pre-cooking time depends on the type, size, quality, and temperature of the fish. Pasteurization is a mild or moderate treatment that typically pasteurizes fishery products placed in hermetically sealed containers to extend the refrigerated shelf-life of different seafood products. The heat treatment of canned fish is to eliminate the pathogenic microorganisms and other microorganisms that cause deterioration during storage.

1.2.3.3 Milk Products

The application heat treatment in milk or its products depends on a trade-off between safety/shelf-life and quality. Thermal processing is used to inactivate the microbial organisms to keep safety and prolong the shelf-life of mild products while ensuring the quality of the product. However, the degree of microbial inactivation required to ensure safety and extend the shelf-life by an acceptable factor and changes in quality of the product is always inversely correlated. Milk is an extremely complex raw material for processing, which has a range of constituents with their nature, stability, and properties affected by the types of heat treatments. Therefore, thermal processing can result in changes of sensory, nutritional, and physicochemical properties of milk. Ultra-high temperature (UHT) is a common heating method in the milk production process, which can inactivate enzymes and kill pathogens and harmful microorganisms, thus prolonging the shelf-life of milk.

1.2.3.4 Canned Foods

Thermal processing of canned foods mainly includes in-flow sterilization and in-container sterilization. The former refers to aseptic processing and aseptic packaging, whereas the latter generally involves the canning process in which the prepared food is filled into a package before sealing and sterilization. There is an increasing interest in the canning industry on using new process modeling and process calculation method for food safety and for optimizing the product quality and process efficiency [7, 8].

1.2.3.5 Ready Meals

Ready meals are multicomponent foods, typically comprising of a meat or vegetable component and a rice, pasta, or potato component. Thermal sterilization is applied to ready meals that are stored at ambient temperature, whereas the pasteurization is used for chilled or frozen ready meals. The latter has advantages in maintaining product quality because of the milder process.

1.2.3.6 Vegetable Products

Vegetable products are usually subjected to rigorous thermal treatment during processing to eliminate pathogenic microorganisms, which is termed as canning. Quality of thermally processed vegetables involves organoleptic properties (appearance, texture, flavor), nutrition value, chemical compositions, mechanical properties, functional characteristics, and deficiencies. The quality of thermally processed vegetables has aroused wide public concern. The main focus on thermal processing of vegetables is to maintain the nutritional and sensory quality through optimizing processing design while reducing the microorganisms to a safe level.

1.2.3.7 Concentrated Juices

Concentrated juices are popular and widely consumed around the world. The fruit products only require mild heat treatment (pasteurization) for long-term conservation because most fruits have a relatively low pH (less than 4.5). The main targets of heat treatment include the elimination of microorganisms and enzyme inactivation. The effects of thermal treatment can be evaluated by the microorganism destruction, the enzyme inactivation, the quality loss, etc. These food component modifications are generally modeled with the reactions kinetic concept [9].

1.3 Non-thermal Processing Methods

Traditional thermal sterilization techniques are widely applied to improve food safety and stability, but it can also cause extensive chemical changes in foods. Comparatively, non-thermal food processing, as a novel technology, is in line with the trend of food safety. The food industry has been improving traditional technologies and developing new technologies to meet the consumer demand for the safety and quality of high nutritional value foods. The non-thermal processing methods, generally used for sterilization and inactivating enzymes, include high-pressure processing (HHP), pulsed electric fields (PEF), high-pressure carbon dioxide (HPCD), high-pressure homogenization (HPH), ionizing radiation (IR), and pulsed magnetic field (PMF). HHP and PEF are most widely investigated in these non-thermal inactivation technologies [10]. HHP, which can improve the microbiological safety of foods while retaining its nutritional and sensory properties, is considered as a promising processing method [11].

1.3.1 High-Pressure Processing (HPP)

In HPP, the pressure between 100 and 1000 MPa is applied to foods for several seconds to minutes. The temperature during high pressure treatment can be set from below 0 °C to above 100 °C. The method can inactivate microorganisms and enzymes without impacting their sensory properties and nutritional value. Moreover, the functional properties of some foods can be improved by this method, producing new value-added products. In addition, there are some other advantages including low energy consumption, short processing times, and no effluents. The main defects of this method include the relatively high capital costs and the inability to process dry foods or foods that contain entrapped air, such as strawberries, which would be crushed by the high pressure.

1.3.2 Pulsed Electric Fields (PEF)

In PEF processing, foods placed between two electrodes are subjected to pulses of high voltage (typically 20–80 kV/cm). The PEF treatment is performed at sub-ambient, ambient or slightly above ambient temperature for less than 1 second to minimally reduce energy loss. The key points in the application of PEF technology involve the generation of high electric field intensities, the design of chambers that impart uniform treatment to foods, and the electrodes that minimize the effect of electrolysis. The high electric field intensities are achieved by storing a large amount of energy in a capacitor bank from a direct current power supply, which is then discharged in the form of a high voltage pulse [12, 13]. PEF has been mainly used for maintaining the quality of foods, such as improving the shelf-life of bread, milk, orange juice, liquid eggs, and apple juice and the fermentation properties of brewer's yeast.

1.3.3 High-Pressure Carbon Dioxide (HPCD)

HPCD is a kind of non-thermal sterilization technology which combines pressure with carbon dioxide. As a kind of natural antimicrobial agents, carbon dioxide can inhibit the aerobic microorganism rather than kill it. Only combining with high pressure, carbon dioxide can meet the demand of production standard. It has been proposed that HPCD can be used as an alternative cold pasteurization technique for foods. There are some fundamental advantages of HPCD technology, for example, it allowed processing at a much lower temperature than thermal pasteurization. The HPCD preservation technology has not been widely used on the large-scale production in food industry, although it has been researched extensively and deeply over the past few years.

1.3.4 High-Pressure Homogenization (HPH)

The definition of mechanical homogenization is the ability to generate a distribution of particles of a homogeneous size, in a liquid, by forcing the liquid under high pressure through a disruption valve [14]. High-pressure homogenization (HPH), also termed dynamic high-pressure homogenization, utilizes pressure in the range from 100 to 400 MPa, and the range of 300–400 MPa is generally referred to as ultra-high pressure homogenization (UHPH). HPH has confirmed its potential for low-temperature pasteurization of food matrices, and the disruption of vegetative microorganisms was suggested to result from a combination of temperature, cavitation, shear, turbulence, impingement, and high pressure [15–18]. However, previous work has shown that bacterial spores are resistant to low homogenization pressure and/or low-temperature treatments, thus limits the application of pasteurization [19, 20].

1.3.5 Ionizing Radiation (IR)

Ionizing radiation has frequencies greater than 10^{18} Hz and carries sufficient energy to eject electrons from molecules it encounters. In practice, three different types are used.

1. High-energy electrons in the form of β particles produced by radioactive decay or machine-generated electrons. Strictly speaking, they are particles rather than electromagnetic radiation, although they do exhibit the properties of waves in some behaviors. Because of their mass and charge, electrons tend to be less penetrating than ionizing radiation; for example, 5 MeV β particles will normally penetrate food materials to a depth of about 2.5 cm.
2. X-rays generated by impinging high-energy electrons on a suitable target.
3. Gamma (γ) rays produced by the decay of radioactive isotopes. The most commonly used isotope cobalt 60, 60Co, is produced by bombarding non-radioactive cobalt, 59Co, with neutrons in a nuclear reactor. It emits high-energy γ rays (1.1 MeV) which can penetrate food up to a depth of 20 cm (cf. β particles). An isotope of cesium, 137Cs, which is extracted from spent nuclear fuel rods, has also been used but is less favored for a number of reasons.

Ionizing radiation can affect microorganisms 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.

1.4 Recently Developed Food Processing Methods

1.4.1 Ohmic Heating

Ohmic heating, also known as "electroconductive heating," "resistance heating," or "Joule heating," allows alternating current to pass through the food and generate heat due to the electrical resistance of the food. Since food is the electrical component of the heater, its electrical characteristics are required to match the capacity of the heater. The way to use electrical resistance for heating purposes is not new, and it developed into a commercial process during the 1980s–1990s. This process is mainly used for pasteurization or UHT sterilization of foods, especially those foods containing larger particles that are difficult to handle by other methods.

Ohmic heating has some merits, such as a deeper heat penetration and a higher energy conversion efficiency (90% of the energy is converted into heat in the food), compared to dielectric heating (such as a microwave). The electrode in Ohmic heating is required to contact well with foods, whereas this is not required in dielectric heating. The food should have sufficient fluidity to be able to pump it through the heater (i.e., food containing up to about 60% solids) due to the special requirement of Ohmic heating. Ohmic heating has several advantages compared with conventional heating. Firstly, the rate of Ohmic heating is very high, which will result in a uniform heating of solids and liquids when their electrical resistance is the same. Secondly, there are no hot surfaces for Ohmic heating, so there is no risk of food burning or damaging by equipment surfaces or localized overheating. Thirdly, particles in liquids are not subject to shearing forces during Ohmic heating, thus this method is suitable for viscous liquids, such as applesauce or carbonara sauce. Lastly, Ohmic heating has a low capital cost, and it is suitable for continuous processing with the instant switch on and shut down.

Ohmic heating has been commercialized and is mainly used as an aseptic processing method for high value-added ready-to-eat foods stored at ambient or refrigerated temperatures. It also serves as a pasteurization method for granular foods, including pasta in tomato or basil sauce, ratatouille, beef bourguignon, lamb curry, vegetable stew, and minestrone soup concentrate, and as a preheating method for canned product [20]. It is also used as a pasteurization method instead of heat treatment and can be applied to milk, liquid eggs, and juices to produce high-quality whole fruit required for yogurt.

Despite the widespread application, this technology is limited by several factors. For example, the electroconductibility of the solid and liquid components is different and varies with increasing temperature, which causes abnormal and intricate heating patterns and difficulties in forecasting the heating features. In addition, there is a shortage of data on the key factors that impact the heating rate and precise temperature-monitoring techniques to describe heat distribution, which results in dangers under processing and the resulting survival of pathogenic spores in low-acid foods.

1.4.2 Microwave Heating

In classical thermal processing, energy from the surfaces of the material is transferred to the material by transmission, conduction, and irradiation of heat. On the contrary, microwave energy is transferred directly to materials through molecular interactions with the electromagnetic field. In traditional methods, energy is transferred on account of thermal gradients, but microwave heating is the conversion from electromagnetic energy to thermal energy by direct mutual effect of the incident irradiation with the molecules of the target stuff. The diversity in the method energy can lead to many potential advantages to employing microwaves for processing of materials [21].

1.4.3 Irradiation

Irradiation takes advantages of ionizing radiation (γ rays from isotopes or, commercially to a fewer extent, from electrons and X-rays) to store foods. It is employed to destroy pathogens or spoilage bacteria, or to prolong the shelf-life of fresh produce by disinfestation or slowing the rate of generation ripening, or sprouting. Sensory and trophic properties are not greatly altered because the treatment does not involve heating foods in any significant extent. The process is mostly used as a sanitary and phytosanitary treatment to help meet the recommendations of the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) of the World Trade Organization (WTO, 2016). Its purpose is to ensure the quality and safety of foods and to fill quarantine requirements in the commerce of products, including the disinfestation of fresh fruits and disinfection of dried vegetable seasonings and spices.

1.5 Chemical Hazards Formed during Thermal Processing

In food industry, the Maillard reaction plays an irreplaceable role in the protection of food nutrition, the flavor of food, and the colors. Meanwhile, some hazardous compounds generated during the Maillard reaction are considered to be related with diabetes, Alzheimer's disease, and atherosclerosis [22]. Due to the effects of these hazards on the health concerns, there have been many studies on this topic. The mostly reported chemical hazards contain α-dicarbonyl compounds, furan, trans-fatty acids (TFAs), heterocyclic amines (HAs), and acrylamide (AA).

1.5.1 α-Dicarbonyl Compounds

α-Dicarbonyl compounds (α-DCs), for instance, methylglyoxal (MGO) and glyoxal (GO), are chemically and biologically reactive components which are generated endogenously and exogenously [23]. In vivo, as endogenous physiological metabolites, they can be generated by many types of intestinal bacteria by human beings [24]. In vitro, α-DCs are produced during thermal processing (barbecue, baking, and frying) and prolonged storage, especially in sugar-containing foodstuffs and beverages. There are four main pathways to result in the formation of α-DCs, including sugar autoxidation, Maillard reaction, degradation of lipid and microbial fermentation. Generally, α-DCs are easily generated in sugar-rich foods or lipid-rich foods like honey, cookies, coffee, wine, beverages, vinegar, and other fried or baked foods [25]. They also occur in atmospheric aerosols, fume smoke, and medical products (peritoneal dialysis fluids) [26].

There are about 18 kinds of α-DCs which have been found in foods until now, and the most-studied are methylglyoxal (MGO), glyoxal (GO), 2,3-butanedione (2,3-BD), 3-deoxyglucosone (3-DG), and 3-deoxypentosulos. These chemicals are important intermediates of the Maillard reaction and significant precursors of flavoring and coloring media. Strecker degradation is the intermediate stage of Maillard reaction. In this stage, α-DCs, including aldehydes with at least one atom and α-aminoketones, such as MGO and GO, can react with amino acids to generate carbon dioxide. These are pivotal forerunners of heterocyclic compounds which are known to enhance cooked flavors like oxazoles, pyrazines, and thiazoles [27]. DMHF (known as furaneol), which is generally formed by cyclization of complete glycosides and/or the reorganization of MGO and GO, has been detected to be a key odor-active compound in many raw and processed foods, such as pineapple grape, as well as in soy sauce, roasted coffee, roasted almond, and bread crust [28]. The accumulation of α-DCs in human body is harmful to health, which has been paid increasing attention recently. The formation of α-DCs can destroy the nutrients in the food. α-DCs can react further with peptides, amino acids and proteins, and phospholipids to produce advanced glycation end products (AGEs) [29]. AGEs may lead to many potentially mediates chronic diseases, such as hyperglycemia, nephropathy, cataracts, and Alzheimer's disease. α-DCs are not only responsible for the formation of many advanced glycation end-products (AGEs) but also of some flavors, fragrance, and colors associated with the Maillard reaction. MGO is a physiological α-dicarbonyl compound that is developed from glycolytic intermediates and generated during the Maillard reaction. It leads to diabetes-associated complications and the aging of proteins. In comparison with non-diabetics, higher levels of MGO are existed in diabetic patient plasma. Due to its correlation with diabetes and involvement with flavor generation, methylglyoxal is arousing increased interest [30]. During extended storage for one year, 3-DG was found to be formed in honey examples at diverse temperatures (10, 20, and 40 °C) [31].

1.5.2 Furan

As a cyclic ether, Furan is a colorless liquid which volatility is high and boiling point is low (32 °C) [32]. Furan has been found in some thermally treated foods, such as coffee, canned meat, baked bread and cooked chicken, etc. In canned and jarred foods, furan will not be lost by evaporation when sealed in vessels that receives a considerable thermal load, resulting in its accumulation on the contrary. The concentration of Furan in foods vary greatly from <1.0 ng/g to hundreds of ng/g. For example, the content of furan was detected from 0.77 ng/g in red ginseng drink and 193.95 ng/g in Korean seasoned beef [33]. The furan unit is not only as a versatile precursor for the synthesis of many cyclic and acyclic compounds, but also as the pivotal structural units which impart the required performances in functional materials [34, 35].

1.5.3 Trans-Fatty Acids (TFAs)

Trans-fatty acids (TFAs) which present at a high level in diet are generated from partial hydrogenation of fats and vegetable or fish oils [34]. Due to microbial hydrogenation in ruminant animals, not only processed foods but also some natural foods such as tallow, butter, and milk also contain small amounts of trans-fatty acids [36]. Compared with cis-fatty acids, hydrogenated fats and oils have higher melting points and stability and prevent rancidity, so they are used in foods to improve texture and stability and extend shelf-life [37, 38]. What has increased our attention is TFAs' unfavorable effects TFAs can increase serum LDL-cholesterol and decrease HDL cholesterol concentrations and is concerned with cardiovascular disease [39].

Various studies have pointed out that the total daily intake of TFAs at baseline is positively associated with the daily intake of energy, saturated, total fat and unsaturated fat, and cholesterol, and inversely correlated with the daily intake of protein, alcohol, carbohydrates, and the use of vitamin supplements [40]. In western Europe, the range of TFAs intake is between 0.5% and 2.1% of energy intake and about 2% in the US food and drink [41, 42]. And the label to report the TFA content of a food as "0" means less than 0.5 or 0.2 g per serving (on the basis of the US and Canadian regulations, separately), which requires the knowlege of the minimum amount that can be exactly measured [43, 44].

1.5.4 Heterocyclic Amines (HAs)

Heterocyclic amines (HAs) are composed of three fused aromatic rings having at least one nitrogen atom in the ring structure, one extra cyclic amino group, and up to four methyl groups as substituents. It is a group of structurally like compounds [45]. Heterocyclic amines are detected mainly in fried, grilled, broiled, roasted, and barbecued meat samples and are considered as highly potential mutagens and carcinogens [46]. Until now, there are in excess of 25 types of HAs which have been isolated and determined in cooked foods [47]. The most studied HAs are as follows: IQ (2-amino-3-methylimidazo[4,5-f]-quinoline), MeIQ (2-amino-3,4-dimethyl-3H-imidazo[4,5-f]quinoline), MeIQx (2-amino-3,8-dimethlimidazo[4,5-f]-quinoxaline), DiMeiQx (2-amino-3,4,8-trimethyl-3H-imidazo[4,5-f] quinoxaline), and PhIP (2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine) [48]. According to the formation process, HAs can be divided into two types: thermic HAs and pyrolytic HAs. Pyrolytic HAs are generated when proteinaceous foods are cooked above 300 °C, while thermic HAs are generated under 300 °C [49]. Excessive consumption of HAs in meat goods can lead to breast and prostate cancer, colon cancer, and lung cancer [50]. These amines, also called thermic HAs, are the produce of a response between amino acids creatine, hexose, and creatinine during common cooking (150–300 °C) [51]. Amino carbolines, also called non-IQ type or pyrolytic

HAs, are generated when protein and amino acids are pyrolyzed at temperatures above 300 °C [52].

1.5.5 Acrylamide (AA)

Acrylamide (AA) occurs in many commonly consumed processed foods, and it is colorless and odorless but potentially hazardous to humans and animals. Because of the Maillard reaction between amino compounds and reducing sugars, acrylamide is formed from food ingredient during heat treatment under low-moisture conditions [53]. The Maillard reaction is the reason for the tasty flavor and golden color of heat-treated foods, and AA is an adverse by-product of Maillard reaction [54, 55].

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