

REVIEW

Open Access



Process-induced toxicants in food: an overview on structures, formation pathways, sensory properties, safety and health implications

Adel Mirza Alizadeh¹ , Mansoureh Mohammadi², Fataneh Hashempour-baltork³, Hedayat Hosseini^{4*} and Fereidoon Shahidi^{5*}

Abstract

With the rapid advances in ready-to-eat food products and the progress of food processing industries, concerns about food security and investigating food safety as well as sensory quality have intensified. Many food safety concerns are attributed to the toxic components, which can be produced during food processing as process-induced toxicants (PITs). The thermal processing of food (e.g., baking, cooking, grilling, roasting, and toasting) may lead to the formation of some highly hazardous PITs for humans and animals. These include acrolein, acrylamide, benzene, ethyl carbamate, chlorinated compounds, heterocyclic organic compounds (HOCs), polycyclic aromatic hydrocarbons (PAHs), heterocyclic aromatic amines (HAAs), biogenic amines (BAs), *N*-nitrosamines, Maillard reaction products (MRPs), and several newly identified toxicants such as 3-monochloropropane-1,2-diol. The occurrence of these contaminants is often accompanied by distinguishing odor, taste, and color. The severity of the sensory attributes can vary depending on the compound concentration. Knowledge about the biochemical and chemical mechanisms of PITs generation is necessary for expanding feasible approaches to limit and control their amounts in food products. This contribution introduces the most significant PITs, highlighting their formation mechanisms, impact on sensory characteristics of foods, analytical methods to detection, risk assessments, and food safety/adverse health effects of ultra-processed foods.

Keywords Food, Ultra-processed food, Thermal processing, Flavors, Sensory properties, Food safety

*Correspondence:

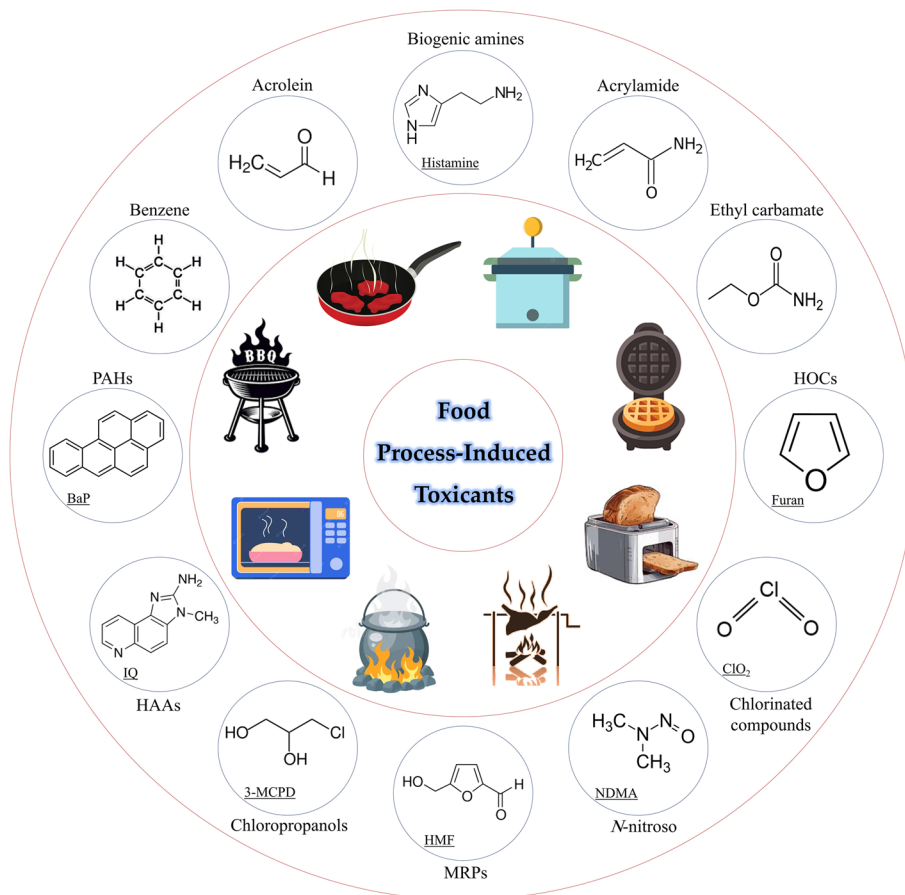
Hedayat Hosseini
hedayat@sbmu.ac.ir
Fereidoon Shahidi
fshahidi@mun.ca

Full list of author information is available at the end of the article



© The Author(s) 2025. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

Graphical Abstract



Introduction

Several factors may lead to chemical or microbial contamination of a complicated food web (Li et al., 2020a). Unlike microbial toxins leading to an instant detriment, chemical contaminants are commonly “silent” killers, which may affect health after long-term and repeated exposure to minute amounts of these compounds (Yu et al., 2014). Potential safety- and security-related chemical contaminants can be classified as natural toxicants, environmental contaminants, processing-aid chemical compounds, agrochemical residues, packaging migrants, and process-induced toxicants (PITs). PITs refer to the materials generated during food processing that have adverse physiological (toxicological) impacts on consumers (Stadler et al., 2008).

Generally, food processes are carried out to modify the physicochemical and sensory attributes of the raw materials and improve the quality, nutritional value, flavor, palatability, and shelf life of food. However, they

may generate potentially toxic components, resulting in adverse effects on the quality and safety of food (Li et al., 2020a; Rafiee et al., 2022; Yarahmadi et al., 2016).

Heating is regarded as the oldest and most trustworthy industrial and domestic food processing method (Li et al., 2020a; Nerin et al., 2016). Heat processing has always been utilized to transform raw materials and crude substances into edible food (Stadler et al., 2008). Due to the formation of several undesirable food contaminants during heat processing, such as Maillard reaction products (MRPs), and polycyclic aromatic hydrocarbons (PAHs), among others, it is imperative to pay full attention to potential harmful effects of over-processing. Modifying the heating method and monitoring the temperature may efficiently diminish the production of undesirable substances (Li et al., 2020a; Nerin et al., 2016). This review intends to shed light on the formation mechanisms of several food PITs and their impact on food safety and sensory characteristics.

Types and occurrence of food PITs

Several factors, such as pre- or post-harvest handling, food composition and formulation, as well as processing and storage conditions, may affect the PITs profile and their level in the final food product. Most food products have complex formulations. The main PITs produced in food matrices are acrolein, acrylamide, heterocyclic organic compounds (such as pyridine, pyrrole, furan, and thiophene), ethyl carbamate, chlorinated compounds (such as chlorine dioxide, sodium chlorite, 3- and 2-monochloropropane-1,2-diol, etc.), pyrolysis products from amino acids and proteins (heterocyclic aromatic amines, and biogenic amines), benzene, *N*-nitrosamines, PAH, and MRPs (Fig. 1). The Maillard reaction is the most significant one in many processed food leading to the formation of various contaminants, some of which can have toxic effects (Stadler et al., 2008). However, at a very low concentration, MRPs impart desirable flavor to food such as those of bread crust. Due to the health effects of PITs, in this section, the main ones are discussed in terms of the formation process and the dominant food matrix.

Acrolein

Acrolein (the most simple unsaturated aldehyde) is an irritating and off-flavor compound formed upon heating of vegetable oils (e.g., sunflower, perilla, rapeseed/canola, rice bran, and soybean oils) during frying and processing of lipid-rich foods containing vegetable oils (e.g., peanut oil and corn oil) (Endo et al., 2013; Seyed Mohammadi Fard et al., 2020). Acrolein was first recognized as a volatile flavor chemical produced in the pyrolysis of animal fats and various processed food products. The principal food sources of acrolein are thermally-processed lipids, which consist substantially of triacylglycerols of diverse fatty acids. However, it may be produced from miscellaneous polyamines and amino acids under the usual physicochemical conditions experienced during food processing (Hikisz et al., 2023; Jiang et al., 2022; Stevens et al., 2008). It has been reported that acrolein is produced by the breakdown of amino acids, like methionine, cystathionine, homocysteine, and homoserine, by subjecting them to heating at a temperature of 100 °C under neutral pH conditions. The deamination and

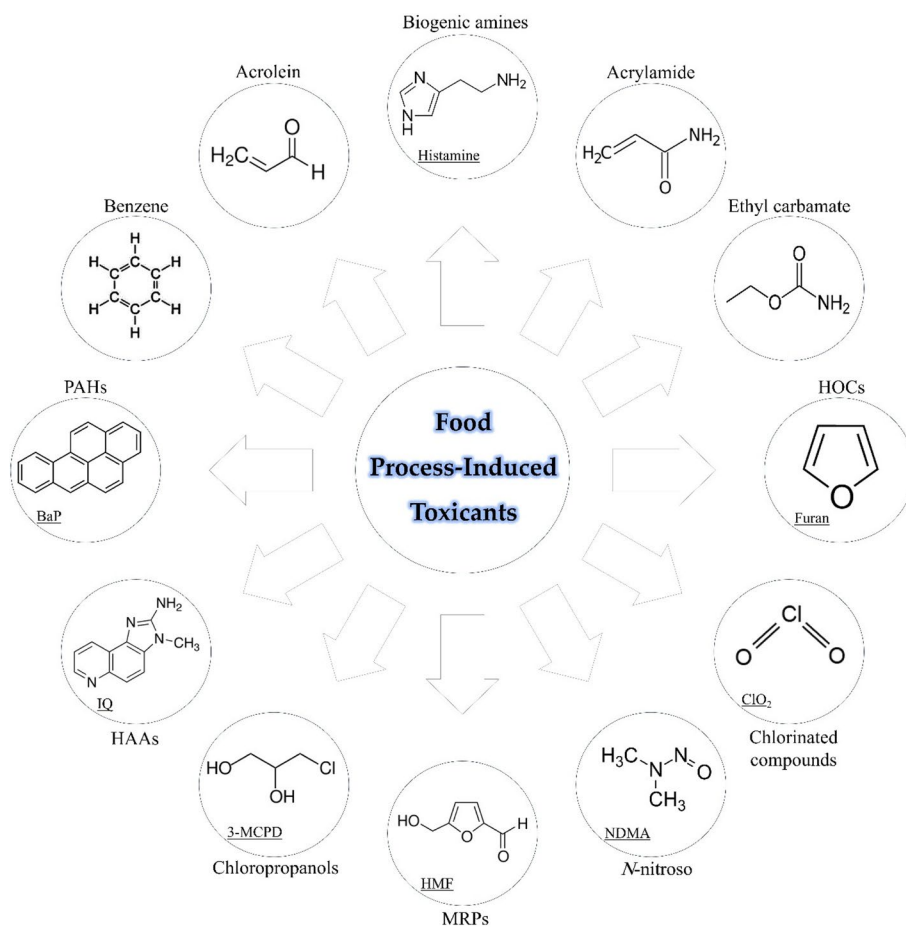


Fig. 1 Schematic of some important process-induced food toxicants

decarboxylation of these amino acids produce methional (3-substituted propanal derived from methionine), which can readily be decomposed to yield acrolein. Additionally, acrolein can be produced through the oxidative breakdown of various fatty acids found in triacylglycerols. The acrolein formation via a free radical mechanism involves homolytic cleavage of R–O bonds, presumably at elevated temperatures through glycerol dehydration (Mehta, 2015).

Acrylamide


























Acrylamide is found primarily in plant-based foods and many cooked (above 120 °C / 248 °F) starchy foods such as potatoes, cereal, and bakery products (Krishnakumar et al., 2014). It is known that the acrylamide content in fried and roasted potatoes will be enhanced by increasing the carbohydrate quantity in the product. The mechanism of acrylamide formation depends on the nature of carbonyl compounds and the processing conditions (pH, water content, and temperature). Acrylamide may be formed from lactic acid via dehydration and decarboxylation, amino acids, carbohydrates/sugars, lipids or amino acids-derived compounds like acrylic acid or acrolein. Several researchers have indicated that the Maillard reaction is the primary pathway for acrylamide generation during the thermal treatment of foods containing asparagine and carbonyl compounds (Lea et al., 2007; Peivasteh-Roudsari et al., 2022). Another route that may be the main pathway of acrylamide production

is the reaction of acrylic acid and ammonia at 180 °C. In this case, acrolein is oxidized to acrylic acid, which then reacts with ammonia released from an amino acid to form acrylamide at high temperatures. Ammonia is formed from an amino acid upon Strecker degradation in the presence of a carbonyl compound. The other minor route of acrylamide formation is the high-temperature treatment of acrolein which is readily formed from glycerol produced from lipid acylglycerols (Yasuhara et al., 2003). Moreover, the pyrolysis of carnosine (beta-alanyl-L-histidine) was found to be responsible for acrylamide generation in some baking processes (Claus et al., 2006).

Heterocyclic organic compounds (HOCs)

Heterocyclic organic compounds are cyclic compounds with ring structures containing carbon and other elements such as oxygen, sulfur, and nitrogen. These components are primarily formed through non-enzymatic browning reactions in foods. Classification of HOCs by ring size is convenient because the rings of a specified size have similar features. For example, three- and four-membered rings are geometrically strained and can readily be opened and reformed, thus serving as well-known reactive intermediates. Five- and six-membered rings, whose sizes allow the development of aromatic character, are stable and readily formed. Seven-membered rings and larger are highly stable but less readily constructed and relatively less well-investigated (Katritzky et al., 2010). Several important HOCs are listed in Table 1.

Table 1 Some important heterocyclic organic compounds

Three-membered heterocyclic rings	Four-membered heterocyclic rings	Five-membered heterocyclic rings	Six-membered heterocyclic rings	Seven-membered heterocyclic rings
Aziridine 	Azetidine 	Furan 	Pyran 	1,2-Diazepine 
Diaziridine 	Oxetane 	Pyrrole 	Pyridine 	1,4-Dithiepan-6-one 
Oxirane 	1,2-diazetidene 	Oxazole 	Pyrazine 	1,3-Oxazepines 
Oxaziridine 	Azetidin-2-one 	Thiophene 	1,2-Thiazine 	1,3-Thiazepine 
Oxadiaziridine 	Thietane 	Pyrazole 	1,3-Oxazine 	1,3-Dioxepins 

Heterocyclic derivatives can be divided into two broad areas: aromatic compounds like furan and non-aromatics such as tetrahydrofuran, piperidine, and dihydrofuran-2,5-dione (Alvarez-Builla et al., 2012). Many of these compounds can be produced over high thermal interactions of amino acids and reducing sugars. The impacts of lipids on the generation of HOCs in a model Maillard reaction have recently been established (Wang et al., 2022b). These compounds may also be formed through enzymatic reactions in fruits and during cheese ripening (Marcinkowska et al., 2022; Senoussi et al., 2022). Furan formation has been reported in various heat-treated foods such as baked bread, coffee, cooked chicken, and canned meat (Vranova et al., 2009). Pyrrole and pyrrole derivatives have also been identified in some food systems. Pyrrole can be formed from pyrrolidine by catalytic dehydrogenation (Yao et al., 2014). Pyrrole derivatives are often produced via the condensation of amines with carbonyl-containing compounds (Anderson et al., 2000). Many pyrrole derivatives have been isolated from foods whose flavors had been improved or impaired by non-enzymatic browning (Shuyun et al., 2022). Naturally occurring pyrazines have been separated from numerous complex food systems that have not undergone heat treatment, demonstrating the existence of various biological pathways for pyrazine formation (Mortzfeld et al., 2020).

Although the effects of lipids on the production of volatile heterocyclic compounds have not been fully investigated, remarkable differences are observed in cooked meat aroma via the removal of the phospholipids and triacylglycerols. These changes were attributed to a reduction in the concentrations of the aldehydes and aliphatic alcohols and a considerable increase in the amounts of the heterocyclic compounds, particularly alkylpyrazines such as 2,5- and 2,6-dimethylpyrazine, 2-methyl-3 (or 6)-pentylpyrazine and 2-methyl-3 (or 6)-hexylpyrazine (Shahidi et al., 2022; Whitfield et al., 1988). The last compounds have a long alkyl-chain substitute on the pyrazine ring. Pyridine and its derivatives can also be found in some processed foods. For example, 2-alkylpyridines were suggested to produce the corresponding unsaturated aldehydes by thermal processing in the presence of ammonia (Zamora et al., 2020). It has been reported that furan can be generated from multiple sources, including a) carbohydrates (the primary sources of furan in food) via thermal degradation, or Maillard reaction of reducing sugars, alone or in the presence of amino acids, b) certain amino acids, e.g., alanine and cysteine/cystine under thermal degradation or oxidation, c) vitamins such as ascorbic acid, dehydroascorbic acid, and thiamine, d) polyunsaturated fatty acids, and e) carotenoids (Becalski et al., 2005; Yaylayan, 2006).

Ethyl carbamate (EC)

EC, also known as urethane, is the ethyl ester of carbamic acid (NH_2COOH) that can be found in various fermented and baked food products as well as other food and beverages like cheese, yogurt, soy sauce, bread, and wine, among others (Li et al., 2017; Weber et al., 2009b). In addition, high consumption of stone fruits such as apples, pears, plums, cherries, and apricot could lead to high intakes of ethyl carbamate (Weber et al., 2009b). EC can be produced, under acidic conditions, via the reaction of urea (which can be found in raw materials like milk and many fermented foods) with ethanol. EC formation from urea will dramatically increase (based on the Arrhenius equation) with the temperature during various food processes such as baking, boiling, and toasting (Abt et al., 2021).

EC can be generated from several precursors like cyanogenic glycosides, arginine, urea, and citrulline during food and beverage fermentation depending on acidity, temperature, and microbial strain (Weber et al., 2009a; Zhao et al., 2013). It can also be produced from cyanogenic glycosides in various processing stages. Enzymatic breakdown of cyanogenic glycosides generates hydrocyanic acid, which is subsequently oxidized to cyanate. The reaction of cyanate with ethanol produces EC (Zhao et al., 2013). The decomposition of arginine by yeasts leads to urea formation, which its subsequent reaction with ethanol forms EC (Weber et al., 2009a). Moreover, EC may be formed from citrulline through the arginine deiminase pathway. Three enzymes named carbamate kinase, ornithine transcarbamylase, and arginine deiminase catalyze the cleavage of l-arginine. EC is created from two intermediate substances; carbamyl phosphate and citrulline (Jiao et al., 2014).

Chlorinated compounds

Chlorinated compounds (as sanitizing agents) play a vital role in the safe production, processing, transportation, and preparation of all food products (McLaren, 2000). Chlorine-based disinfectants are used in dairy, poultry, egg, and meat industries to prevent the growth of pathogens and foodborne diseases. They are available in solid forms, such as calcium hypochlorite, and liquid forms, like acidified sodium chlorite, sodium hypochlorite, *N*-chloramines, and chlorine dioxide (Lehner et al., 2009; Rafiee et al., 2022). Moreover, chlorine and its derivatives are extensively used in the food industry to wash, sanitize, and sort fruits and vegetables. It is also extensively used in food processing and transportation to disinfect all surfaces (e.g., work surfaces, instruments, machinery, and containers) which contact with edible products (Chlorine Chemistry, 2002). Chlorine is predominantly added to water for washing and rinsing equipment

during routine cleaning-in-place (CIP) operations (Sadeghi et al., 2019). Chlorinated compounds may be formed while washing food contact surfaces with chlorinated disinfectants (Cressey et al., 2008; Trinetta et al., 2011). Studies have indicated that chlorinated compounds and related by-products may be formed or introduced during the treatment of poultry, red meat, fish and fishery products, and fresh fruits and vegetables. Despite the importance of chlorinated disinfectants in the food industry, there is relatively little information about the generation of potentially toxic chlorinated compounds through the reaction of disinfectants with food components. The formation of chlorinated compounds has been reported in chicken meat treated with aqueous chlorine (chlorine dioxide and acidified sodium chlorite) mainly through oxidation reactions. It has been indicated that chlorination results in the formation of carcinogenic substances such as trihalomethanes and semicarbazide in poultry meat at sufficient concentrations of chlorine derivatives. For example, semicarbazide ($\text{CH}_5\text{N}_3\text{O}$), a chemical belonging to the hydrazine family, which is known to be carcinogenic in animals, is formed following exposure of chicken flesh to sodium hypochlorite (Xie et al., 2014). Trihalomethanes (THM), like chloroform, have also been detected in chicken tissue after treatment with chlorinated chill water (Vizzier-Thaxton et al., 2010).

Chlorine dioxide (ClO_2) is a polar gas highly soluble in water that can react with carbohydrates, lipids (fat), amino acids, peptides, and proteins in foods (Andrés et al., 2022). Most commercial generators use sodium chlorite as the common precursor chemical to generate chlorine dioxide for drinking water applications (Hsieh et al., 2023). Some reducing components in the food matrix, such as ascorbic acid, could readily be oxidized by the strong oxidant ClO_2 (Chen, 2017). Oxidation is the predominant reaction of ClO_2 during chlorination. Thus, the double bonds in the fatty acid moieties in foods can undergo oxidation through ClO_2 treatment. Therefore, caution should be exercised during the ClO_2 treatment of poultry meats that contain polyunsaturated fatty acids (PUFA), like linoleic acid. ClO_2 can also react with carbohydrates through two pathways, namely oxidative cleavage of the C_2 and C_3 carbon bonds to form carboxylic acids and oxidation of the glycosidic bond. These reactions generally result in the production of oxidation products (Fukayama et al., 1986). The reaction of ClO_2 at high concentrations with proteins and amino acids does not appear to result in chlorinated derivatives; however, the cleavage of hydrogen and peptide bonds, decomposition of aromatic amino acids, and oxidation of SH groups to SS bonds have been observed in wheat flour treated with chlorine dioxide (Abedi et al., 2020). (Tan et al., 1987) reported that ClO_2 is reduced to chlorite

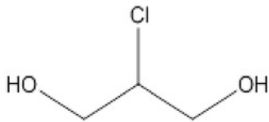
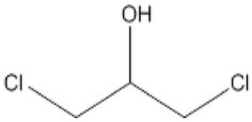
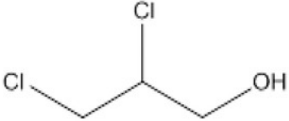
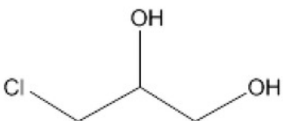
ion during food treatment, and the amino acids are oxidized as cysteine produces cysteic acid, tyrosine forms dopaquinone, methionine is oxidized to sulfoxide and subsequently to the corresponding sulfone, and tryptophan forms indoxyl, isatine, and indigo red. The residues or transformation products that could result from food processing with ClO_2 are inorganic oxychlorine anions (i.e., chlorite, chlorate), oxidized organics (i.e., oxidized lipids, oxidized amino acids), and organochlorines (i.e., chlorinated lipids, chlorinated proteins) (FAO/WHO, 2008).

Chloropropanols

Chloropropanols are process-induced toxicants that can be formed during various food processes via the reaction of hydrochloric acid with glycerol and lipids (Wenzl et al., 2007). The compounds 3-monochloropropane-1,2-diol (3-MCPD) and 2-monochloropropane-1,3-diol (2-MCPD) are well-investigated food contaminants, which have recently emerged as crucial problems due to the identification of high levels of fatty acid esters in the foods with high lipid contents. The most significant compounds of this group of toxins are presented in Table 2. 3-MCPD, a well-known toxic compound, is detected in diverse food products, like acid hydrolyzed vegetable proteins (HVPs), cereals, beer, meat products, and many vegetable oils (Jędrkiewicz et al., 2016). The primary source of human exposure to 3-MCPD is its generation through the heat treatment of foods. High-temperature processes (above 100 °C), including baking, broiling, grilling, or roasting, are significant factors in producing this compound in foods (Hamlet et al., 2002). The highest levels of 3-MCPD in food products (>1000 mg/kg) were generally identified in soy sauce and soy sauce-based products, as well as in foods and food ingredients containing acid-hydrolyzed vegetable protein and high chloride (salt) content (Humans, 2013; Kanekanian, 2010).

Chloropropanols are generated in HVPs through the hydrochloric acid-mediated hydrolysis step of the production process. Hydrochloric acid reacts with phospholipids, triacylglycerols, and glycerol and partial acylglycerols resulting from the acid hydrolysis of triacylglycerols (CONTAM, 2016). Hydrochloric acid protonates the primary and secondary hydroxyl groups of glycerol to produce alkyloxonium cations. Dissociation of water from the primary and secondary alkyloxoniums and further reaction with the chloride result in a racemic mixture of 3-MCPD enantiomers and 2-MCPD, respectively. The 2- and 3-MCPD generation from acylglycerols and glycerol enhances with the salt concentration and gets the maximum at about 15% water content and is mainly produced from triacylglycerols rather than glycerol. 3-MCPD can also be produced through the direct

Table 2 Structures of the main chloropropanols

2-Monochloropropane-1,3-diol (2-MCPD) 	1,3-Dichloropropane-2-ol (1,3-DCP) 
2,3-Dichloropropane-1-ol (2,3-DCP) 	3-Monochloropropane-1,2-diol (3-MCPD) 

replacement of chloride ions with the hydroxyl group of glycerol (CONTAM, 2016). The maximum formation of 3-MCPD was observed when chloride reacted with lecithin, followed by the reaction of diacylglycerols and glycerol (Velisek et al., 2003).

Heterocyclic aromatic amines (HAAs)

Amino acids are prominent constituents of most biomass, and their molecules contain the functional groups NH_2 and COOH . The exposure of high-protein foods such as meat products to elevated temperatures may lead to the pyrolysis of their amino acids, which is related to crucial health concerns (Moldoveanu, 2010). Of particular interest among the pyrolysis products are the polycyclic aromatic compounds (PAC), including nitrogen-containing polycyclic aromatic compounds (N-PACs) and polycyclic aromatic hydrocarbons (PAHs) (Sharma et al., 2002). Therefore, pyrolysis of amino acids in the food matrix can produce a complex mixture of products. Zhao et al. (2021) observed high concentrations of *N*-containing heterocycles after the pyrolysis of lysine and tryptophan. In addition, it has been found that the pyrolysis of tryptophan could form β -carbolines (Bellmaine et al., 2020). Liu et al. (2016) reported quinoline derivatives, indole derivatives, and pyrrole derivatives as the pyrolysis products of proline. Sharma et al. (2002) indicated that proline was entirely converted to volatile products at 300 °C. A critical issue in the pyrolysis of amino acids in foods is the formation of heterocyclic aromatic amines. Heterocyclic aromatic amines (HAAs) are formed during high-temperature food processes, e.g., broiling, and cooking, especially in burned meat. The generation of HAAs is primarily related to the characteristics of the food matrix, such as the type of food and the presence of different precursors, water content, and lipids (Adeyeye et al., 2021). These compounds are generally formed by

heating nitrogen-containing food ingredients, mainly of animal origins, like creatine and proteins (Nadeem et al., 2021). Several HAAs have been isolated from pyrolysates formed from amino acids at 550 °C (Moldoveanu, 2010).

All HAAs have aromatic and heterocyclic structures and can be classified into two main groups, polar or non-polar (Cheng et al., 2006; Murkovic, 2007). Polar HAAs, also known as amino-imidazoarenes (AIA), can be identified by the 2-aminoimidazo group and a methyl group attached to one of the nitrogens in the imidazole ring system (Al-bashabsheh, 2019). The imidazole ring is derived from creatine/creatinine. Consequently, the formation of polar HAAs does not occur without this precursor (Murkovic, 2007). Polar HAAs are subgrouped, depending on the groups attached to the 2-aminoimidazo. These subgroups include quinolones, quinoxalines, and pyridines (Adeyeye, 2020; Cheng et al., 2006). In contrast, non-polar HAAs, known as amino-carbolines, are subdivided into pyridoindole and dipyrdoimidazole types (Murkovic, 2007). They consist of five-membered heterocyclic aromatic rings sandwiched between two six-membered aromatic rings (Cheng et al., 2006).

HAAs can also be classified into IQ- (imidazoquinolines) and non-IQ-types (Table 3). The HAAs produced at 150 to 300 °C are named IQ-type HAAs, thermic HAAs (imidazoquinoxaline or imidazoquinoline), or amino imidazoarenes. At higher temperatures, pyrolysis of amino acids and proteins results in non-IQ-type HAAs or pyrolytic HAAs (Dong et al., 2020). Both IQ- and IQx-types HAAs are formed through the Maillard reaction, as postulated by many researchers (Quan et al., 2020; Teng et al., 2018). In this view, sugars and amino acids reaction produces intermediates that undergo reverse-aldol reaction to give enol-type compounds, which then react with creatinine to form IQ- or IQx-type HAAs (Murkovic, 2007). The prevalent HAAs in meat include IQ, MeIQ,

Table 3 Some of the polar and non-polar heterocyclic aromatic amines

Polarity	Group	HAA	Chemical name	IQ- or Non-IQ
Polar (Amino-Imidazo-Azarenes)	Quinolines	IQ	2-Amino-3-methylimidazo[4,5-f]quinolone	IQ
		MeIQ	2-Amino-3,4-dimethylimidazo[4,5-f]quinoline	IQ
	Quinoxalines	IQx	2-Amino-3-methylimidazo[4,5-f]quinoxalines	IQx
		MeIQx	2-Amino-3,8-dimethylimidazo[4,5-f]quinoxaline	IQx
		4,8-DiMeIQx	2-Amino-3,4,8-trimethylimidazo[4,5-f]quinoxaline	IQx
		7,8-DiMeIQx	2-Amino-3,7,8-trimethylimidazo[4,5-f]quinoxaline	IQx
		4,7,8-TriMeIQx	2-Amino-3,4,7,8-tetramethylimidazo [4,5-f]quinoxaline	IQx
	Pyridines	PhIP	2-Amino-1-methyl-6-phenylimidazo[4,5-b]pyridine	IQ
		DMIP	Dimethylimidazopyridine	IQ
		TMIP	Trimethylimidazopyridine	IQ
Non-Polar (Amino-Carbolines)	α -amino-carbolines	AaC	2-Amino-9H-dipyrido[2,3-b]indole	Non-IQ
		MeAaC	2-Amino-3-methyl-9H-dipyrido[2,3-b]indole	Non-IQ
	β -amino-carbolines	NorHarman	9H-Pyrido[3,4-b]indole	Non-IQ
		Harman	1-Methyl-9H-pyrido[3,4-b]indole	Non-IQ
	γ -amino-carbolines	Trp-P-1	3-Amino-1,4-dimethyl-5H-pyrido[4,3-b]indole	Non-IQ
		Trp-P-2	3-Amino-1-methyl-5H-pyrido[4,3-b]indole	Non-IQ
	δ -amino-carbolines	Glu-P-1	2-Amino-6-methyl-dipyrido[1,2-a:3',2'-d]imidazole	Non-IQ
		Glu-P-2	2-Amino-dipyrido[1,2-a:3',2'-d]imidazole	Non-IQ

MeIQx, 4,8-DiMeIQx, PhIP, and AaC (Özsaraç et al., 2019; Zhou et al., 2022b).

Benzene

Benzene (C₆H₆) is an aromatic hydrocarbon extensively utilized as an intermediate for producing polymers and other products and as a solvent in the chemical industries. Human exposure to benzene happens via consuming contaminated water and foods and inhalation. Benzene can enter the food primarily through contaminated water, packaging, or raw materials and storage in polluted areas. It may also be formed during irradiation or cooking by thermal degradation of food ingredients, additives, and preservatives, like benzoate (Heshmati et al., 2018a; Sadighara et al., 2022). Fruits and vegetables can be contaminated with benzene from emissions caused by fire and using fossil fuel-burning equipment (Salviano dos Santos et al., 2015). Benzene has also been detected in other foods and beverages containing benzoate salts and benzoic, ascorbic, or erythorbic acids, such as cranberry juice.

Benzene can be formed in foods through three mechanisms: (a) via the thermal pyrolysis and restructuring of precursors, (b) as a result of irradiation (by the radiolytic and oxidative breakdown of phenylalanine), and (c) from ascorbic acid and benzoate (Stadler et al., 2008). Ascorbic acid is utilized in food and beverages as a nutrient or preservative. The literature indicated benzene generation in beverages containing ascorbic acid and benzoate under certain conditions (Heshmati et al., 2018a; Makhoul

et al., 2019). Benzene can be generated through decarboxylation of benzoic acid by a hydroxyl radical. Lachenmeier et al. (2008) reported that carrot juices have high benzene contamination due to heat-induced formation. Benzene may also migrate into food from plastic containers (Alamri et al., 2021; Marć, 2020).

N-nitrosamines

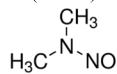
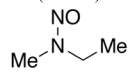
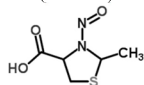
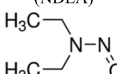
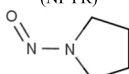
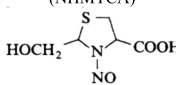
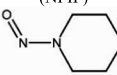
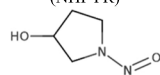
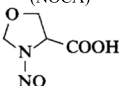
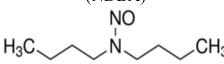
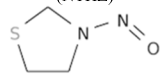
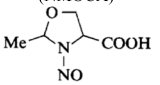
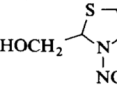
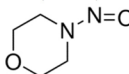
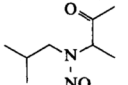
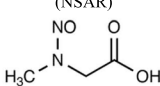
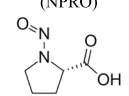
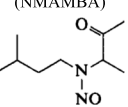
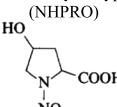
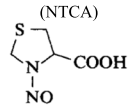
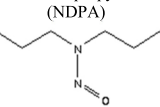
N-nitrosamines [R₁N(R₂)N=O] or N-nitroso compounds (NOCs) can easily be found in various foods and other matrices such as air, water, and packing materials. N-nitrosamines have been an issue raised from nitrite addition in production of processed meats such as bacon, sausage, and ham, to prevent the growth of *Clostridium botulinum*. These PITs are formed by reactions of N-containing substances (especially secondary amines) and their derivatives with nitrosating agents (Shakil et al., 2022). The nitrosating agent N₂O₃ may be produced from nitrites (NO₂), nitrates (NO₃), and nitrocompounds (R-NO₂), such as nitrous acid (HNO₂), which can be formed from nitrogen oxides (NO_x) under acidic conditions. The formation of N-nitroso compounds (NOCs) under basic conditions is of great importance for industrial or workplace situations (Stadler et al., 2008). In meats and meat products, N-nitrosamines can be formed during various processing operations such as curing, smoking, and salting. NOCs have also been found at trace levels in other foods, including cheese, cocoa, powdered milk and eggs, instant soups, coffee, and spices. N-nitrosodimethylamine (NDMA) is the predominant

volatile *N*-nitrosamine found in fish and seafood (Park et al., 2015). It can also be found in dairy products, beer, and other alcoholic beverages. The formation of nitrosamines increases with time, temperature (e.g., while frying), and acidity (e.g., in the stomach) (NTP, 2016). The most significant *N*-nitroso compounds in foodstuffs are summarized in Table 4.

(Chandan et al., 2013) indicated that *N*-nitrosamines are unstable in PCCC processes (post-combustion CO₂ capture) because of the low electron density surrounding the nitrogen atoms. They are promptly decayed into carbonium ions and nitrogen gas (N₂). Monoethanolamine (MEA), a primary amine for the PCCC process, cannot directly form stable *N*-nitrosamines in gas or liquid form. Nevertheless, it may be degraded to secondary amines, which are subsequently nitrosated to *N*-nitramines and *N*-nitrosamines by nitrite (Chen et al., 2018a). In addition, MEA can be converted into

diethanolamine (DEA) by NO_x, which is then nitrosated to nitrosodiethanolamine (NDEA) (Fostås et al., 2011). *N*-nitrosodimethylamine (NDMA) can be identified as an MEA by-product, which may be generated via the breakdown of NDEA (Fostås et al., 2011). The volatile and small alkylamines (including aliphatic amine and psychotropic alkylamines) and mono- and dimethylamines (MMA and DMA, respectively) are also probable decomposition products of MEA (Lepaumier et al., 2009). Moreover, the reaction of CO₂ and MEA may produce *N*-(2-hydroxyethyl) ethylenediamine (HEEDA), which can further be degraded into secondary amines, like morpholine (MOR) (Lepaumier et al., 2009). Consequently, *N*-nitrosomorpholine (NMOR) and NDMA can be generated through the nitrosation of MOR and DMA, respectively, or the decomposition of NDEA (Loeppky et al., 1979). In addition, *N*-nitramines and *N*-nitrosamines may be produced from

Table 4 Some important *N*-nitroso compounds

<p><i>N</i>-Nitrosodimethylamine (NDMA)</p> 	<p><i>N</i>-Nitrosoethylmethylamine (NEMA)</p> 	<p><i>N</i>-Nitroso-2-methyl-thiazolidine-4-carboxylic acid (NMTCA)</p> 
<p><i>N</i>-Nitrosodiethylamine (NDEA)</p> 	<p><i>N</i>-Nitrosopyrrolidine (NPYR)</p> 	<p><i>N</i>-Nitroso-2-hydroxymethyl-thiazolidine-4-carboxylic acid (NHMTCA)</p> 
<p><i>N</i>-Nitrosopiperidine (NPIP)</p> 	<p><i>N</i>-Nitroso-3-hydroxypyrrolidine (NHPYR)</p> 	<p><i>N</i>-Nitrosooxazolidine-4-carboxylic acid (NOCA)</p> 
<p><i>N</i>-Nitrosodibutylamine (NDBA)</p> 	<p><i>N</i>-Nitrosothiazolidine (NTHZ)</p> 	<p><i>N</i>-Nitroso-5-methyloxazolidine-4-carboxylic acid (NMCOCA)</p> 
<p><i>N</i>-Nitroso-2-hydroxymethylthiazolidine (NHMTHZ)</p> 	<p><i>N</i>-Nitrosomorpholine (NMOR)</p> 	<p><i>N</i>-Nitroso-N-(1-methylacetyl)- 2-methylpropylamine (NMAMPA)</p> 
<p><i>N</i>-Nitrososarcosine (NSAR)</p> 	<p><i>N</i>-Nitrosoproline (NPRO)</p> 	<p><i>N</i>-Nitroso-N-(1-methylacetyl)- 3-methylbutylamine (NMAMBA)</p> 
<p><i>N</i>-Nitroso-4-hydroxyproline (NHPRO)</p> 	<p><i>N</i>-Nitrosothiazolidine-4-carboxylic acid (NTCA)</p> 	<p><i>N</i>-Nitrosodipropylamine (NDPA)</p> 

2-amino-2-methyl-1-propanol (AMP, which is more stable than MEA) by the reaction with NO_x. Researchers have reported that the nitrosation of AMP is higher than that of MEA (Dai et al., 2013; Dai et al., 2012). Secondary amines, like piperazine, morpholine, and diethanolamine, can directly form significant concentrations of stable nitrosamines. The formation rate of *N*-nitramines from primary amines is slower than that from secondary amines since the reactivity of secondary amine substituents is maintained in *N*-nitramines (Nielsen et al., 2012). The carcinogenic compounds *N*-Nitrosodialkylamines have been formed via the reaction of nitrite with secondary amines present in food in an acidic environment (Laskin et al., 2018). The formation of nitrosamines in foods and other environments depends on the pH, temperature, and alkalinity of amine. The formation rate of *N*-nitroso compounds from secondary amines increases proportionally with a decrease in the alkalinity of the amines. Tertiary aliphatic amines do not react with dinitrogen trioxide (N₂O₃) in strong acidic pH and cannot directly generate *N*-nitrosamines in terms of the absence of amine hydrogen; however, they can produce *N*-nitramines by increases in pH at the optimum temperature of the nitrosation process (Gunturu et al., 2019).

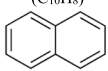
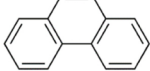
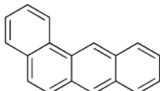
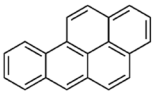
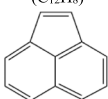
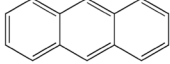
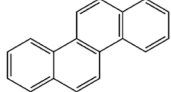
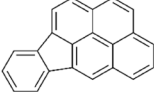
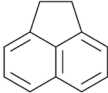
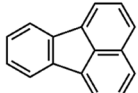
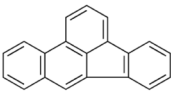
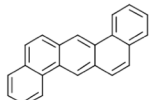
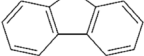
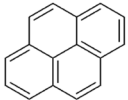
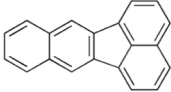
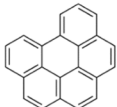
To eliminate *N*-nitrosamine formation in cured meat, Shahidi and co-workers formulated nitrite free curing systems, they pre-formed the natural colorant in cured products as part of the combinations (there are several

papers with Pegg and also with Sen and 3 or so patents to reference a couple of them; Also, there is a book on the topic by Pegg and Shahidi) (Pegg et al., 2006, 2008; Shahidi et al., 1992; Shahidi et al., 1991).

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are environmentally resistant organic compounds with varied structures and toxicity consisting only of carbon and hydrogen atoms in two or more aromatic rings. PAHs can be formed either via biological processes or as products of incomplete combustion of fuels during industrial and some domestic cooking practices (Abdel-Shafy et al., 2016). Compounds containing up to four benzene rings are known as light PAHs (L-PAHs), and those containing more than four are known as heavy PAHs (H-PAHs). H-PAH are more stable and toxic than L-PAHs (Sahoo et al., 2020). Heat treatment or thermal processing such as grilling, broiling, frying, barbecuing, toasting, and roasting of fish, meat, and other food products over direct flames or intense heat leads to the generation of PAHs on food surfaces. Some important PAHs in various foods are presented in Table 5. Benzo(a) pyrene (BaP) is a prototypical carcinogenic PAH, which can produce reactive cytotoxic and carcinogenic metabolites after metabolic activation by the cytochrome P450 enzymes (Crowell et al., 2014). These PAHs are generated via condensing smaller organic substances through either pyrosynthesis or pyrolysis. These organic substances are

Table 5 The most important polycyclic aromatic hydrocarbons

<p>Naphthalene (C₁₀H₈)</p> 	<p>Phenanthrene (C₁₄H₁₀)</p> 	<p>Benzo[a]anthracene (C₁₈H₁₂)</p> 	<p>Benzo[a]pyrene (C₂₀H₁₂)</p> 
<p>Acenaphthalene (C₁₂H₈)</p> 	<p>Anthracene (C₁₄H₁₀)</p> 	<p>Chrysene (C₁₈H₁₂)</p> 	<p>Indeno[1,2,3-cd]pyrene (C₂₂H₁₂)</p> 
<p>Acenaphthene (C₁₂H₁₀)</p> 	<p>Fluoranthene (C₁₆H₁₀)</p> 	<p>Benzo[b]fluoranthene (C₂₀H₁₂)</p> 	<p>Dibenz[a,h]anthracene (C₂₂H₁₄)</p> 
<p>Fluorene (C₁₃H₁₀)</p> 	<p>Pyrene (C₁₆H₁₀)</p> 	<p>Benzo[k]fluoranthene (C₂₀H₁₂)</p> 	<p>Benzo[g,h,i]perylene (C₂₂H₁₂)</p> 

readily degraded (pyrolysis) at high temperatures, and the resulting free radicals are recombined to generate stable polynuclear aromatic components (pyrosynthesis). High temperatures (about 500–700 °C) are optimal for PAHs creation; however, they can also be produced at lower temperatures in various foods (Singh et al., 2016). A common pathway to yield PAHs may involve Diels–Alder reaction and rearrangement. The significance of pyrolysis depends on the process temperature. At temperatures below 400 °C, only low concentrations of PAHs are generated, while at 400 to 1000 °C, the PAH concentration linearly increases with temperature. Temperature influences the structure and variety of the resulting PAHs (Chen et al., 2001; Stadler et al., 2008). The mechanism of hydrogen abstraction acetylene addition (HACA) is well accepted as the main reaction route leading to the formation of PAHs and nascent soot in combustion flames (Liu et al., 2019). Another reason for HACA to be the prevalent PAH formation mechanism is a high abundance of benzene/phenyl and acetylene in combustion flames of various types of aromatic and aliphatic fuels (including ethane, butane, butadiene, ethylene, methane, benzene, toluene, heptane, gasoline mixtures and even several types of polymers such as polystyrene, polyethylene, and polyvinyl chloride) in a broad range of distances from the burner surface (Kislov et al., 2013; Roesler et al., 2003; Wang et al., 2003). The PAHs can be formed under local fuel-rich conditions by adding C₂–C₅ hydrocarbons to aromatic rings followed by ring closure (National Research Council, 1988).

High contents of PAH have been reported in foods such as fish smoked by traditional techniques, mussels and other seafood from polluted waters, and charcoal-grilled or barbecued foods such as fatty meat and meat products processed under prolonged and severe heat conditions (Duedahl-Olesen et al., 2022; Farrington, 2020; Kafouris et al., 2020). The PAHs are also generated in coffee during the roasting process of green coffee beans (Houessou et al., 2005, 2008). The PAH production in fat and edible oils is mainly associated with the contaminated raw material and the contamination during processing (e.g., solvent extraction or seed drying). High PAH amounts can be formed in oils during drying the raw seeds with direct fire (Stadler et al., 2008). In addition, wheat, oats, barley, and corn grown close to industrial areas contain higher PAH amounts than similar crops cultivated in farther sites (Şahin et al., 2022). Researchers have indicated that PAHs in vegetables can be detected in the soil in which they have been cultivated. According to reports, the presence of these compounds in carrots or potatoes can be reduced by washing and peeling. However, when it comes to leafy vegetables like lettuce, removing these compounds is difficult due to their entrapment in the

hydrophobic cell walls of the plants (Huang et al., 2018; Mohammed et al., 2019; Zhao et al., 2021).

Maillard reaction products (MRPs)

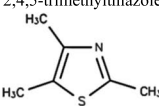
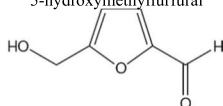
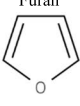
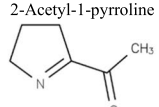
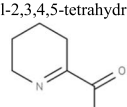
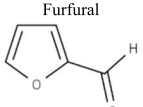
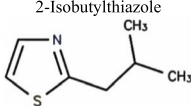
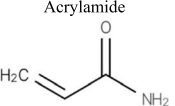
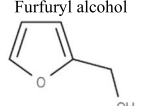
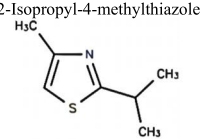
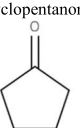
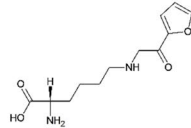
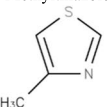
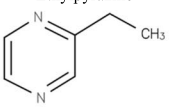
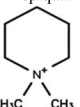
The non-enzymatic browning reaction, also named the Maillard reaction (MR), is an amino-carbonyl or sugar-amino reaction that occurs widely in food and biological systems (Gürsul Aktağ et al., 2021). Processing at high temperatures (>150 °C) and low moisture contents results in an interaction between reducing sugars and amino acids generally in less than 2 h, at a pH of 7.4, leading to different flavors and brown colors of foods, like milk, honey, malt, bread, and cocoa (Wang et al., 2011). Under these conditions, some carbohydrates, such as oligo- and polysaccharides, preferentially react as complete molecules at the reducing end. Maillard reaction products (MRPs) include aldehydes, ketones, dicarbonyls, acrylamides, and heterocyclic amines, all of which contribute to flavor, as well as melanoidins and advanced glycation end products (AGEs), which are polymeric products formed at the advanced stages of MR and some of them can be carcinogenic (Tamanna et al., 2015). AGEs, as reactive intermediates, and other MRPs are produced via parallel and sequential counteractions involving cyclization, dehydration, enolization, fragmentation, and oxidation (Poulsen et al., 2013). The Maillard reaction reduces the bioavailability of essential amino acids, such as lysine, and results in the formation of advanced Maillard reaction products, such as Ne-(2-furoylmethyl)-l-lysine (Furosine), which is a marker of the Maillard reaction (van Rooijen et al., 2014). Several main MRPs in food matrices are listed in Table 6.

The Maillard reaction in food can occur under acidic or neutral conditions (A) and in alkaline media (B), as shown below (Singla et al., 2018).

A) The first stage involves the reaction of a nitrogen-containing molecule and a reducing sugar (a hexose) that produces water and an intermediate (an *N*-substituted glycosylamine, which is called Schiff's base). The Amadori rearrangement results in a 1-amino-1-deoxy-2-ketose. At a pH of ≤7, the Amadori product would be converted into Schiff's base furfural or 5-hydroxymethylfurfural (HMF), which can subsequently generate various products, including brownish melanoidins. The simultaneous creation of various sub-products, such as gaseous substances and 3-deoxyglucosone, should be noticed.

B) The first stages (in acidic or neutral conditions) afford the Amadori product. At a pH greater than 7, the Amadori product undergoes transformations into different intermediates, which include dicarbonyl (fission) products and reductones. Reductones, when in a state of chemical equilibrium with dehydroreductones, have the potential to interact with fission products, resulting

Table 6 Some main Maillard reaction products

2,4,5-trimethylthiazole 	5-hydroxymethylfurfural 	Furan 
2-Acetyl-1-pyrroline 	6-Acetyl-2,3,4,5-tetrahydropyridine 	Furfural 
2-Isobutylthiazole 	Acrylamide 	Furfuryl alcohol 
2-Isopropyl-4-methylthiazole 	Cyclopentanone 	Furosine 
4-Methylthiazole 	Ethylpyrazine 	Mepiquat 

in the formation of melanoidins or aldehydes. The dicarbonyl products (e.g., methylglyoxal and diacetyl) can also produce α -aminoketones. Anyhow, brownish melanoidins are the final products of the Maillard reaction.

Biogenic amines (BAs)

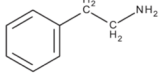
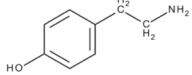
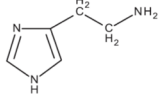
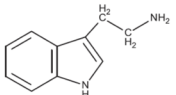
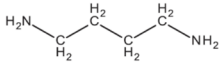
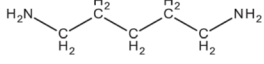
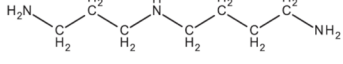
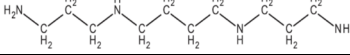
The most prevalent biologically active amines in food products (exogenous BAs) are histamine, putrescine, cadaverine, tryptamine, tyramine, and phenethylamine (Mohammadi et al., 2023b). They are typically formed by microbial decarboxylation of amino acids and may be produced in any foodstuff subjected to the fermentation process or microbial contamination during processing, ripening, or storage (Aflaki et al., 2014). In addition, putrescine may be created via the deamination of agmatine, a polyamine derived from arginine. Physiologically natural amines (endogenous BAs), including spermine and spermidine, are not generated by microbial decarboxylases. Their intracellular biosynthesis requires the aminopropyl group internalization into the precursor putrescine. Structures of main BAs in food formed by decarboxylation of respective amino acids are shown in Table 7. Although biogenic amines in foods generally have microbiological origins, the natural polyamines spermine and spermidine are the principal amines in fresh foodstuffs like fish, milk, meat, fruits, and vegetables where

microbial growth and proliferation have not occurred. Several bacterial groups, such as Enterobacteriaceae and lactic acid bacteria (LAB), can decarboxylate amino acids and generate variable quantities of BAs (Motarjemi, 2013). Thermal processing can destroy the BAs-producing bacteria in foods; however, some BAs, like histamine, may still be formed in thermally processed food products in case of recontamination and temperature abuse after heating (Naila et al., 2010). According to reports, the consumption of *N*-nitroso compounds and nitrites, which include those derived from BAs, leads to a slight increase in the accumulation of nitrogenous compounds in the body. However, these compounds primarily originate from microbial activities and the internal metabolic processes of nitrates consumed by mammals (Motarjemi, 2013).

Correlation of PITs with food sensory aspects

It has been known that high-temperature food processing leads to the generation of several decomposition compounds, which may provide either desirable qualities, like delicious taste and odor, or render undesirable outcomes, such as adverse health effects. Aromatized foods have been developed in recent decades due to increased progress in the food industry. Thermal processing technologies lead to several chemical reactions, including the

Table 7 Several main biogenic amines

Type	Precursor	Biogenic Amine	Structure
Aromatic amines	L-Phenylalanine	Phenylethylamine	
	L-Tyrosine	Tyramine	
	L-Histidine	Histamine	
	L-Tryptophan	Tryptamine	
Aliphatic amines	L-Arginine and L-Glutamine via L-Agmatine and L-Ornithine	Putrescine	
	L-Lysine	Cadaverine	
Polyamines	Putrescine	Spermidine	
	Putrescine	Spermine	

Maillard reaction, caramelization, and lipid oxidation, affecting food safety and sensory quality. Food aromatization requires thermal-induced changes, the presence or absence of additional salt, oil, and sugar, or the replacement of some natural flavor ingredients. Moreover, optimal formulation and processing strategies of food aroma incorporated systems are needed to warrant the successful inclusion and protection of flavor ingredients such as amino acids and carbohydrates, thus preventing their degradation and formation of off-flavor in the final product (Guerzoni et al., 2011).

Acrolein (2-propenal), one of the most undesirable food PITs, is produced during deep-frying in edible fats and oils. According to (Ewert et al., 2012), the concentration of acrolein significantly increased in oils containing high amounts of linolenic acid, such as rapeseed/canola or linseed/flax oils. In this connection, (Endo et al., 2013) stated that there is a relationship between acrolein content and linolenic acid as its primary source during the heating of vegetable oils. (Shibata et al., 2018) demonstrated that acrolein could be formed as the main volatile compound from the triacylglycerol oxidation of fish oil. The thermal degradation of glycerin was specified with an aldehyde, named acrolein by Berzelius, that is a contraction of 'acrid' (due to its pungent smell) and 'oleum' (oil or oil-like consistency) (Pradipta et al., 2021). It has been reported that in an extremely diluted condition, the odor of acrolein is not entirely undesirable, being

somewhat ethereal; however, low amounts of acrolein in the room environment quickly brings the workers' eyes to tears (Stevens et al., 2011). It also provides irritating and unpleasant odors in processed food. The smell of burnt fat while heating/cooking oils to the smoke point is caused by the pyrolysis of glycerol to acrolein (Ng et al., 2019). The reaction of the carbonyl with oils, e.g., butter, tallow, peanut oil, and corn oil, results in the production of volatile compounds, such as acrolein (Khorshidian et al., 2015; Pickenhagen et al., 1996).

Mercapto flavor compounds, the sulfur-containing substances responsible for meat flavor, are valuable aroma components providing pleasant and desirable flavors to foods such as onion, sesame oil, garlic, and barbecued and thermally-processed foods. Thus, the mercapto flavor compounds may be used as a food additive. They can also be produced via microbial decomposition of methionine and cysteine, resulting in sulfidic, mercaptan-like, hydrogen sulfide, and stale cabbage off-odors. These compounds are also produced during the thermal processing of food via the Maillard reaction together with acrylamide. Therefore, they may coexist with acrylamide in thermally processed foods. However, when these flavor compounds react with acrylamide through Michael addition reactions, also called a Michael donor, sulfur anions (S^{2-}) are about 280 times more reactive than amino groups ($-NH_2$) in environments with the analogous reaction mechanism. Accordingly, mercapto flavor

compounds can considerably affect the acrylamide concentration in food (Mohammadi et al., 2021; Xiong et al., 2017). Moreover, thermal processing time and temperature may significantly influence acrylamide content and food color. Increasing frying time and temperature can cause the browning of food and result in acrylamide production (Koh, 2007).

HOCs have been recognized as significant volatile compounds in many foods. These compounds are present in traces in food flavors such as those of meat (beef, lamb, chicken), fish, cereals (wheat, corn, rice, barley), bread, nuts (peanuts, almonds, soya bean, filberts, pecan), milk and dairy products, fruits, vegetables (potatoes, artichoke, asparagus, dry red beans, beetroots, leeks, tomatoes), spices and condiments (trassi, pepper), alcoholic and nonalcoholic beverages (tea, cocoa, coffee, beer, whiskey, rum), essential oils (jasmine), and tobacco. Studies on flavors of deep-fat fried foods indicated the existence of furan, pyridines, pyrazines, cyclic polysulfides, oxazoles, and thiazole, with long-chain alkyl substitutes on their heterocyclic ring. The compound 2-pentylpyridine with potent tallow-like and fatty odor was identified in fried chicken and French fries flavors (Hou et al., 2019; Song et al., 2012). Pyrazines are the principal contributors to cocoa products' roasted, nutty, green, and earthy aromas. It has been reported that alkylpyrazines have toasted, nutty, or roasted notes and significantly participate in roasted and fried chicken flavors (Bicas et al., 2021). The compounds 2,5-dialkylpyrazines in wine, originating from oak wood, reminisced rancid butter (Shinkaruk et al., 2019; Wu et al., 2021). In addition, 2-methylpyrazine imparted nutty and chocolate flavors, and 2-ethyl-6-methylpyrazine induced roasted hazelnut flavor to light-roasted coffee (Lee et al., 2017). However, these two compounds generated fermented, harsh, and overripe flavors, also known as a black roast defect, in dark-roasted coffee (Yang et al., 2016). Furthermore, 2-hydroxymethyl-3,6-diethyl-5-methylpyrazine caused burnt or overcooked rice flavor in alcoholic beverages (Zhao et al., 2018a, 2018b). Pyrazine derivatives 2-isopropyl-methoxypyrazine and 2-isobutyl-methoxypyrazine resulted in moldy and earthy off-flavors in fish (Mohammadi et al., 2021). Similarly, 3-alkyl-2-methoxypyrazines contributed to earthy off-flavor in potato products. Naturally occurring methoxyalkylpyrazines also imparted green and earthy notes to fruits and vegetables (Bicas et al., 2021). Trimethylpyrazine and tetramethylpyrazine are the main components with a grassy and nutty flavor in cocoa products (Barišić et al., 2019). *N*-Heterocyclic bases, such as 2-acetyltetrahydropyridine, 2-acetyl-1-pyrroline, and 2-ethyltetrahydropyridine, could induce a mousy odor to wine (Snowdon et al., 2006; Wu et al.,

2021). The roasted and popcorn-like aroma of cooked rice was attributed to 2-acetyl-1-pyrroline. The odor of rice bran was also ascribed to 2-acetylthiazole (Lina et al., 2022). Thiazoles are a group of HOCs with a five-membered ring containing nitrogen and sulfur in the 3 and 1 positions, respectively (Ripain et al., 2021). Some of the alkylthiazoles detected in processed foods like French fried potato, including 2-butyl-4-propylthiazole, 2-butyl-4-methyl-5-ethyl thiazole, 2,4-dimethyl-5-pentylthiazole, and 2,4-dimethyl-5-propylthiazole, have a potent characteristic green, sulfury, and sweet aroma. Thiazolines, reduced forms of thiazoles, such as 2-ethyl-4,5-dimethyl-3-thiazoline and 5-ethyl-2,4-dimethyl-3-thiazoline, have also been identified as contributors to the meaty odor in boiled beef and chicken (Yeo et al., 2022). One of the most noticeable products of substituted pyridines is 2-acetyl tetrahydropyridine, which imparts a mousy off-flavor to wine (Hayasaka, 2019). Furthermore, 2-acetylpyridine and 3-carbomethoxy-pyridine are substantial components of potato chips and roasted nuts, respectively (Vernin, 1982). According to Zhang et al. (2021), *N*-heterocyclic compounds impart roasted, earthy, burnt, and nutty odors to oils extracted from seeds roasted at > 150 °C. It has been found that *O*-heterocyclic compounds contribute to the caramel-like aroma, *N*-heterocyclics correlate to bready, nutty, and corny aromas, and *S*-heterocyclic compounds have meaty, roasted, or vegetable notes (Zha et al., 2021). (Carvalho et al., 2022) indicated that furan derivatives remarkably contribute to tamarind aroma. (Bicas et al., 2021) reported that furans induce caramel- and coffee-like notes to light-roasted coffee and spicy and bitter flavors to dark-roasted coffee. The compound 2-pentylfuran was recognized as responsible for sweet, green, fruity, and fire-burning aromas, and 2-ethylfuran was correlated to grassy, fruity, and floral odors in fermented dark tea (Xiao et al., 2022). (Lina et al., 2022) reported that 2-pentylfuran causes a nut-like aroma in cooked rice at low concentrations; however, high concentrations give less pleasant soybean aroma characteristics. The compound 2-methyl-3-furanthiol produces a sulfur and meaty off-flavor in alcoholic beverages and vegetable and sulfury flavors in dark-roasted coffee (Bicas et al., 2021; Wang et al., 2020a, 2020b). This compound and bis (2-methyl-3-furyl) disulfide were identified as substantial contributors to the meaty odor of cooked pork, chicken, and beef (Bicas et al., 2021). Some pyrazoles, such as tartrazine (E102), are widely used as food colorants (Mandal, 2019). In addition, *N*-methylimidazoles such as 4-(5-) methylimidazole are recognized as aromatic heterocyclic organic compounds. During the caramelization process in the food industry, 4-(5-) methylimidazole (4-MeI) can be produced, which is considered a caramel marker (Cunha et al., 2011).

EC is a by-product of various food processes such as distillation, fermentation, and long-term storage (Hasnip et al., 2004). According to the literature, EC is almost odorless and colorless, with a cooling, saline, and bitter taste (HSDB, 2006).

Chlorinated compounds contribute to the flavor of foods and emanate from both natural and pollutant sources. These compounds are the most prevalent halogenated flavor components introduced to food (Kittel et al., 2002). It has been found that chlorine contributes to the flavor primarily in the form of chloroanisoles. Researchers have shown that chloroanisoles can be found in musty-flavored foods and beverages (Monteiro et al., 2022; Muchiri et al., 2020). According to (Curtis et al., 1974), chicken feed containing chloroanisoles resulted in musty-tasting meat. In this connection, 2,4,6-trichloroanisole, a chlorinated derivative of anisole, is the chief cause of cork taint and smell in all bottled food products, such as wine, that use cork stoppers (Cravero, 2020). Studies have indicated that at slightly higher concentrations, this compound could impart a moldy, musty, dank, or cellar-like flavor to the wine (Mazzoni et al., 2020; Slabizki, 2016). It has been reported that 2,3,6-trichloroanisole induced moldy off-flavor in fish (Mohammadi et al., 2021). (Bleicher et al., 2022) suggested that the volatile halogenated compounds could contribute to meat aromas. Chlorine flavor and unpleasant taste can be formed in drinking water and raw food when contaminated with chlorinated compounds (Puget et al., 2010). Chlorophenols and bromophenols were identified as contributors to medicinal and iodine-like off-flavors in fish (Mohammadi et al., 2021).

In many foods, especially plant-based meat alternatives, hydrolyzed vegetable proteins are utilized as seasonings or flavoring agents to give a richer or meat-like taste (Wang et al., 2022a). During the production of HVPs, organic chemical compounds chloropropanols, including 3-MCPD and 1,3-DCP, can be formed via the reaction of the hydrochloric acid with residual lipids and the reaction of 3-MCPD with acetic acid, respectively (Genualdi et al., 2017). Pure 3-MCPD is a liquid with a pleasant odor and a straw color (Humans, 2013).

As mentioned, the mechanism of HAAs formation depends on the heating temperature and time during thermal processing. HAAs are identified as the principal toxicants formed in protein-rich foods like meat and meat products during thermal processing and flavor-forming (Barzegar et al., 2019). These compounds may be present in trace levels in Maillard reaction products and contribute to Amadori-type processed flavors. Furthermore, these browning-type food flavoring components can participate in meat, bread, and other culinary flavors (Teng et al., 2018). Sugars and free amino acids on the

meat surface react through the Maillard reaction during thermal processing, resulting in various products essential for the flavor and color of cooked meat and meat products. Furthermore, sulfur-containing amino acids are acknowledged as precursors for the ultimate taste of these foodstuffs (Shahidi et al., 2014). (Gibis et al., 2010) indicated that the preference for roasted flavor and color significantly increases HAAs' daily intake.

The primary reactions during the heating that lead to the formation of flavors in foods such as meat and meat products include pyrolysis, thermal degradation, inter-reactions of amino acids and peptides, or interaction of sugars with amino acids or peptides (Shahidi, 2012). Sulfur-containing amino acids like cysteine and methionine are considered indispensable for developing the characteristic aroma of some foods, such as onion and cabbage (Marcinkowska et al., 2022). (Fujimaki et al., 1969) identified 7 to 8 volatile compounds from pyrolyzed cysteine and cystine, including 2-methylthiazolidine (a result of the reaction of acetaldehyde with mercaptethylamine), and 11 volatile compounds from the pyrolysis of methionine. The volatile compounds generated from the pyrolysis of L-cysteine and DL-methionine created popcorn-like and methylmercaptane aromas, respectively. The heterocyclic compounds produced from cystine via Maillard reactions and Strecker degradation revealed the strong-smelling notes of sulfur, roasted and toasted foods, popcorn, hazelnut, and ripe fruits (Pripis-Nicolau et al., 2000). Cysteine and methionine, which generate volatile compounds with low olfactory thresholds, such as methional, through light-induced oxidation reactions and Strecker degradation, play a significant role in wine aroma and off-odors (Mayr et al., 2015). Hydrogen sulfide produced from cystine or cysteine induced a rotten egg odor in alcoholic beverages (Wu et al., 2021). (Fracassetti et al., 2021) associated cabbage- and onion-like odors and light-struck taste in white wine with methanethiol and dimethyl disulfide. Likewise, methanethiol was recognized as a contributor to sulfur, garlic, rotten, or cabbage off-flavors in Baijiu, an alcoholic beverage (Wang et al., 2020a, 2020b). Volatile sulfides generated through the brewing process, especially dimethyl sulfide, could also impart unpleasant roasted corn, rotten vegetable, or sulfur smells to beer (Wu et al., 2021). (Dong et al., 2019) related 3-(methylthio) propanal with onion flavor in alcoholic beverages. Besides, dimethyl disulfide and dimethyl trisulfide imparted sulfide odor and Japanese pickles off-flavor to alcoholic beverages, respectively (Chen et al., 2017; Wang et al., 2020b). These two compounds were also related to the cooked flavor in potato products (Kocadağlı et al., 2021). In this regard, several

researchers have shown that methional, methanethiol, and alkyl sulfides could contribute to the sulfur-, cabbage-, onion-, and garlic-like notes in the odor profile of different cheese types (Bicas et al., 2021; Ianni et al., 2020). It has been indicated that phenylacetaldehyde and 3-methylbutyraldehyde, the Strecker degradation products of phenylalanine and leucine, have roasted peanut and refreshing malty aromas, respectively (Lina et al., 2022; Weerawatanakorn et al., 2015). Several researchers reported honey-like and floral aroma characteristics of phenylacetaldehyde (Bicas et al., 2021; Jin et al., 2019; Kocadağlı et al., 2021). Acetaldehyde and diacetyl, produced during beer fermentation, could cause pungent grassy and butterscotch off-flavors in beer, respectively (Olaniran et al., 2017; Wu et al., 2021). Acetaldehyde can also induce fresh-fruity notes in yogurt and nutty, bruised apple and almond flavors in wine. Moreover, acetaldehyde and dimethyl sulfide contribute to the cooked odor in tomato products (Bicas et al., 2021).

Benzenes can be formed in foods and soft drinks via process-induced changes, like high-temperature chemical transformations and ionizing radiation, and from the reactions of added or naturally occurring precursors such as ascorbic acid and sodium benzoate. Moreover, they may be formed in food additives, like liquid smoke, through processing (Desvita et al., 2021; Heshmati et al., 2018a). Benzene generation was also reported during the production of soft drinks, especially those with an orange flavor (Mercer, 2006). Results from the State of Florida Laboratories indicated trace amounts of benzene in Koala Springs flavored-mineral water (Morsi et al., 2012). It has been demonstrated that 1,2,3-trimethoxybenzene contributes to the stale odor; 1,2-dimethoxybenzene was related to fabric, grass, and wood attributes, and benzaldehyde imparted floral and honey-like aromas to fermented dark tea (Xiao et al., 2022). (Jin et al., 2019) described the almond-like flavor characteristics of benzaldehyde. Benzeneacetaldehyde imparted a floral aroma in stir-fried beef (Bai et al., 2022).

Cured meats have excellent marketability in terms of desirable texture, flavor and color, and long-term shelf life (Da Silva Cardoso et al., 2020). *N*-nitrosamines are formed in cured meats and other food products because nitrite, nitrate, and salts are added to these products to inhibit the germination of *Clostridium botulinum* spores and their toxin formation. Nitrite can also prevent the extension of off-flavors and react with pigments in meat products to impart the desired pink color of cured meats (Scanlan, 2003). According to Deng et al. (2021), the characteristic cured flavor of bacon is primarily due to the action of nitrite on the meat, and acceptable bacon can be manufactured using sodium nitrite. During meat

cooking, *N*-nitrosopiperidine can participate in cured meat products' aroma (Krol et al., 1974).

Production of smoked foods such as smoked meat and fish (mainly via smoking, grilling, frying, roasting, baking, etc.) has been very popular for at least 10,000 years. Nowadays, smoking is generally applied to generate a pleasant flavor, color, and appearance in smoked foodstuffs. The principal smoke flavoring components are carbonyl compounds rendering the traditional color and texture of smoked foods, phenolic compounds, and organic acids, especially acetic acid (IOFI, 2012). However, health hazards might be related to smoked foods due to the potential presence of carcinogenic compounds of wood smoke, primarily PAHs and their derivatives, like oxygenated PAHs or nitro-PAHs (Shen et al., 2012). Very high combustion temperatures have been used in traditional food smoking processes in which foods were directly subjected to all compounds of the smoke. Direct heating of meat products results in higher amounts of PAHs than indirect methods in which PAHs are somewhat omitted via condensation in tars (Boylston et al., 2012; Šimko, 2005). The PAHs composition and concentration and the intensity of smoke flavor in food products depend on various factors, such as the heat source, oxygen accessibility, smoking temperature and duration, fat content, the water activity of the foodstuff, the distance between the heating source and the food, design of the instrument, and fat drainage, among others (Abdel-Shafy et al., 2016; García-Falcón et al., 2005). The highest PAH amounts in smoked foods are typically observed on food surfaces, and the maximum concentrations of these compounds are produced at the end of the smoking process (Essumang et al., 2014). (Guillén et al., 2004) reported high amounts of PAHs with different molecular weights as the main flavor ingredients of smoked artesian cheese.

In several food systems, carbohydrates such as monosaccharides and polysaccharides are involved in preserving a broad spectrum of ligand molecules like flavor and odor compounds. In addition, proteins and sugars are essential for various chemical reactions. Maillard reaction is a significant factor affecting food flavor and is related to the type and proportion of amino acids and reducing sugars. Researchers have reported that some functions of MRPs are associated with the sensory characteristics of the final food product (Bredie et al., 2006; Jaeger et al., 2010). The Maillard reaction results in protein cross-linking, AGEs formation, browning of the final product, and the generation of flavor compounds. Melanoidins are heterogeneous nitrogen-containing brown pigments produced by the Maillard reaction (Henle, 2005). The primary step of the Maillard reaction (Fig. 2) is a Schiff base formation through an interaction between the carbonyl groups of reducing sugars and the amino

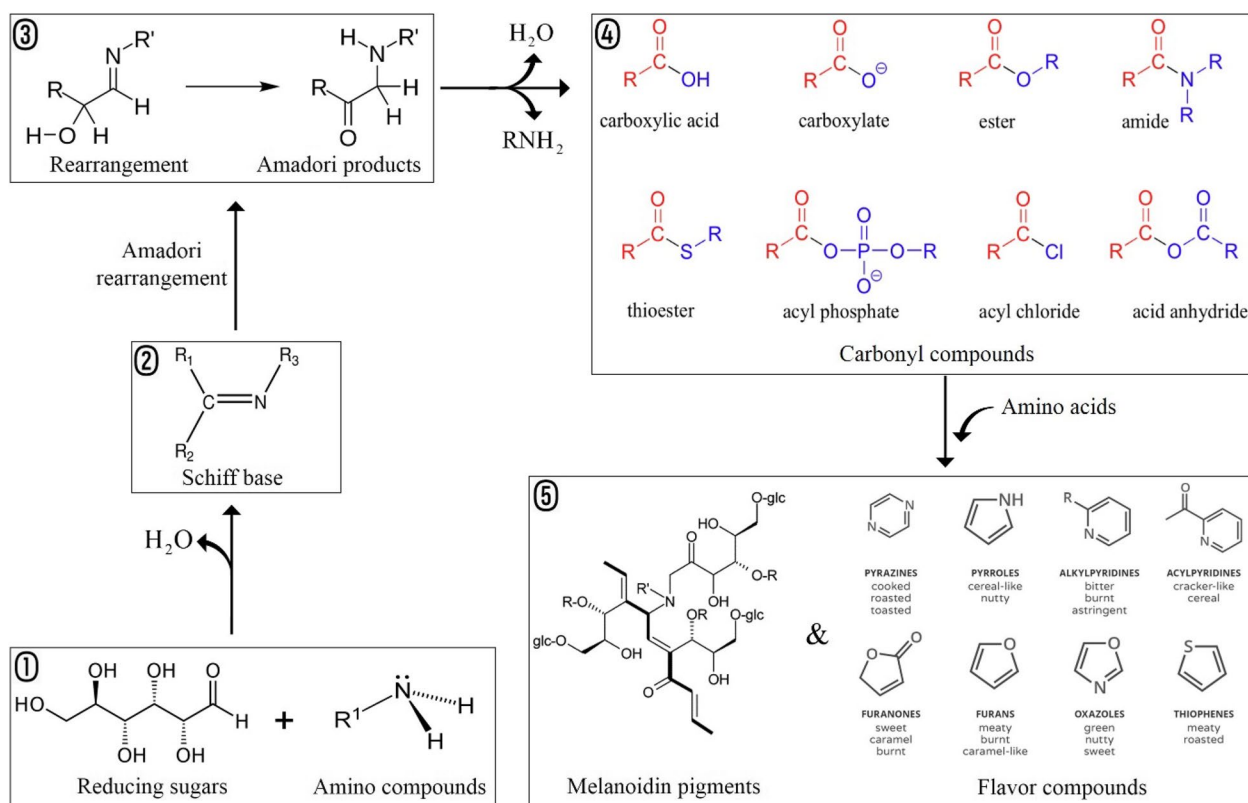


Fig. 2 The simple schematic of color and flavor formation in the Maillard reaction

nitrogen of amino acids. The Schiff base may be rearranged to generate an Amadori product, whose further decomposition creates principal intermediates for producing color and flavor compounds (Stadler et al., 2008).

The Maillard reaction is extensively utilized to improve the aroma of bakery products, meat products, and beverages. Pyrazines, by-products of the Maillard reaction, participate in cocoa, cooked, roasted, and toasted flavors (Farah et al., 2012). Methoxypyrazines, predominantly found in various alcoholic beverages, possess an aroma of green bell pepper (Wamhoff et al., 2012). Several MRPs participate in diverse food flavors, such as pyrroles (cereal-like and nutty flavors), alkylpyrazines (nut, barbecue, bitter, burnt, scorched, and astringent flavors), acylpyridines (cracker-like and cereal flavors), furanone (sweet, caramel, and burnt flavors), furans (meaty, burnt, and caramel-like flavors), furfural (caramel, bread, and woody, and sweet aroma), oxazoles (green, nutty, and sweet flavors), and thiophenes (meaty and roasted flavors) (Chang et al., 2021; Compoundchem, 2015; Li et al., 2020b). (Wu et al., 2018) indicated that the bread supplemented with Maillard reaction products had a better smell and taste than ordinary bread. Furfural was identified as a contributor to the bitter taste in alcoholic beverages and fresh bread and coffee-like notes in roasted

coffee. The honey-like flavor of roasted coffee was also attributed to HMF (Bicas et al., 2021; Wu et al., 2021). According to (Zha et al., 2021), furaneol (4-hydroxy-2,5-dimethyl-3(2H)-furanone), which is a furan derivative, has strawberry-like and burnt pineapple aromas and can be utilized as a flavor enhancer in sweet food products. This compound was also involved in the sweet odor of roasted almonds, the curry-like or burnt sugar-like off-odor in nonfat dry milk, and the caramel-like and meaty notes of cooked beef (Bicas et al., 2021; Jin et al., 2019; Yang et al., 2013). The cooked meat flavor characteristic of 3-methyl-2-thiophene carboxaldehyde was reported by Shen et al. (Shen et al., 2021). (Chen et al., 2018b) showed that 2-octylfuran and 3-phenylfuran induced caramel-like flavor, geranyl acetone, (E)-2-octen-1-ol, and 1-octen-3-ol were significantly related to mushroom-like flavor, however, 3-methylbutanal, 2,5-thiophenedicarboxaldehyde, and 2-thiophene-carboxaldehyde contributed to the meat-like characteristic of MRPs. Other researchers have also demonstrated the mushroom-like aroma of 1-octen-3-ol (De Araújo Cordeiro et al., 2020; Lina et al., 2022; Wu et al., 2021; Xiao et al., 2022). (Bassam et al., 2022) reported that 2-pentylfuran was related to caramel-like, sweet, and burnt aromas in the aroma profile of grilled meat. Ethyl maltol (2-ethyl-3-hydroxy-4(4H)

pyranone) has been found to give a caramel-like aroma to foods (Zha et al., 2021). Generally, 125 °C was identified as an optimal temperature for preparing MRPs with abundant volatile compounds and favorable sensory characteristics. The concentration of free amino acids and 50-GMP, which participate in the umami taste, in MRPs derived under 125 °C were 3 to 4 times higher than those in the mushroom hydrolysate (Chen et al., 2018b). According to (Huang et al., 2011), controlling the Maillard reaction by some sulfur-containing compounds, such as L-cysteine and thiamine, may allow tastier and healthier (more antioxidant activity) foods to fulfill food producers' and consumers' demands. It has been reported that heterocyclic sulfur-containing compounds are the most significant MRPs responsible for cooked meat's boiled, roasted, meaty, and savory flavor (Ismail et al., 2022). Cooked meat aroma characteristic of sulfur-containing MRPs was also indicated by Ji et al. (Ji et al., 2020). (Shen et al., 2021) demonstrated that dimethyl trisulfide has an onion-like aroma at low concentrations; however, high concentrations result in the undesirable sulfur flavor of MRPs. (Karangwa et al., 2017) showed that a combination of peptide-xylose-cysteine resulted in MRPs with more dark-brown color and less amino acid concentration than the other MRPs. These MRPs also exhibited pleasant mouthfeel and taste continuity with a more intense umami taste and meat-like flavor than the others. Similar results were obtained by adding cysteine, methionine, and thiamine to sesame seed hydrolysates (SSH) on MRP's composition and sensory quality. Sulfur-containing MRPs indicated lower bitterness and stronger caramel and meat flavors than SSH-MRPs due to the lower concentration of bitter amino acids and higher contents of furan and sulfur compounds, respectively (Shen et al., 2021). Pyrazines, especially 2,6-dimethylpyrazine, mainly generated via Maillard reaction and Strecker degradation, impart nutty, toasted, roasted, and burnt aromas to roasted peony seed oil (Jin et al., 2019). It has been reported that alkyl-pyrazines (e.g., 2,3-diethyl-5-methylpyrazine, 2-ethyl-3,6-dimethylpyrazine,

and 2-ethyl-3,5-dimethylpyrazine) and Strecker aldehydes (such as methional) considerably contributed to the baked flavor of potato products (Kocadağlı et al., 2021). Nevertheless, the formation of alkylpyrazines and Strecker aldehydes during the Maillard reaction has significantly been correlated with acrylamide formation (Elmore et al., 2013; Kocadağlı et al., 2021). Table 8 illustrates examples of flavor production by alkylamino acids and sugars (Maillard reaction) in a solution at 100 °C based on the findings of (Mabrouk, 1979).

Biogenic amines, low molecular weight organic bases, are substantial toxicants in many foodstuffs. They are used as criteria for quality control of food products, as they can be responsible for flavor variations. Bas may also be involved in the Maillard reaction (Pereira et al., 2015). High concentrations of biogenic amines can be found in fermented, aged, putrid, and spoiled food products. Biologically active amines form the generic and specific taste of mature fruit-vegetable and are precursors of several flavor compounds (Silva, 2005). (Palacios, 2006) demonstrated that cadaverine and putrescine could reduce the value of wine flavor by contributing to rotten and putrefied meat flavors, respectively. High histamine concentrations can be accumulated in fish before any signs of spoilage are noticed, such as an undesirable smell or taste. Scombroid poisoning, also named histamine toxication, is a typical food poisoning related to eating spoiled histamine-rich fish. The symptoms of scombroid poisoning are variable and include a peppery or metallic taste, burning in the lips, tongue, mouth, and throat, thirst, headache and dizziness, weak pulse (low blood pressure), palpitation, difficulty swallowing, abdominal pain, vomiting, nausea, diarrhea, and allergic signs, e.g., rash, hives, facial swelling, and flushing (Brock et al., 2021; Grattan et al., 2021). The odor known as "amine/ammoniacal" in meat and meat products has been developed by cadaverine, putrescine, dimethylamine, and trimethylamine (Zhou et al., 2022a). It has been illustrated that putrescine and cadaverine are responsible for developing putrid and fecal off-flavors in foodstuffs. These unpleasant smells are

Table 8 Flavors created through the thermal processing of amino acids and sugars

Amino acid	Dihydroxyacetone	Glucose	Fructose	Maltose	Sucrose
Glycine	Baked potato	Caramelized sugar, faint beer	Unpleasant caramel smell	Weak	Objectionable weak NH ₃
Methionine	Baked potato	Overcooked sweet potato	Objectionable chopped cabbage	Over cooked cabbage	Unpleasant burned wood
Glutamic acid	Chicken broth	Old wood, pleasant	Too weak	Too weak	Pleasant caramel
Lysine	Strong dark com syrup	Backed sweet potato	Objectionable fried butter	Unpleasant wet wood	Rotten wet potato
Phenylalanine	Very strong, hyacinth	Rancid caramel, unpleasant violets	Stinging smell, very objectionable	Pleasant sweet caramel	Unpleasant sweet caramel

associated with the sensory specifications of ammonia and manure, respectively (Westling et al., 2016). Besides, histamine induces pungent off-flavor, and phenylethylamine contributes to fishy off-flavor (Mohammadi et al., 2021). Those cheeses, which are quickly matured and have a strong flavor, can contain notable amounts of aromatic biogenic amines. (Andic et al., 2010) reported that tyramine is the principal biogenic amine in Van Herbed cheese. In contrast, (Qureshi et al., 2013) indicated that Gama lost cheese, a native Norwegian mold-ripened cheese, contained a significantly higher putrescine content (11 to 25 mg.kg⁻¹). The biogenic amines, especially cadaverine, and some amino acids may contribute to the distinct bitter taste of Camembert cheese (Westling et al., 2016).

As mentioned, several food contaminants may be produced during food manufacturing operations. Various toxicants are formed in different processes primarily due to existing components, internal and external factors, processing conditions, and packaging technologies. They affect the food quality characteristics such as appearance and flavor and negatively impact consumers' health by causing harmful consequences. Table 9 summarizes the formation conditions of significant and prevalent food processing contaminants and the sensory characteristics in food matrices (updated from (Ragavan et al., 2017).

Toxicological profiling of PITs

Food PITs are thought to pose a serious risk to human health and can have a number of negative consequences. A few of these contaminants are really dangerous. Acute poisoning with mild to severe effects and even death are possible health outcomes. Long-term adverse health consequences include mutations in DNA, increased risk of cancer, and mutagenic activity. Acrylamide's DNA-adduction and mutagenic qualities have been shown in a few *in vitro* and *in vivo* investigations (Besaratinia et al., 2005, 2007; Koyama et al., 2011; Vikström et al., 2011). Acrolein has been shown to have negative impacts on people by several researches. It can result in DNA adducts, reproduction, carcinogenicity, and protein-DNA crosslinking (Abraham et al., 2011; Minko et al., 2008). The Maillard reaction products, like HMF and acrylamide, have also indicated some adverse consequences on the human body (Stadler et al., 2008). The International Agency for Research on Cancer (IARC) classified furan as an animal carcinogen and a possible human carcinogen (Bakhiya et al., 2010). Toxicity studies on HMF and its metabolite, 5-sulphoxymethylfurfural (SMF), have shown serositis of peritoneal tissues and hepatotoxic effects (Bauer-Marinovic et al., 2012). *In vivo* studies on individual PAHs (mainly on BaP) have shown various toxicological effects, such as hematological effects,

reproductive and developmental toxicity, immunotoxicity, carcinogenicity, and genotoxicity (DNA-damaging) of these compounds. In 2012, BaP was concluded as a human carcinogen by IARC (FSAI, 2015). Moreover, food exposure to elevated temperatures may lead to considerable changes in the food matrix, such as the pyrolysis of amino acid constituents, a process related to significant health issues. A summary of the health risks and toxicities of food PITs is presented in Table 10.

Analytical methods to detection of PITs

As analytical methodologies increase in sensitivity allowing the detection and determination of process toxicants formed during food processing, an increasing number of significant issues will arise as well. The analytical instrumentation required for sensitive detection and accurate determination (about micro and nanoscale) of these toxicants will become more costly and prohibitively in so many cases. For example, this has been encountered in the case of acrylamide for which the preferred analytical procedures for determining the content in foods involve gas chromatography-mass spectrometry (GC/MS) or mass spectrometry combined with other techniques such as liquid chromatography-tandem mass spectrometry (LC-MS/MS) (Wenzl et al., 2008). Nevertheless, accurate measurements of these toxicants in different food products are critical for establishing the relations between diet and health. Several analytical techniques have been developed to measure the toxicants which can be produced in food during processing. For instance, for determination of benzene and other volatile organic compounds in food products, the most predominant approaches are the static and dynamic purge and trap headspace coupled to gas chromatography-mass spectrometry or GC/flame ionization detection (FID). A summary of the analytical techniques employed for the determination of process-induced toxicants in food products is presented in Table 11.

Risk assessment of PITs

Risk assessments for food safety are methodical analyses of possible risks related to food items or additives. These evaluations seek to pinpoint and examine health hazards to people that may arise from things like dangerous germs, chemical pollutants, or other chemicals (EFSA, 2010). Information about the consumption of pertinent foods and the amounts of the chemical of interest in those foods are needed to estimate dietary intakes of food contaminants. The direct screening of human organs and bodily fluids has become a more popular method of determining exposure in recent years. Accurate food intake measurements are necessary for exposure evaluations that gauge the concentrations of

Table 9 Summary of formation conditions and sensory properties of food PITs

Toxicants	Formation	Precursors/Starting materials	Conditions	Possible foods	Related sensory properties
Acrolein	Thermal processing and fermentation	Cooking oil, methionine, threonine, ascorbic acid, degradation of carbohydrates, lipid peroxidation, glycerol, 3-hydroxypropionaldehyde	Temperature 180 °C, acidic pH, LAB metabolism, distillation	Deep fried fat foods, distilled spirits, and alcoholic beverages	Pungent and suffocating odor and oil or oil-like consistency
Acrylamide	Thermal processing	Asparagine, reducing sugars	Maillard reaction, Temperature above 120 °C	Potato chips, bakery foods, coffee, cereal products, etc	Brown color and mercapto flavors
HOCS	Fermentation and thermal processing	High thermal interactions and degradation of amino acids and reducing sugars, ammonia, lipids, poly-unsaturated fatty acids, and carotenoids	Maillard reaction, caramelization	Vegetables, fruits, dairy products, nuts, cocoa, coffee, meat products, bread, chicken products, fish, potato products, alcoholic and nonalcoholic beverages, cereals, etc	Sweet, sulfury green, bready, corny, meaty, popcorn-like, caramel-like, roasted, toasted, earthy, vegetable, burnt, nutty, and mousy aromas, rancid butter attributes, burnt or overcooked rice, chocolate, grassy, nutty, fermented, harsh, overripe, moldy and earthy flavors, food colorants
Furan and derivatives	Fermentation and thermal processing	Carbohydrates (e.g., glucose, fructose), amino acids (such as alanine, serine, cystine, cysteine), vitamins (like ascorbic acid, dehydroascorbic acid, thiamine), polyunsaturated fatty acids, carotenoids	Fermentation, thermal degradation, Maillard reaction, Temperature above 90 °C	Fruit juices, coffee, instant foods, milk products, dark tea, rice, alcoholic beverages, meat and chicken products, roasted almond, etc	Tamarind, grassy, floral, nut-like, sweet, green, fruity, strawberry-like, burnt pineapple, fire-burning, soybean, meaty, vegetable, coffee-like, caramel-like, sulfur, spicy, bitter, and burnt flavors
EC	Fermentation and thermal processing	Carbamyl phosphate, citrulline, cyanogen, diethyl pyrocarbonate, urea, ammonia, ethyl alcohol, and amino acids	Fermentation, distillation, and High temperature	Alcoholic beverages, bread, soy sauce, fermented milk, yogurt, cheese, sugarcane spirits, and cachaca	Cooling, saline, and bitter taste
Chlorinated compounds	Disinfection process	Aqueous chlorine, chloroanions, and chlorophenols	Chlorination	Poultry meat, fish, wine, drinking water, vegetables, and fruits	Dank or cellar-like aroma, Musty, corked, chlorine, moldy, medicinal, and iodine-like flavors
Chloropropanols and glycidol	Thermal processing	Oils and fats, chlorine, and diacylglycerol	High temperature	Hydrolyzed vegetable proteins, edible fats and oils, infant and baby foods, soy sauce, cereal-based products, soups, meat, and dairy products	Meat-like taste, pleasant odor, and straw color
HAAs	Thermal processing	Amino acids, proteins, nitrogenous bases, glucose, pH, sugar, and creatinine content	Temperature about 150–300 °C	High-protein foods such as meat and meat products and fish, and other food products, including roasted coffee, food flavors, smoked cheese, soup cubes, alcoholic beverages, and even milk	Browning-type food flavors, culinary flavors, and roasted flavor and color

Table 9 (continued)

Toxicants	Formation	Precursors/Starting materials	Conditions	Possible foods	Related sensory properties
Benzene and derivatives	Fermentation, thermal processing, ionizing radiation	Preservatives and additives, e.g., benzoates, ascorbic acid, erythroic acid, β -carotene, phenylalanine, and terpenes	Acidic conditions, presence of Cu(II) and Fe(III) ions, curing above 100 °C for 30 min	Carbonated beverages, roasted and smoked foods, canned infant carrot juice, dark tea, stir-fried beef	Orange flavor, stale, honey-like, almond-like, and floral aromas, fabric, grass, and wood attributes
Nitrosamines and analogs	Curing	Preservatives and additives, e.g., nitrates, ascorbic acid, and heme	Curing process, acidic condition	Cured meat products	Pink color and cured flavor
PAHs	Thermal processing	Incomplete combustion of organic compounds, fats and oils, wood, carbon-based materials, and liquid smoke	Temperature about 500–700 °C, heat source, oxygen accessibility, smoking temperature and duration, fat content, water activity of the foodstuff, distance between heating source and food, design of the food device, drainage of fat, etc	Roasted, dried, fried, grilled, barbecued, and smoked meat and smoked meat products, smoked fish and seafood, edible oils and fats, fatty foods, coffee beans	Smoke flavor
MIRPs	Fermentation and thermal processing	Amino acids, peptides, and reducing sugars	Maillard reaction, Strecker degradation, high temperatures, alkaline, acid or neutral pH	Potato products, bakery products, meat products, milk products, coffee, alcoholic beverages, fried, roasted, and grilled foods, and starch-based food products	Dark-brown and golden-brown colors, cocoa, caramel-like, cracker-like, coffee-like, cereal-like, mushroom-like, onion-like, bready, woody, barbecue, green bell pepper, umami, scorched, green, sweet, nutty, meaty, bitter, boiled, baked, sulfur, savory, cooked, roasted, toasted, burnt, and astringent flavors
HMF	Thermal processing	Reducing sugars	Acidic conditions, Maillard reaction, caramelization	Coffee, bakery foods, malt and malt-based foods, dry fruits, sugar-containing foods, honey, fruit-juices, UHT-milk, vinegars, jams, alcoholic products, high-fructose corn syrup	Almonds and toasted almonds, caramel, cocoa, hazelnut, honey-like, and toasted bread aromas
BAs	Fermentation	Amino acids	Enzymatic decarboxylation, microbial decarboxylation, pH, temperature, oxygen content, salt and sugar content	Cheese, fermented food products (such as vinegar and alcoholic beverages), seafood, meat products, milk products, mature fruits and vegetables, and aged food products	Amine/ammoniacal odor, fecal, pungent, rotten, putrid, and fishy off-flavors, bitter, peppery, or metallic taste, and burning in the lips, tongue, mouth, and throat

Table 10 A summary of toxic effects of food PITs

Toxins	Types	IARC ^a	TDI ^b (mg/kg bw/day)	Major Risks and Toxicity (human and animal studies)	Ref.
Acrolein	-	Group 3	0.0005	Play a role in many disease states such as spinal cord injury, multiple sclerosis, Alzheimer's disease, cardiovascular disease, diabetes mellitus, neuro-, hepato-, and nephrotoxicity, and DNA and protein adducts. Acrolein can react with DNA to form mutagenic α - and γ -hydroxy-1, N2-cyclic propano-2'-deoxyguanosine adducts.	(Moghe et al., 2015; Wang et al., 2012)
Acrylamide	-	Group 2A	0.0002	Acrylamide is a human neurotoxicant and has genotoxic and carcinogenic effects. Several studies have demonstrated its potential association with cancers of various organs, such as reproductive organs, gastrointestinal tract, kidney, lungs, and brain.	(Besaratinia et al., 2007; Exon, 2006; Hogervorst et al., 2007, 2008; Hogervorst et al., 2009; Mucci et al., 2006; Wilson et al., 2009)
HOCS	a) Furan b) Pyridines	a) Group 2B b) Group 2B	0.001	Heterocyclic Organic Compounds such as furan, pyridines, and pyrazines are potent hepatotoxicants and liver carcinogens in rodents. Cytotoxicity, hepatocarcinogenicity, and carcinogenesis are probably ascribable to a genotoxic mechanism.	(Bakhiya et al., 2010; Neuwirth et al., 2012; Stadler et al., 2008; Stuart et al., 2000)
EC	-	Group 2A	0.3	Ethyl carbamate has been verified to be a multisite carcinogen in experimental animals. It can react with DNA. This reaction is probably the mode of the mutagenic action observed in many cellular and animal systems. The main target tissues are the lungs. However, it can induce tumors in different organs, such as the liver, mammary gland, skin, etc.	(Jiao et al., 2014; Sulukan et al., 2021)

Table 10 (continued)

Toxins	Types	IARC ^a	TDI ^b (mg/kg bw/day)	Major Risks and Toxicity (human and animal studies)	Ref.
Chlorinated compounds	a) Chlorine dioxide	a) Group 3	a) 0.03	Chlorine produces carcinogenic and mutagenic compounds in the water. It has been related to sensitization, neurotoxicity, mutagenicity, reproductive effects, and cancer. There is inadequate evidence to establish chloroform and ClO ₂ carcinogenicity in humans, and safety assessments have been based on their toxicity in laboratory animals. ClO ₂ is a mucous/respiratory membrane irritant, and inhalation of excessive concentrations can cause pulmonary edema. It indicated no teratogenic effects in animal studies.	(Czarneski et al., 2021; European Medicines Agency, 2014; Taylor et al., 2004; Wang et al., 2015)
	b) Chloroform	b) Group 2B	b) 0.01-0.015		
Chloropropanols	a) 3-MCPD	a) Group 2B	a) 0.002	3-MCPD produced enlarged kidneys, renal failure, and long-lasting diuresis. In addition, it has nephrotoxicity, carcinogenicity, and infertility effects on animals. Studies have indicated that the testes, kidneys, and mammary glands are the chief target tissues of 3-MCPD. There are limited data on 2-MCPD toxicity.	(Buhrike et al., 2017; CONTAM, 2016)
	b) 2-MCPD				
HAAs	a) IQ b) MeIQ c) MeIQx	a) Group 2A b) Group 2B c) Group 2B	< 0.000001 to 0.000017	Heterocyclic Aromatic amines (HAAs) are known to be food-borne mutagens and carcinogens and have been considered a cause of various cancers, such as lung, pancreas, rectum, colon, bladder, stomach, prostate, colorectal, and breast. It has been reported that HAAs are over 100-fold more mutagenic than aflatoxin B1 and over 2,000-fold more mutagenic than Benz[<i>a</i>]pyrene.	(Adeyeye, 2020; Nagao et al., 2016; Tu et al., 2019)

Table 10 (continued)

Toxins	Types	IARC ^a	TDI ^b (mg/kg bw/day)	Major Risks and Toxicity (human and animal studies)	Ref.
Benzene	-	Group 1	0.004	Benzene is a carcinogen which creates tumors at multiple organs of animals and acute myeloid leukemia in humans. In addition, benzene-containing mixtures may harm the hematopoietic system, such as pancytopenia.	(Boogaard, 2023; Loomis et al., 2017)
N-nitrosamines	a) NDMA, NDEA b) NEMA, NMOR, NPIP, NPYR, NSAR, NDIBA, NDPA, NMVA c) NPRO, NHPRO, NDPha	a) Group 2A b) Group 2B c) Group 3	a) 0.000004 to 0.0000093	Most N-nitrosamines are pre-carcinogens and, upon metabolic activation, afford electrophilic intermediates that react with cellular components such as protein, RNA, and DNA. Many of these compounds have mutagenic, carcinogenic, and teratogenic effects on living beings.	(CONTAM et al., 2023; Rudheva et al., 2021)
PAHs	a) Benz[a]pyrene b) Benz[a]anthracene, chrysene, naphthalene, benzo[b]fluoranthene, and benzo[k]fluoranthene c) other PAHs	a) Group 1 b) Group 2B c) Group 2A or 2B	None established	Evidence indicates that the critical concern associated with PAHs is cancer risk. Many PAHs have immunotoxic, mutagenic, teratogenic, or carcinogenic effects on humans and animals. These compounds can suppress the immune system in rodents. Long-time exposure of animals to PAHs induced skin cancer (via skin contact), stomach cancer (via ingestion), and lung cancer (via inhalation). In addition, PAHs can react with DNA, resulting in genotoxic damage.	(Abdel-Shafy et al., 2016; Patel et al., 2020)
MRPs	a) HMF b) Furosine	a) IARC does currently not provide an evaluation of HMF	a) None established, although no-observed adverse effect level (NOAEL) is 80 to 100 b) None established	HMF and its derivatives confer organotoxic, carcinogenic, mutagenic, genotoxic DNA-damaging, and enzyme-inhibitory effects. In addition, studies have shown that Nε-(2-furoylmethyl)-L-lysine (Furosine) is a potent toxicant for kidney cells.	(Lachenmeier et al., 2018; Saeed et al., 2017; Shapla et al., 2018)

Table 10 (continued)

Toxins	Types	IARC ^a	TDI ^b (mg/kg bw/day)	Major Risks and Toxicity (human and animal studies)	Ref.
Bas	Histamine	-	FDA has established a tolerable maximum level of 50 for histamine in tuna and mahi-mahi fish or between 50 and 500 for histamine in other fish species	They can have toxic or carcinogenic effects as precursors of carcinogenic N-nitro compounds. Urticaria, a fall in blood pressure, tachycardia, nausea, vomiting, diarrhea, headache, and convulsions are the histamine poisoning symptoms.	(Agata et al., 2020; FDA, 2011)

^a Group 1 (Carcinogenic to humans), Group 2A (Probably carcinogenic to humans), Group 2B (Possibly carcinogenic to humans), Group 3 (Not classifiable as to its carcinogenicity to humans), Group 4 (Probably not carcinogenic to humans)

^b Oral Tolerable Daily Intake (TDI) Values from United States Environmental Protection Agency (US EPA)

Table 11 Summary of various analytical methods for the determination of process-induced toxicants in food products

Toxin	Method	Matrix	LOD	LOQ	Recovery (%)	Ref.
Acrolein	Headspace solid-phase micro extraction and gas chromatography-mass spectrometry (HS-SPME GC/MS)	Surface and drinking water	0.06 µg/L	0.2 µg/L	91–104%	(Lim et al., 2012)
	Liquid chromatography with pulsed electrochemical detection (LC/PED)	Heated vegetable oils	0.15 µM	-	104–106%	(Casella et al., 2004)
	Solid-phase microextraction gas chromatography mass spectrometric (SPME-GC/MS)	French fries, potato chips and shoestring potatoes	0.84 ng/g	1.40 ng/g	-	(Osório et al., 2011)
Acrylamide	Liquid chromatography-tandem mass spectrometry (LC-MS/MS)	Wheat bread, bran bread, and whole wheat bread	1.5 µg/kg	5.0 µg/kg	99.3%	(Alpözen et al., 2015)
	High-performance liquid chromatography with ultraviolet detection (HPLC-UV)	Baked and deep-fried Chinese foods	8.0 µg/kg	25 µg/kg	89.0–103%	(Wang et al., 2013)
	High-performance liquid chromatography (HPLC) with pre-column ultraviolet derivatization	Starch-based foods (fried potato chips, biscuits, and Chinese fried/baked foods)	15 µg/kg	50 µg/kg	89.6–102.0%	(Geng et al., 2011)
Heterocyclic Organic Compounds (Furan)	Solid phase extraction and high performance liquid chromatography—diode array detector (SPE-HPLC/DAD)	Apple cider and wine	0.002–0.093 mg/L	0.01–0.31 mg/L	80.5–103%	(Hu et al., 2013a)
	Static headspace-gas chromatography (HS-GC)	Soy sauces, vinegars, fruit juices, beer, alcoholic drinks, milk and milk beverages, infant formulas, coffee, salad sauce, tomato ketchup, baby-food purees, chocolates and meat products	0.2 ng/g	0.5 ng/g	80.3–107.2%	(Shen et al., 2016)
	Headspace gas chromatography coupled to tandem quadrupole mass spectrometry (HS-GC-MS/MS)	Baby food	0.021 µg/kg	0.071 µg/kg	80–96%	(Pugajeva et al., 2016)

Table 11 (continued)

Toxin	Method	Matrix	LOD	LOQ	Recovery (%)	Ref.
Ethyl carbamate	Gas chromatography–mass spectrometry in selective ion monitoring mode (GC/MS-SIM)	Apple juice, soju, milk, corn oil, rice porridge, peanut butter, beef flat fish, and sea mustard	0.69–6.08 µg/kg	2.10–18.43 µg/kg	80.75–121.82% (intra-day) and 78.84–116.98% (inter-day)	(Ryu et al., 2016)
	Gas chromatography–mass spectrometry (GC/MS)	Kimchi, fermented soybean paste, jeotgals, yoghurt, bread, cheese, and vinegar	-	10 ng/mL	76.9% to 118.1%	(Lim et al., 2011)
Chlorinated compounds (chlorine dioxide)	High-performance liquid chromatography with fluorescence detection (HPLC-FLD)	Soy Sauce	3.91 µg/L	13.03 µg/L	81.5–95.4%	(Zhou et al., 2017)
	High Performance Liquid Chromatography (HPLC)	Water	0.2 µg/ml	-	98.4%	(Watanabe et al., 1998)
	Gas chromatography–mass spectrometry (GC/MS)	Water	1.0 ng/mL	-	-	(Shin et al., 2006)
Chloropropanols (3-MCPD)	Ion chromatography (IC)	Various Foodstuffs	0.05 mg/L	-	81.6%–92.5%	(Zhao et al., 2017)
	High-performance liquid chromatography with fluorescence detection (HPLC-FLD)	Water and Vegetable Oil	0.36 ng/mL	1.20 ng/mL	93.39 – 97.39%	(Hu et al., 2013b)
	Gas chromatography–mass spectrometry (GC/MS)	Various Foodstuffs	4.18 ~ 10.56 ng/g	-	90.38 ~ 122.46%	(Kim et al., 2015)
Amino Acid pyrolysis (Heterocyclic Amines)	Gas chromatography–flame ionization detection (GC-FID)	Various Foodstuffs	0.50 µg/kg	-	-	(Ahmad et al., 2017)
	Electrospray ionization with liquid chromatography–mass spectrometry (LC/MS)	Cooked Meat and Chicken Dishes	0.99 ng/g	3.33 ng/g	60 and 100%	(Jo et al., 2008)
	Liquid chromatography–mass spectrometry (LC/MS)	Cooked meat and fish	0.0049–0.018 ng/g	-	-	(Iwasaki et al., 2010)
	Liquid chromatography–tandem mass spectrometry (LC-MS/MS)	Agricultural products (apple juice, vinegar, flour, cereal, jam, chocolates, cookies, and potato chip)	0.02 ~ 1.55 ng/mL (non-fat liquid), 0.15 ~ 2.32 ng/g (nonfat solid) and 0.23 ~ 2.59 ng/g (fat solid)	0.072 ~ 4.68 ng/mL (non-fat liquid), 0.46 ~ 7.03 ng/g (non-fat solid) and 0.71 ~ 7.86 ng/g (fat solid)	72.7 ~ 117.8% (non-fat liquid), 71.8 ~ 119.1% (non-fat fat solid) and 75.1 ~ 116.5% (fat solid)	(Lee et al., 2015)

Table 11 (continued)

Toxin	Method	Matrix	LOD	LOQ	Recovery (%)	Ref.
Benzene	Headspace gas chromatography-mass spectrometry (HS-GC/MS)	Yogurt	≤ 0.5 µg/L	≤ 0.75 µg/L	76 to 80%	(Vinci et al., 2010)
	Gas chromatography-mass spectrometry (GC/MS) with Headspace gas chromatography-mass spectrometry (HS-GC/MS)	Various Foodstuffs (alcoholic soft drink, fruit juice, pickle, lime juice and mayonnaise and dressing salad)	0.11 µg/L	0.36 µg/L	88.95 to 98.7%	(Heshmati et al., 2018b)
N-nitrosamines	Headspace gas chromatography-mass spectrometry (HS-GC/MS)	Carrot juice	0.04 µg/L	0.13 µg/L	92.4–94.7%	(Lachenmeier et al., 2008)
	Microwave-assisted extraction (MAE) coupled dispersive micro solid-phase extraction (D-µ-SPE) and gas chromatography with chemical ionisation mass spectrometry (GC-CI-MS)	Various meat products	0.01 to 0.12 ng/g	0.03–0.36 ng/g	74–107%	(Huang et al., 2013)
	Two-dimensional gas chromatography with Nitrogen Chemiluminescence Detector (GCxGC-NCD)	Various meat products	1.66–3.86 µg/L	6.96–16.71 µg/L	76– 85%	(Ozel et al., 2010)
Polycyclic Aromatic Hydrocarbons (PAHs)	Liquid chromatography tandem mass spectrometry (LC-MS/MS) using atmospheric pressure chemical ionisation and electrospray ionisation	Processed meat products	0.2–1 µg/kg	0.8– 1.6 µg/kg	50–130%	(Herrmann et al., 2014)
	Liquid chromatography-tandem mass spectrometry (LC – MS/MS) equipped with the atmospheric pressure photoionization (PhotoSpray APPI)	Shrimp	0.02–0.51 µg/g	-	75–125%	(Smoker et al., 2010)
Polycyclic Aromatic Hydrocarbons (PAHs)	Gas Chromatography-Mass Spectrometry (GC/MS)	Toasted Bread	0.1–1 µg/kg	0.3–3 µg/kg	72.46–99.06% (H-PAH) and 82.39–95.01% (L-PAH)	(Al-Rashdan et al., 2010)
	Liquid-liquid microextraction (MAE-DLLME) followed by gas chromatography-mass spectrometry (GC/MS)	Grilled meat	0.15–0.3 ng/g	0.47–1 ng/g	85–104%	(Kamankesh et al., 2015)

Table 11 (continued)

Toxin	Method	Matrix	LOD	LOQ	Recovery (%)	Ref.
Maillard Products: Furosine	High-performance liquid chromatography-mass spectrometry (HPLC-MS)	Fresh and processed ginsengs	0.05 mg/mL	0.18 mg/mL	-	(Li et al., 2018)
Maillard Products: 5-hydroxymethylfurfural	Gas chromatography-mass spectrometry (GC-MS)	Orange juice, multifloral honey, breakfast cereals, plum jam, biscuits and oranges	12 ng/g	39 ng/g	-	(Teixidó et al., 2006)
Maillard Products: N ε-(carboxymethyl) lysine (CML) and N ε-(carboxyethyl) lysine (CEL)	Liquid chromatography-tandem mass spectrometry (LC-MS/MS)	Breads and biscuits	1.3 ng/g (CML)-1 ng/g(CEL)	4 ng/g (CML)-3 ng/g(CEL)	88.76–93.21% (CML) and 87.64–95.15% (CEL)	(He et al., 2014)
Histamine	Iron-cobalt co-doped carbon dots labeled in indirect competitive enzyme-linked immunosorbent assay (ic-ELISA)	Fish samples	0.5 mg/kg	1.67 mg/kg	103.4%	(Li et al., 2021)
	High Performance Liquid Chromatography (HPLC)	Fish and fishery products	2.8 mg/kg	4.3 mg/kg	100.44 to 101.84%	(Kounoun et al., 2022)

chemical substances in meals. For the purpose of evaluating exposure, especially by sensitive populations, comprehensive food consumption statistics for both the median and average consumer as well as for various demographic groups are essential. Furthermore, comparable diet statistics are necessary for the development of an international risk assessment approach to food safety, especially with regard to staple foods from various parts of the world (Joint et al., 1995). Based on hazard identification, hazard characterization, and exposure assessment, risk characterization seeks to offer a qualitative and/or quantitative evaluation of the likelihood and severity of known or anticipated adverse health consequences in a particular population. The risk characterization step determines the health risks for chemicals that are assumed to have a threshold of toxicity by comparing people's exposure, determined by structured approaches using deterministic or probabilistic methods, with the acceptable daily intake (ADI), tolerable daily intake (TDI), and estimated daily intake (EDI). The resultant distribution of exposure assessments is then compared with health-base recommendation values based on the toxicological profile of the chemical of interest. This allows a probabilistic description of the risk of exceeding these levels (Ingenbleek et al., 2020). The US/EPA's probabilistic risk assessment methodology was used to estimate daily PIT consumption and calculate cancer (Incremental Lifetime Cancer Risk, or ILCR) and non-cancer hazards (Target Hazard Quotient, or THQ) in order to assess health risk. A comprehensive diet research strategy, focused surveys, or monitoring programs can all produce occurrence data for pollutants and residues. Because focused surveys and monitoring programs often concentrate on foodstuffs that are anticipated to contain the substance of interest, the results are not indicative of levels in food as a whole. Analyses of meals prepared for ingestion and combined into composite samples provide the foundation of whole diet research (Benford, 2013). PITs contaminants are a broad category of substances that are combined when food is being produced. These may result in market regulation and have a negative effect on health. These chemicals will almost always form; it only depends on the particular procedure and components. The amount of the identification in food items, tracking or maximum limits, non-carcinogenic and carcinogenic adverse effects, and suggestions to reduce the risk vary depending on the a hazardous substance. Studies have indicated that pregnant women across various age groups and trimesters may have major health complications due to dietary acrylamide exposure, including an increased risk of carcinoma. Foodstuffs were graded in order of how much they contributed to the average exposure to acrylamide: French fries comes first, then bread

and coffee. Other than coffee, acrylamide intake from bread and French fries carries a high potential for cancer. According to these results, pregnant women should abstain from high-acrylamide foods such fried potatoes, bread, and coffee for the sake of their unborn children's health (Pekmezci et al., 2024). To determine how much furan and its methyl derivatives—2-methylfuran, 3-methylfuran, and 2,5-dimethylfuran / 2-ethylfuran—found in common meals exposed newborns and toddlers, a research was carried out. To calculate the health hazards associated with risk, the margin of exposure (MoE) was utilized. The examined samples had concentrations of furan and its derivatives of 10 and 80.3 $\mu\text{g}/\text{kg}$, respectively. The danger connected to consuming the examined substances in both age groups is shown by the MoEs for neoplastic effects in the majority of fictitious situations. MoEs for non-neoplastic effects show the possible risk for significant exposure (95th %) with 3-methylfuran and Σ 2,5-dimethylfuran/2-ethylfuran (Minorczyk et al., 2023). According to the evaluation of EC's health risks in Serbian fruit spirits, it was found in 40% of the analyzed samples and was statistically greater in stone fruit spirits. Men accounted for 49 and 98% of the samples with MoE values below the limit at average and chronic excessive use, respectively, whereas women accounted for 19 and 96% of the samples with MoE values over the limit. In contrast to ILCR based on essentially safe dosage, which revealed 25 and 69% of the samples posing a risk to women's and men's health, respectively, cancer risk approach based on the oral slope factor suggested risk concern for 96% of the samples at average intake, independent of gender. It is important to think about taking precautions during the manufacturing of spirits and regulating EC legally (Kusonić et al., 2023). A research evaluated the possible health concerns linked to newborns' and young children's food exposure to perchlorate and chlorate, which are included in baby formulae sold in China. Infant formulae had detection rates of 46 and 98.7% for perchlorate and chlorate, respectively, with mean levels of 9.98 and 112.01 $\mu\text{g}/\text{kg}$ and highest values of 151 and 1475 $\mu\text{g}/\text{kg}$. The average and 95th % values of the daily exposure to perchlorate for infants and young children aged 0–36 months who were fed baby formulae were 0.07 and 0.17 $\mu\text{g}/\text{kg}$ bw daily, respectively. These values were less than the TDI of perchlorate, which is 0.3 $\mu\text{g}/\text{kg}$ bw daily. The TDI of 3 $\mu\text{g}/\text{kg}$ bw per day for chlorate was exceeded by the mean and P95 values of 0.83 and 1.89 $\mu\text{g}/\text{kg}$ bw per day of exposure to chlorate through baby formulae in 0–36-month-old babies and young children. The TDI of perchlorate and chlorate in baby formulae was not exceeded by the P95 exposure of newborns and young children in the 0–6 months, 7–12 months, and 13–36 months age groups. As a result, Shanghai

considers the risk of exposing newborns and young children aged 0 to 36 months to perchlorate and chlorate from baby formulae to be acceptable (Yu et al., 2024). The research project assessed possible adverse effects that Iranian consumers could face from oral exposure to 3-MCPD through chocolate eating. Results indicated a highly significant relationship between the kind of chocolate and the 3-MCPD level. Based on the estimated non-carcinogenic scenario, there is no risk to consumers' health from consuming such samples because the Hazard Indices (HI) in the probabilistic technique were less than 1. For the local and imported products with less than 70% cocoa, the predicted MOEs at the 50th, 80th, and 95th % showed a de minimis public health risk. However, MOEs obtained at the same three percentiles for domestic chocolates with more than 80% dark chocolate caused alarm (Taghizadeh et al., 2024). Samples of sausages and grilled hamburgers with varying percentages of red meat were chosen for the study's HAA risk evaluation. The samples of sausages and hamburgers had HAAs ranging from 35.9 to 2050 ng/g and 59.5 to 1530 ng/g, respectively. For the whole study population, low and high daily intake of IQ, MeIQ, and MeIQx by hamburger consumption were determined at 21.9 and 2856.5 ng/day per capita, respectively. For sausage consumers, the HAA daily consumption in a favorable scenario (5th %) is 22.8 ng/capita, whereas in an unfavorable scenario (95th %), it was 3990 ng/day per capita. The findings demonstrated that, across all age categories, male population exposure to HAAs was greater than that of female population. Furthermore, aging increased the quantity of chronic daily intake (CDI) of HAAs (Mohammadi et al., 2023a). Benzene was detected in eighty-eight liquid herbal food supplements that were gathered in Serbia. It was determined that 41.2% of supplements preserved with benzoate (0.9–51.7 µg/kg) contained benzene. There was no evidence of any health issue associated with benzoene exposure: estimations of ILCR did not approach one more cancer case per 100,000 people; maximum THQ varied from 0.39% (for toddlers) to 0.84% (for adolescents); minimum MoE were between 35,680 (for adolescents) to 77,419 (for toddlers). Nonetheless, steps to lessen the amount of benzene in food should be taken (Vojvodić et al., 2023). A scientific opinion on the hazards to the nation's health associated with *N*-nitrosamines in food was requested from EFSA. The potential risk evaluation was limited to the ten carcinogenic *N*-nitrosamines (NDMA, NMEA, NDEA, NDPA, NDBA, NMA, NSAR, NMOR, NPIP, and NPYR) that are found in foodstuffs. The daily exposure to *N*-nitrosamines varied between 0 and 208.9 ng/kg bw across different age groups, circumstances, and investigations. The primary dietary group that increases the risk

of cancer-causing *N*-nitrosamine exposure is animal-based foods. With the exception of certain baby studies where the P95 exposure was nil, MoEs ranged from 3,337 to 48 at the 95th % exposure. The MoE for carcinoma-causing *N*-nitrosamines at the 95th % exposure is very probable (98–100% certain) to be fewer than 10,000 for all age categories, according to the CONTAM Panel's conclusion, which highlights health concerns (Chain et al., 2023). Eight polycyclic aromatic hydrocarbons chemicals were found in both raw and processed marine products in South Korea, according to the results of the research. With a concentration of 14.22 µg/kg, dried bonito flake, or katsuobushi, showed the highest amount of benzo[a]pyrene, above the 5.0 µg/kg regulatory limit set by the European Commission. In katsuobushi, the total concentration of PAH8 was 220.5 µg/kg. Chrysene was the most common PAH8 congener in all marine goods, with shellfish having the greatest detection rate (70%), followed by fish (19%) and crustacea (8%). Shellfish mostly included petrogenic PAHs from the aquatic environment, whereas grilled fish mostly contained pyrogenic PAHs from combustion leftovers. The methods of grilling, smoking, and drying all had a major role in the production of PAH8 in various food products. The population of South Korea is thought to be less concerned about being exposed to PAH8 from marine products based on the findings of a risk assessment conducted utilizing a MoE method through a whole diet research (Paik et al., 2024). The 5-HMF level of common bread varieties in Turkey was found. The samples' 5-HMF concentrations varied from 3.50 to 120 mg/kg. The white, semi-industrial and traditional bread categories had the highest 5-HMF values. Males and females between the ages of 15 and 18 had greater 5-HMF exposure levels than those in other age groups. When 5-HMF exposure was taken into account, the THQ readings revealed a comparatively large health concern (Basaran et al., 2022). In Morocco, a histamine risk assessment was carried out for several fishing categories of products. When compared to fresh fish, the projected dangers of consuming canned, semi-preserved, and frozen fish are smaller. Sardine has the highest risk, scoring 35, which translates to 39 cases annually. When control measures are implemented, the score drops to 20 (or one patient year), representing an anticipated 38 patient reduction annually. For frozen fish, the hazards score ranges from zero (one patient for a millennium) to eleven (three patients for a millennium). It goes from 0 to 21 for fish that has been semi-preserved. The risk score for canned fish ranges from 12 (five patients over a millennium) to 21 (15 patients over a century). The majority of Moroccan fish items are therefore categorized as "low risk" (Hariri et al., 2018).

Food matrices impacts on PITs

As might be assumed, the primary chemical reactions that occur during food processing involve the principal food components: proteins, lipids, carbs, and vitamins. These substances can react with one another as well as with different food additives such as nitrites, sulphite, aldehydes, and alkali (Alcolado et al., 2023). This can result in food items having less nutritional value, producing odors and browning that is either desired or unwanted, and very rarely, producing dangerous substances.

As the most reactive food ingredient, proteins can react with fats, carbohydrates, vitamins, polyphenols, and a variety of chemical substances. The most significant and well researched response is perhaps the Maillard reaction that occurs when protein and reducing sugars interact (Kathuria et al., 2023). Early Maillard reactions involve the primary combination of reducing sugars and the essential amino acid lysine, resulting in the formation of a biologically unavailable deoxyketosyl substance. This reaction is crucial for dairy products, as they can lose a significant amount of their lysine content without any noticeable color changes during processing and storage (Xiang et al., 2021a). Brown pigments result from later Maillard reactions, which also lessen nutritional value and produce a variety of pleasant flavors and aromas. These reactions have been linked, at least in part, to the flavors and aromas of freshly baked products, coffee, cocoa, beer, cooked meats and vegetables (Hedegaard et al., 2013). Four primary types of Maillard tastes have been identified; the most significant of these are the cyclic enolones, which provide caramel flavors, and the *N*-heterocyclics, which produce roasted, nutty, and baked flavors (Taylor et al., 2002). The breakdown of several vitamins, the interactions between lipids and alkali and proteins, and some findings from studies on the interactions between proteins and formaldehyde and polyphenols were also discovered earlier (Hurrell, 1980). Foods include a large variety of naturally occurring and useful components called polyphenols. Proteins are bound by polyphenols, which then react with carbonyl chemicals. Polyphenol-protein binding modifies the structure and function of proteins. Maillard reactions are inhibited by reactions with carbonyl molecules (Lund, 2021).

When it comes to fat reactions, heated fat goes through three main types of reactions: polymerization, oxidation, and hydrolysis. Once hydrolysis occurs, free fatty acids are formed, and when these acids are present in enough quantities, they can significantly alter the oil's flavor. Hydroperoxides are produced during oxidation, and these hydroperoxides can subsequently be heated to produce secondary oxidation products such as keto acids, hydroxy acids, epoxy acids, and carbonyl compounds like formaldehyde, acetaldehyde, acrolein, and EC. The

creation of crosslinks, either by oxidation products or carbon-carbon bonds through additional heating in the absence of oxygen, is the cause of polymerization (Ayala et al., 2014). Nonetheless, it is beyond dispute that, under certain circumstances, fat can serve as a source of hazardous substances. Additionally, fats and their oxidation byproducts have the potential to degrade other food components, including proteins, heme pigments, and fat-soluble vitamins (A, D, and E) (Mohan et al., 2022). Foods include oilseeds, fishmeal, and frozen or dried fish can all have interactions between proteins and lipids. It appears that significant protein degradation may occur before meals that have experienced severe lipid oxidation are deemed unsatisfactory from an organoleptic perspective (Hurrell, 1980).

Foods high in fatty acids that have been thermally treated can produce lipid oxidation products, which may be detrimental to human health (Zhuang et al., 2022). Fatty acids in oils and fats degrade due to a process called lipid peroxidation, which is autocatalytic and occurs in the presence of free radicals and molecular oxygen. For many foods that include fats and oils, this process is the main cause of degradation, which results in losses of quality and nutrients. Many secondary lipid peroxidation products, including alkanals, alkenals, alkadienals, and hydroxyalkenals, are produced when fatty acids are oxidatively degraded (Yin et al., 2020). Oxidation and breakdown of ω -6 polyunsaturated fatty acids (PUFAs), such as linoleic acid and arachidonic acid, can produce 4-hydroxynonenal (4-HNE) by enzymatic or non-enzymatic pathways (Liao et al., 2020). 4-HNE can be produced during the heating of oils and integrated into fried meat and skin samples throughout the cooking process. If 4-HNE, a hazardous aldehyde, is ingested with food over an extended period of time, it may be linked to a variety of medical issues (Ma et al., 2020; Steppeler et al., 2016).

The Maillard reaction is known to be highly dependent on the reaction circumstances and to happen more frequently at higher temperatures, in alkaline environments, and with a moisture level of around 15%. While only reducing sugars among carbohydrates possess the required carbonyl groups to participate in the reactions, non-reducing sugars like sucrose can hydrolyze into reducing sugars like glucose and fructose when baking biscuits or roasting peanuts. There are also significant differences in the reactivity of the various reducing sugars (Pang et al., 2021). It was shown that specialized milk powders for lactose-intolerant newborns were much more vulnerable to Maillard reactions during preservation than regular milk powders when the lactose in the milk was hydrolyzed to glucose and galactose. The lactose-hydrolyzed sample, maintained at 25 °C and 0.62 activity of water, showed a significant decrease

in chemically reactive lysine in the first month, but the usual milk powder showed a 20% decline after 9 months. Similarly, it has been shown that extra caution needs to be used when spray-drying lactose-hydrolyzed milks or unique baby formulae that include glucose rather than lactose, since the standard process caused blocks half of the lysine (Pischetsrieder et al., 2012; Xiang et al., 2021b).

Chemical additives to food may be detrimental which include alkali, nitrites, and sulphites. Thiamin may be destroyed by sulphites and alkali, and nitrosamines, which are very carcinogenic, can be created when amines such the amino acid proline combine with nitrites (Drabik-Markiewicz et al., 2009). In food technology, alkali-treated food proteins are now widely used to produce functional proteins with the required stabilizing, foaming, and emulsifying properties, protein isolates, and solutions that are appropriate for protein fiber spinning. The development of a toxic component in the protein as a result of alkali treatment was identified as the cause of a distinct type of histopathological lesion observed in the kidneys of rats fed industrial grade soy protein. This was subsequently discovered to be due to lysinoalanine generated by adding the ϵ -amino lysine residue to the double-bonded form of dehydroalanine created by cystine or serine breakdown. While free lysinoalanine can be harmful to the kidneys, most researchers showed that alkali-treated proteins with high lysinoalanine levels have no negative effects, possibly with the exception of reducing lysine availability and protein digestibility (Sarwar Gilani et al., 2012). In reality, home cooking processes produce lysinoalanine in egg whites and a few other products (Zhao et al., 2015). In Latin America, alkali-treating corn has been done for generations, and it has the benefit of releasing nicotinic acid from its bound form, which helps against pellagra symptoms (Harper et al., 1958).

Ultra-processed foods and adverse health effects

According to the Nova food categorization system, a wide variety of ready-to-eat goods are classified as ultra-processed foods (UPF), including packaged snacks, carbonated soft beverages, instant noodles, and ready-made meals (Monteiro et al., 2019a). The products mentioned are defined as industrial mixes made mostly of chemicals that have been chemically altered and removed from food, plus flavorings, textures, colors, and additives for added durability and minimum to no inclusion of entire foodstuffs (Monteiro et al., 2019b).

Prior to consumption, UPF undergoes a variety of multidirectional procedures and alterations. Each product has a substantial quantity of additional sugar, salt, saturated fat, and other additives (Gramza-Michalowska, 2020). According to its definition, UPF is the end product of several processing steps taken to create a formulation

mostly made of inexpensive energy, nutrients, and carefully chosen additives, with the least amount of whole-foods (Monteiro et al., 2018). Various research' findings provide credence to the idea that the world's food supply's bias toward UPFs might help to partially explain rising trends in the prevalence of chronic non-communicable illnesses and an overall greater risk of death (Fiolet et al., 2018; Mendonça et al., 2016, 2017). It has been established that regular UPF intake raises the amount of free sugars, carbs, saturated and total fats, and salt in the diet, raising the risk of a number of diet-related illnesses. Additionally, it should be noted that a strong negative linear association between the amount of protein, dietary fiber, and minerals in the diet and the composition of UPFs was discovered (Rauber et al., 2018).

The unfavorable health consequences linked to UPFs could not be entirely explained by the nutrients they contain or their energy density; rather, physical and chemical characteristics of the industrial processing techniques, materials, and byproducts may also play a role. First of all, changes made to the food matrix during intense processing, commonly referred to as dietary reconstitution, may have an impact on satiety, digestion, and nutrient absorption (Fardet, 2016). Second, there is growing findings in humans that adverse health effects are associated with exposure to additives, such as emulsifiers, colorants, non-sugar sweeteners, nitrates and nitrites (Lane et al., 2024). Third, extensive industrial food processing can result in the production of potentially hazardous compounds such as acrolein, acrylamide, furans, HAAs, industrial trans-fatty acids, and PAHs, which have been connected to increased risks of chronic inflammatory disorders (Martínez Steele et al., 2023; Srour et al., 2022). Lastly, pollutants including phthalates, mineral oils, microplastics, and bisphenols that can have an adverse effect on health can find their way into UPFs (Srour et al., 2022).

Emerging green non-thermal technologies on PITs

Non-thermal techniques, which prevent nutritional breakdown, side hazardous reactions, and changes in mechanical and physical qualities, are becoming more and more important as new green technologies to supplement or replace existing manufacturing processes. The term "novel processes" refers to the following: irradiation, oscillating magnetic fields (OMF), ultrasound (US), ohmic heating (OH), superheated steam, ultrafiltration, supercritical carbon dioxide, antimicrobial agents, biological treatment, atmospheric cold plasma (ACP) and corona discharge plasma jet (CDPJ), high hydrostatic pressure (HHP), pulsed electric fields (PEF), pulsed light (PL), and so on (Mirza Alizadeh et al., 2021a).

With a focus on oil absorption and acrylamide generation, the study examined the effects of 60 kV ACP

pretreatment on potato strip properties before and after frying for varied lengths of time (5, 10, and 15 min). Potato samples that were given a cap had noticeably improved physicochemical properties. By destroying asparagine and deactivating amylase, ACP significantly decreased the synthesis of acrylamide during frying. After 14 days, ACP changed the color of the strip, making it brighter and less red and yellow (Nateghi et al., 2024). Additionally, research was carried out by CDPJ to decrease the BaP and AA contents in roasted coffee beans. The roasted beans' initial amounts of BaP and AA were reduced by 53.6 and 32.0%, respectively, after 60 min of CDPJ treatment (powered by 20 kV DC/1.5 A). Significant changes were seen in the quantity overall phenolic compounds and the Agron color indexes (Lee et al., 2020).

In the food sector, cutting back on AA is crucial. There are ways to remove AA once it has formed, but there are also ways to prevent AA from forming in the first place, such as by removing its precursors or interfering with the Maillard process. Combining established practices with cutting-edge approaches, such as employing asparaginase in conjunction with the blanching procedure (a traditional method) is more effective than applying it alone for AA reduction. The major impacts of this response on the pleasant sensory features of heated meals are that mitigation strategies affecting the MR may have a detrimental impact on color and taste. Reducing AA in food items without compromising end product qualities and features is a vital problem for the food industry, as MR is a precursor to the production of distinct and desirable flavor and color in food products. Thus, one unique tactic to lessen worries about the sensory qualities of cooked food is to employ developing technology (Nematollahi et al., 2021).

The investigation into the ultrasonic degradation of naphthalene, phenanthrene, and pyrene at three distinct, relatively high frequencies revealed that phenanthrene degrades to concentrations less than our experimental detection limit, which is less than 1 µg/L, for all three frequencies and power inputs ≥ 133 W. At 582 kHz, phenanthrene breaks down much more quickly than it does at 862 and 1142 kHz. The rates of degradation per unit mass for naphthalene, phenanthrene, and pyrene are similar for all three frequencies, although lower for the former. Moreover, under the same conditions, naphthalene degrades with less energy than phenanthrene, which in turn takes less energy than pyrene (Manariotis et al., 2011).

The study assesses the amount of BAs present during the ripening process of ovine and bovine cheeses made from milk that has been homogenized at 100 MPa prior

to cheese making. The findings demonstrated that the kind of milk used for cheese-making and the treatment given to the raw materials had a substantial impact on both the microbial ecology and the BAs concentrations of cheeses throughout ripening. Specifically, the counts of microorganisms in Caciotta revealed that the high pressure homogenization (HPH) of milk considerably decreased the amount of lactobacilli, yeasts, and Micrococcaceae at the end of ripening. However, the HPH administration to milk promoted the growth of yeasts in the cheese from cows. Additionally, compared to bovine cheeses, the ovine cheeses exhibited a much greater buildup of BA. Nonetheless, at the conclusion of ripening, the HPH treatment of milk was able to significantly lower the biogenic amine contents in both cheese typologies (Lanciotti et al., 2007).

In order to remove carcinogenic and mutagenic compounds from food, biological approaches are now showing promise as alternatives to physical and chemical detoxification techniques. Biological decontamination procedures using lactic acid bacteria (LAB) and probiotics have gained attention recently as a novel, environmentally friendly way to reduce the contamination of food with PAHs (Mirza Alizadeh et al., 2021b, 2022). Numerous academic publications have also discussed the processes underlying the deactivation of food-borne carcinogens' toxicity, particularly that of AA and PAHs (Khorshidian et al., 2020; Yousefi et al., 2019). The process of PITs breakdown involves the following steps: the conversion of organic and stable carcinogens into less toxic degradable hydrophilic metabolites; activation of antioxidative enzymes such as oxidase, manganese peroxidases, lipases, etc.; and, most importantly, the binding of heat-generated cancer-causing chemicals to the cell wall and peptidoglycans of these bacterial cells, which may eliminate them scientifically (Das et al., 2023). One possible strategy to lower the amount of BAs in food is to use adjunct cultures that are able to digest BAs. *Bacillus subtilis* DEPE IB1, isolated from gouda-type cheese, has been used in studies to reduce the content of BAs including histamine, tyramine, phenylethylamine, putrescine, and cadaverine in food items. During the culture period, the concentration of the evaluated BAs decreased due to the combined effects of the cultivation temperature (8, 23, and 30 °C) and the starting pH of the medium (5 to 8) under both aerobic and anaerobic circumstances. The starting pH of the medium and the culture temperature had a substantial impact on the breakdown process of biogenic amines by *Bacillus subtilis*. At the conclusion of the culture, 65–85% of the detected BAs were drastically decreased in concentration (Butor et al., 2023).

Conclusion

Thermal processing provides cooked and delicious taste and tempting aroma notes to foodstuff. In the food and beverage processing industries, organoleptic characteristics, including flavor (taste and aroma), texture, and appearance, play a critical role in the appreciation of food products. Food off-flavors or taints are caused by undesirable compounds generated via microbial or chemical reactions through processing, storage, or transportation. Off-flavors are emerging problems of many food products and are often associated with the presence of toxic substances. Some of the desirable processed food flavors can also be related to the production of dangerous and carcinogenic toxins. PITs formed during food processing have health risks to humans; however, they are preventable through various procedures if the causes are known. Most food PITs are formed due to employing high temperatures or long-time heating during food preparation and processing. Therefore, avoiding overheating foods or exploiting non-thermal food processes like steaming, ultrasound, cold plasma, pulsed electric field, pulsed light, high-pressure processing, and radiation will probably decrease PITs formation. Controlling or limiting the precursors of these toxicants can also be beneficial. For example, acrylamide formation in foods such as potato and cereal products can be restricted by decreasing the content of reducing sugars (e.g., glucose and fructose) and free amino acids (asparagine). Alternatively, reducing ascorbic and benzoic acid levels can efficiently diminish benzene formation and PITs concentrations in the final food product. Furthermore, managing dietary exposure to these contaminants can significantly restrict their levels and following toxic effects in humans. Foods that have undergone extensive processing (ultra-processed foods) are directly associated with a number of detrimental health outcomes, such as an increased risk of heart disease, cancer, type 2 diabetes, poor mental health, an increased risk of cardiovascular disease, dementia, and early mortality. In this regard, avoiding over-fried, burnt, and stuck-on foods of pots and pans, limiting the consumption of smoked foods and ready-to-eat products, and cooking food in an appropriate portion quantity might be beneficial for decreasing PIT intake. Apart from the aforementioned aspects, in response to new concerns about food safety, creative and cutting-edge analytical technique methods are being created. These techniques may yield extremely precise and sensitive findings, which makes them an invaluable tool for quality and safety assurance of food. These include testing for desired nutrients or flavor components, keeping an eye out for unwanted residues, pollutants, or by-products, verifying the validity of ingredients, and evaluating recipes or additive composition in the final product. Thus, it's critical to

evaluate these toxins in processed food using precise and sensitive techniques.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s43014-024-00295-9>.

Additional file 1

Acknowledgements

Not applicable.

Authors' contributions

Adel Mirza Alizadeh: Supervision, Conceptualization, Visualization, Investigation, Methodology, Writing – Original Draft, Writing – Review & Editing. Mansoureh Mohammadi: Investigation, Writing – Original Draft. Fataneh Hashempour-baltork: Investigation, Writing – Original Draft. Hedayat Hosseini: Project administration, Supervision, Investigation, Writing – Review & Editing. Fereidoon Shahidi: Project administration, Supervision, Investigation, Writing – Review & Editing.

Funding

No funds, grants, or other support was received.

Data availability

No datasets were analyzed or generated during the course of the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Dr.Fereidoon Shahidi is editor-in-chief of Food Production, Processing and Nutrition and he was not involved in the journal's review of, or decisions related to this manuscript.

Author details

¹Department of Food Safety and Hygiene, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran. ²Department of Food Quality Control and Hygiene, Faculty of Medical Sciences and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran. ³Halal Research Center of IRI, Iran Food and Drug Administration, Ministry of Health and Medical Education, Tehran, Iran. ⁴Department of Food Science and Technology, Faculty of Nutrition Science, Food Science and Technology/National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran. ⁵Department of Biochemistry, Memorial University of Newfoundland, St. John's, NL A1C 5S7, Canada.

Received: 15 April 2024 Accepted: 9 September 2024

Published online: 12 January 2025

References

- Abdel-Shafy, H. I., & Mansour, M. S. M. (2016). A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egyptian Journal of Petroleum*, 25(1), 107–123. <https://doi.org/10.1016/j.ejpe.2015.03.011>
- Abedi, E., & Pourmohammadi, K. (2020). The effect of redox agents on conformation and structure characterization of gluten protein: An extensive review. *Food Science & Nutrition*, 8(12), 6301–6319.

- Abraham, K., Andres, S., Palavinskas, R., Berg, K., Appel, K. E., & Lampen, A. (2011). Toxicology and risk assessment of acrolein in food. *Molecular Nutrition & Food Research*, 55(9), 1277–1290.
- Abt, E., Incorvati, V., Robin, L. P., & Redan, B. W. (2021). Occurrence of ethyl carbamate in foods and beverages: Review of the formation mechanisms, advances in analytical methods, and mitigation strategies. *Journal of Food Protection*, 84(12), 2195–2212.
- Adeyeye, S. A. O. (2020). Heterocyclic amines and polycyclic aromatic hydrocarbons in cooked meat products: A review. *Polycyclic Aromatic Compounds*, 40(5), 1557–1567.
- Adeyeye, S. A. O., & Ashaolu, T. J. (2021). Heterocyclic amine formation and mitigation in processed meat and meat products a mini-review. *Journal of Food Protection*, 84(11), 1868.
- Aflaki, F., Ghoulipour, V., Saemian, N., & Salahinejad, M. (2014). A simple method for benzoyl chloride derivatization of biogenic amines for high performance liquid chromatography. *Analytical Methods*, 6(5), 1482–1487.
- Agata DD, Mirosław M, Jacek O. (2020). Histamine and other biogenic amines in food. *Journal of Veterinary Research* (0);000010247820200029. <https://doi.org/10.2478/jvetres-2020-0029>
- Ahmad, N., & Muhammad, R. N. (2017). Safety assessment of commercially processed foods by quantifying 3-monochloropropane 1, 2-diol. *Journal of Food Safety and Hygiene*, 2(1/2), 37–41.
- Al-bashabsheh, Z. Q. (2019). *The inhibitory effect of natural antioxidants on formation of 2-amino-1-methyl-6-phenylimidazo [4, 5-b] pyridine (PhIP) in a model system [Doctor of Philosophy, Kansas State University]*. <http://hdl.handle.net/2097/39596>
- Al-Rashdan, A., Helaleh, M. I., Nisar, A., Ibtisam, A., & Al-Ballam, Z. (2010). Determination of the levels of polycyclic aromatic hydrocarbons in toasted bread using gas chromatography mass spectrometry. *International journal of analytical chemistry*, 2010(1), 821216.
- Alamri, M., Qasem, A. A., Mohamed, A. A., Hussain, S., Ibraheem, M. A., & Shamlan, G.... Qasha, A. S. (2021). Food packaging's materials: A food safety perspective. *Saudi Journal of Biological Sciences*, 28(8), 4490–4499.
- Alcolado, C. I., Garcia-Rio, L., Mejuto, J. C., Moreno, I., Poblote, F. J., & Tejada, J. (2023). Oxidation of aldehydes used as food additives by peroxynitrite. *Antioxidants*, 12(3), 743.
- Alpözen, E., Güven, G., Özdestan, Ö., & Üren, A. (2015). Determination of acrylamide in three different bread types by an in-house validated LC-MS/MS method. *Acta Alimentaria*, 44(2), 211–220.
- Alvarez-Builla, J., & Barluenga, J. (2012). Heterocyclic Compounds: An Introduction. *Modern Heterocyclic Chemistry*, 43, 1–9.
- Anderson, L. R., & Liu, K. C. (2000). Pyrrole and pyrrole derivatives. In *Kirk-Othmer Encyclopedia of Chemical Technology*. (Ed.). <https://doi.org/10.1002/0471238961.1625181801140405.a01>
- Andic, S., Gencelelep, H., & Kose, S. (2010). Determination of biogenic amines in herby cheese. *International Journal of Food Properties*, 13(6), 1300–1314.
- Andrés, C. M. C., Lastra, J. M. P., Andrés Juan, C., Plou, F. J., & Pérez-Lebeña, E. (2022). Chlorine dioxide: friend or foe for cell biomolecules? A chemical approach. *International Journal of Molecular Sciences*, 23(24), 15660.
- Ayala, A., Muñoz, M. F., & Argüelles, S. (2014). Lipid peroxidation: Production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. *Oxidative Medicine and Cellular Longevity*, 2014, 360438. <https://doi.org/10.1155/2014/360438>
- Bai, S., You, L., Ji, C., Zhang, T., Wang, Y., & Geng, D.... Luo, R. (2022). Formation of volatile flavor compounds, maillard reaction products and potentially hazard substance in China stir-frying beef sao zi. *Food Research International*, 159, 111545.
- Bakhiya, N., & Appel, K. E. (2010). Toxicity and carcinogenicity of furan in human diet. *Archives of Toxicology*, 84(7), 563–578.
- Barišić, V., Kopjar, M., Jozinović, A., Flanjak, I., Ačkar, Đ., & Miličević, B.... Babić, J. (2019). The chemistry behind chocolate production. *Molecules*, 24(17), 3163.
- Barzegar, F., Kamankesh, M., & Mohammadi, A. (2019). Heterocyclic aromatic amines in cooked food: A review on formation, health risk-toxicology and their analytical techniques. *Food Chemistry*, 280, 240–254. <https://doi.org/10.1016/j.foodchem.2018.12.058>
- Basaran, B., Anlar, P., Yilmaz Oral, Z. F., Polat, Z., & Kaban, G. (2022). Risk assessment of acrylamide and 5-hydroxymethyl-2-furfural (5-HMF) exposure from bread consumption: Turkey. *Journal of Food Composition and Analysis*, 107, 104409. <https://doi.org/10.1016/j.jfca.2022.104409>
- Bassam, S. M., Noleto-Dias, C., & Farag, M. A. (2022). Dissecting grilled red and white meat flavor: Its characteristics, production mechanisms, influencing factors and chemical hazards. *Food Chemistry*, 371, 131139.
- Bauer-Marinovic, M., Taugner, F., Florian, S., & Glatt, H. (2012). Toxicity studies with 5-hydroxymethylfurfural and its metabolite 5-sulphoxymethylfurfural in wild-type mice and transgenic mice expressing human sulphotransferases 1A1 and 1A2. *Archives of Toxicology*, 86(5), 701–711.
- Becalski, A., & Seaman, S. (2005). Furan precursors in food: A model study and development of a simple headspace method for determination of furan. *Journal of AOAC International*, 88(1), 102–106.
- Bellmaine, S., Schnellbaecher, A., & Zimmer, A. (2020). Reactivity and degradation products of tryptophan in solution and proteins. *Free Radical Biology and Medicine*, 160, 696–718.
- Benford, D. J. (2013). Risk assessment of chemical contaminants and residues in foods. In *Persistent organic pollutants and toxic metals in foods* (pp. 173–187). Woodhead Publishing. <https://doi.org/10.1533/9780857098917.1.173>
- Besaratinia, A., & Pfeifer, G. P. (2005). DNA adduction and mutagenic properties of acrylamide. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis*, 580(1), 31–40. <https://doi.org/10.1016/j.mrgentox.2004.10.011>
- Besaratinia, A., & Pfeifer, G. P. (2007). A review of mechanisms of acrylamide carcinogenicity. *Carcinogenesis*, 28(3), 519–528. <https://doi.org/10.1093/carcin/bgm006>
- Bicas, J. L., & Rodriguez-Amaya, D. B. (2021). Generation of process-derived flavors and off-flavors. In *Chemical changes during processing and storage of foods* (pp. 385–451). Academic Press. <https://doi.org/10.1016/B978-0-12-817380-0.00009-9>
- Bleicher, J., Ebner, E. E., & Bak, K. H. (2022). Formation and Analysis of Volatile and Odor Compounds in Meat—A Review. *Molecules*, 27(19), 6703. <https://www.mdpi.com/1420-3049/27/19/6703>
- Boogaard, P. J. (2023). Human biomonitoring of low-level benzene exposures. *Critical Reviews in Toxicology*, 52(10), 799–810.
- Boylston, T., Chen, F., Coggins, P., Hydlig, G., McKee, L., & Kerth, C. (2012). *Handbook of meat, poultry and seafood quality*. John Wiley & Sons.
- Bredie, W. L., Boesveld, M., Martens, M., & Dybdal, L. (2006). Modification of bread crust flavour with enzymes and flavour precursors. In *Developments in Food Science* (Vol. 43, pp. 225–228). Elsevier. [https://doi.org/10.1016/S0167-4501\(06\)80054-3](https://doi.org/10.1016/S0167-4501(06)80054-3)
- Brock, I., Eng, N., & Maitland, A. (2021). Adult-onset mast cell activation syndrome following scombroid poisoning: A case report and review of the literature. *Journal of Medical Case Reports*, 15(1), 1–6.
- Buhrke, T., Schultrich, K., Braeuning, A., & Lampen, A. (2017). Comparative analysis of transcriptomic responses to repeated-dose exposure to 2-MCPD and 3-MCPD in rat kidney, liver and testis. *Food and Chemical Toxicology*, 106, 36–46. <https://doi.org/10.1016/j.fct.2017.05.028>
- Butor, I., Jančová, P., Purevdorj, K., Klementová, L., Kluz, M., Huňová, I., ... Buňková, L. (2023). Effect of Selected Factors Influencing Biogenic Amines Degradation by *Bacillus subtilis* Isolated from Food. *Microorganisms*, 11(4), 1091. <https://www.mdpi.com/2076-2607/11/4/1091>
- Carvalho, F., Maciel, B., & Morais, A. (2022). Tamarind enzymatic inhibitors: Activities and health application perspectives. *Food Reviews International*, 38(sup1), 56–69.
- Casella, I. G., & Contursi, M. (2004). Quantitative analysis of acrolein in heated vegetable oils by liquid chromatography with pulsed electrochemical detection. *Journal of Agricultural and Food Chemistry*, 52(19), 5816–5821.
- Chandan, P. A., Remias, J. E., Neathery, J. K., & Liu, K. (2013). Morpholine nitrosation to better understand potential solvent based CO2 capture process reactions. *Environmental Science & Technology*, 47(10), 5481–5487.
- Chang, H., Wang, Y., Xia, Q., Pan, D., He, J., Zhang, H., & Cao, J. (2021). Characterization of the physicochemical changes and volatile compound fingerprinting during the chicken sugar-smoking process. *Poultry Science*, 100(1), 377–387.
- Chen, B. H., & Chen, Y. C. (2001). Formation of polycyclic aromatic hydrocarbons in the smoke from heated model lipids and food lipids. *Journal of Agricultural and Food Chemistry*, 49(11), 5238–5243.
- Chen, S., Sha, S., Qian, M., & Xu, Y. (2017). Characterization of volatile sulfur compounds in moutai liquors by headspace solid-phase microextraction gas chromatography-pulsed flame photometric detection and odor activity value. *Journal of Food Science*, 82(12), 2816–2822.

- Chen, X., Huang, G., An, C., Yao, Y., & Zhao, S. (2018a). Emerging N-nitrosamines and N-nitramines from amine-based post-combustion CO₂ capture – A review. *Chemical Engineering Journal*, 335, 921–935. <https://doi.org/10.1016/j.cej.2017.11.032>
- Chen, X., Yu, J., Cui, H., Xia, S., Zhang, X., & Yang, B. (2018b). Effect of temperature on flavor compounds and sensory characteristics of maillard reaction products derived from mushroom hydrolysate. *Molecules*, 23(2), 247.
- Chen, Z. (2017). A focus on chlorine dioxide: The promising food preservative. *J Exp Food Chem*, 3, e107.
- Cheng, K. W., Chen, F., & Wang, M. (2006). Heterocyclic amines: Chemistry and health. *Molecular Nutrition & Food Research*, 50(12), 1150–1170.
- Chlorine Chemistry. (2002). *Chlorine and Food Safety White Paper*. The Chlorine Chemistry Council. <https://chlorine.americanchemistry.com/Chlorine-Benefits/Health-and-Safety/Chlorine-and-Food-Safety-White-Paper.pdf>
- Claus, A., Weisz, G. M., Schieber, A., & Carle, R. (2006). Pyrolytic acrylamide formation from purified wheat gluten and gluten-supplemented wheat bread rolls. *Molecular Nutrition & Food Research*, 50(1), 87–93.
- Compoundchem. (2015). *A guide to the maillard reaction*. Compound Interest. Retrieved 27 september 2019 from <https://www.compoundchem.com/wp-content/uploads/2015/01/The-Maillard-Reaction.pdf>
- CONTAM. (2016). Risks for human health related to the presence of 3-and 2-monochloropropanediol (MCPD), and their fatty acid esters, and glycidyl fatty acid esters in food. *Efsa Journal*, 14(5), e04426.
- CONTAM, Schrenk, D., Bignami, M., Bodin, L., Chipman, J. K., del Mazo, J.,... Nebbia, C. S. (2023). Risk assessment of N-nitrosamines in food. *Efsa Journal*, 21(3), e07884.
- Cravero, M. C. (2020). Musty and moldy taint in wines: A review. *Beverages*, 6(2), 41.
- Cressey, P., Nokes, C., & Lake, R. (2008). Chlorinated compounds formed during chlorine wash of chicken meat. *Institute of Environmental Science & Research Limited, Christchurch, New Zealand*.
- Crowell, S., Hanson-Drury, S., Williams, D., & Corley, R. (2014). In vitro metabolism of benzo [a] pyrene and dibenzo [def, p] chrysene in rodent and human hepatic microsomes. *Toxicology Letters*, 228(1), 48–55.
- Cunha, S., Barrado, A., Faria, M., & Fernandes, J. (2011). Assessment of 4-(5-) methylimidazole in soft drinks and dark beer. *Journal of Food Composition and Analysis*, 24(4–5), 609–614.
- Curtis, R. F., Dennis, C., Gee, J. M., Gee, M. G., Griffiths, N. M., Land, D., & G.,... Robinson, D. (1974). Chloroanisoles as a cause of musty taint in chickens and their microbiological formation from chlorophenols in broiler house litters. *Journal of the Science of Food and Agriculture*, 25(7), 811–828.
- Czarneski, M. A., & Lorchiem, P. (2021). Validation of chlorine dioxide sterilization. In *Handbook of Validation in Pharmaceutical Processes*, Fourth Edition (pp. 325–338). CRC Press. <https://doi.org/10.1201/9781003163138>
- Da Silva Cardoso, P., Fagundes, J. M., Couto, D. S., de Marchi Pires, E., Guimaraes, C. E. D., Ribeiro, C. D. F., & Otero, D. M. (2020). From curing to smoking: Processes and techniques for the production of pastrami. *Brazilian Journal of Development*, 6(8), 61511–61520.
- Dai, N., & Mitch, W. A. (2013). Influence of amine structural characteristics on N-nitrosamine formation potential relevant to postcombustion CO₂ capture systems. *Environmental Science & Technology*, 47(22), 13175–13183.
- Dai, N., Shah, A. D., Hu, L., Plewa, M. J., McKague, B., & Mitch, W. A. (2012). Measurement of nitrosamine and nitramine formation from NO x reactions with amines during amine-based carbon dioxide capture for postcombustion carbon sequestration. *Environmental Science & Technology*, 46(17), 9793–9801.
- Das, A. K., Bhattacharya, D., Das, A., Nath, S., Bandyopadhyay, S., Nanda, P. K., & Gargaoua, M. (2023). Current innovative approaches in reducing polycyclic aromatic hydrocarbons (PAHs) in processed meat and meat products. *Chemical and Biological Technologies in Agriculture*, 10(1), 109. <https://doi.org/10.1186/s40538-023-00483-8>
- De Araújo Cordeiro, A. R. R., de Medeiros, L. L., Bezerra, T. K. A., Pacheco, M. T. B., de Sousa Galvão, M., & Madruga, M. S. (2020). Effects of thermal processing on the flavor molecules of goat by-product hydrolysates. *Food Research International*, 138, 109758.
- Deng, S., Bai, X., Li, Y., Wang, B., Kong, B., Liu, Q., & Xia, X. (2021). Changes in moisture, colour, residual nitrites and N-nitrosamine accumulation of bacon induced by nitrite levels and dry-frying temperatures. *Meat science*, 181, 108604.
- Desvita, H., & Faisal, M. (2021). Characteristic of liquid smoke produced from slow pyrolysis of cacao pod shells (*Theobroma cacao* L). *GEOMATE Journal*, 20(80), 17–22.
- Dong, H., Xian, Y., Li, H., Bai, W., & Zeng, X. (2020). Potential carcinogenic heterocyclic aromatic amines (HAAs) in foodstuffs: Formation, extraction, analytical methods, and mitigation strategies. *Comprehensive Reviews in Food Science and Food Safety*, 19(2), 365–404.
- Dong, W., Guo, R., Liu, M., Shen, C., Sun, X., & Zhao, M.,... Huang, M. (2019). Characterization of key odorants causing the roasted and mud-like aromas in strong-aroma types of base Baijiu. *Food Research International*, 125, 108546.
- Drabik-Markiewicz, G., Van den Maagdenberg, K., De Mey, E., Deprez, S., Kowalska, T., & Paelinck, H. (2009). Role of proline and hydroxyproline in N-nitrosamine formation during heating in cured meat. *Meat Science*, 81(3), 479–486. <https://doi.org/10.1016/j.meatsci.2008.10.002>
- Duedahl-Olesen, L., & Iona, A. C. (2022). Formation and mitigation of PAHs in barbecued meat—a review. *Critical Reviews in Food Science and Nutrition*, 62(13), 3553–3568.
- EFSA. (2010). Application of systematic review methodology to food and feed safety assessments to support decision making. *Efsa Journal*, 8(6), 1637.
- EFSA Panel on Contaminants in the Food Chain (EFSA CONTAM Panel) Schrenk, D., Bignami, M., Bodin, L., Chipman, J. K., del Mazo, J.,... Nebbia, C. S. (2023). Risk assessment of N-nitrosamines in food. *Efsa Journal*, 21(3), e07884.
- Elmore, J., Halford, N., Briddon, A., Dodson, A., Muttucumaru, N., & Mottram, D. (2013). Acrylamide and flavour in potato crisps. In *Acrylamide, furans and other food-borne contaminants, from plant science to food chemistry. Aspects of Applied Biology* 116, 103–110. Wellesbourne, Warwick, Association of Applied Biologists.
- Endo, Y., Hayashi, C., Yamanaka, T., Takayose, K., Yamaoka, M., Tsuno, T., & Nakajima, S. (2013). Linolenic acid as the main source of acrolein formed during heating of vegetable oils [journal article]. *Journal of the American Oil Chemists' Society*, 90(7), 959–964. <https://doi.org/10.1007/s11746-013-2242-z>
- Essumang, D., Doodoo, D., & Adjei, J. (2014). Effective reduction of PAH contamination in smoke cured fish products using charcoal filters in a modified traditional kiln. *Food Control*, 35(1), 85–93.
- European Medicines Agency. (2014). Chloroform (all mammalian food producing species), *European public MRL assessment report (EPMAR), Committee for Medicinal Products for Veterinary Use*, Reference Number: EMA/CVMP/350579/2013.
- Ewert, A., Granvogl, M., & Schieberle, P. (2012). Comparative Studies on the Generation of Acrolein as Well as of Aroma-Active Compounds during Deep-Frying with Different Edible Vegetable Fats and Oils. In *Recent Advances in the Analysis of Food and Flavors*, Chapter 9, pp 129–136. ACS Publications. <https://doi.org/10.1021/bk-2012-1098.ch009>
- Exon, J. (2006). A review of the toxicology of acrylamide. *Journal of Toxicology and Environmental Health, Part B*, 9(5), 397–412.
- FAO/WHO. (2008). Benefits and risks of the use of chlorine-containing disinfectants in food production and food processing: report of a joint FAO/WHO expert meeting, Ann Arbor, 27–30 May 2008.
- Farah, D., Zaibunnisa, A., Misnawi, J., & Zainal, S. (2012). Effect of roasting process on the concentration of acrylamide and pyridines in roasted cocoa beans from different origins. *APCBEE Procedia*, 4, 204–208.
- Fardet, A. (2016). Minimally processed foods are more satiating and less hyperglycemic than ultra-processed foods: A preliminary study with 98 ready-to-eat foods. *Food & Function*, 7(5), 2338–2346. <https://doi.org/10.1039/c6fo00107f>
- Farrington, J. W. (2020). Need to update human health risk assessment protocols for polycyclic aromatic hydrocarbons in seafood after oil spills. *Marine Pollution Bulletin*, 150, 110744.
- FDA. (2011). Guidance for the Industry: Fish and Fishery Products Hazards and Controls Guidance, Fourth Edition, U.S. Department of Health and Human Services Food and Drug Administration Center for Food Safety and Applied Nutrition, pp 468, Florida Sea Grant.
- Fiolet, T., Srour, B., Sellem, L., Kesse-Guyot, E., Allès, B., & Méjean, C.,... Touvier, M. (2018). Consumption of ultra-processed foods and cancer risk: Results from NutriNet-Santé prospective cohort. *BMJ*, 360, k322. <https://doi.org/10.1136/bmj.k322>

- Fostås, B., Gangstad, A., Nenseter, B., Pedersen, S., Sjøvoll, M., & Sørensen, A. L. (2011). Effects of NO_x in the flue gas degradation of MEA. *Energy Procedia*, 4, 1566–1573.
- Fracassetti, D., Di Canito, A., Bodon, R., Messina, N., Vigentini, I., Foschino, R., & Tirelli, A. (2021). Light-struck taste in white wine: Reaction mechanisms, preventive strategies and future perspectives to preserve wine quality. *Trends in Food Science & Technology*, 112, 547–558.
- FSAI. (2015). Polycyclic Aromatic Hydrocarbons (PAHs) in Food. *Toxicology Factsheet Series*(2). <https://www.fsa.ie/WorkArea/DownloadAsset.aspx?id=8416>
- Fujimaki, M., Kato, S., & Kurata, T. (1969). Pyrolysis of sulfur-containing amino acids. *Agricultural and Biological Chemistry*, 33(8), 1144–1151. <https://doi.org/10.1080/00021369.1969.10859440>
- Fukayama, M. Y., Tan, H., Wheeler, W. B., & Wei, C.-I. (1986). Reactions of aqueous chlorine and chlorine dioxide with model food compounds. *Environmental Health Perspectives*, 69, 267.
- García-Falcón, M., & Simal-Gándara, J. (2005). Polycyclic aromatic hydrocarbons in smoke from different woods and their transfer during traditional smoking into chorizo sausages with collagen and tripe casings. *Food Additives and Contaminants*, 22(1), 1–8.
- Geng, Z., Wang, P., & Liu, A. (2011). Determination of acrylamide in starch-based foods by HPLC with pre-column ultraviolet derivatization. *Journal of Chromatographic Science*, 49(10), 818–824.
- Genualdi, S., Nyman, P., & DeJager, L. (2017). Simultaneous Analysis of 3-MCPD and 1, 3-DCP in Asian Style Sauces Using QuEChERS Extraction and Gas Chromatography-Triple Quadrupole Mass Spectrometry. *Journal of Agricultural and Food Chemistry*, 65(4), 981–985.
- Gibis, M., & Weiss, J. (2010). Inhibitory effect of marinades with hibiscus extract on formation of heterocyclic aromatic amines and sensory quality of fried beef patties. *Meat Science*, 85(4), 735–742.
- Gramza-Michałowska, A. (2020). The Effects of Ultra-Processed Food Consumption-Is There Any Action Needed? *Nutrients*, 12(9). <https://doi.org/10.3390/nu12092556>
- Grattan, L. M., Kilmon, K. A., & Fiore, A. (2021). Chapter 28 - Seafood intoxications. In J. G. Morris & D. J. Vugia (Eds.), *Foodborne Infections and Intoxications* (Fifth Edition) (pp. 455–478). Academic Press. <https://doi.org/10.1016/B978-0-12-819519-2.00008-6>
- Guerzoni, M. E., Gianotti, A., & Vernocchi, P. (2011). Chapter 34 - Effect of Starch Addition to Fluid Dough During the Bread Making Process A2 - Preeedy, Victor R. In R. R. Watson & V. B. Patel (Eds.), *Flour and Breads and their Fortification in Health and Disease Prevention* (pp. 375–384). Academic Press. <https://doi.org/10.1016/B978-0-12-380886-8.10034-0>
- Guillén, M. D., & Sopolana, P. (2004). Occurrence of polycyclic aromatic hydrocarbons in smoked cheese. *Journal of Dairy Science*, 87(3), 556–564.
- Gunturu, S. K., Menavath, T. R. N., & Karthikeyan, R. (2019). Foods containing nitrosoamines causes carcinogenesis—an insight review. *PharmaTutor*, 7(5), 20–27.
- Gürsul Aktağ, I., & Gökmen, V. (2021). Investigations on the formation of α -dicarbonyl compounds and 5-hydroxymethylfurfural in fruit products during storage: New insights into the role of Maillard reaction. *Food Chemistry*, 263, 130280. <https://doi.org/10.1016/j.foodchem.2021.130280>
- Hamlet, C., Jayaratne, S., & Matthews, W. (2002). 3-Monochloropropane-1, 2-diol (3-MCPD) in food ingredients from UK food producers and ingredient suppliers. *Food Additives & Contaminants*, 19(1), 15–21.
- Hariri, O. E., Bouchriti, N., & Bengueddour, R. (2018). Risk Assessment of Histamine in Chilled, Frozen, Canned and Semi-Preserved Fish in Morocco; Implementation of Risk Ranger and Recommendations to Risk Managers. *Foods*, 7(10). <https://doi.org/10.3390/foods7100157>
- Harper, A., Punekar, B., & Elvehjem, C. (1958). Effect of alkali treatment on the availability of niacin and amino acids in maize. *The Journal of Nutrition*, 66(2), 163–172.
- Hasnip, S., Caputi, A., Crews, C., & Brereton, P. (2004). Effects of storage time and temperature on the concentration of ethyl carbamate and its precursors in wine. *Food Additives and Contaminants*, 21(12), 1155–1161.
- Hayasaka, Y. (2019). Quantitative analysis of mousy off-flavour compound 2-acetyl tetrahydropyridine in wine using liquid chromatography tandem mass spectrometry interfaced with atmospheric chemical ionisation. *Journal of Chromatography A*, 1588, 108–114.
- He, J., Zeng, M., Zheng, Z., He, Z., & Chen, J. (2014). Simultaneous determination of N ϵ -(carboxymethyl) lysine and N ϵ -(carboxyethyl) lysine in cereal foods by LC–MS/MS [journal article]. *European Food Research and Technology*, 238(3), 367–374. <https://doi.org/10.1007/s00217-013-2085-8>
- Hedegaard, R. V., & Skibsted, L. H. (2013). 16 - Shelf-life of food powders. In B. Bhandari, N. Bansal, M. Zhang, & P. Schuck (Eds.), *Handbook of Food Powders* (pp. 409–434). Woodhead Publishing. <https://doi.org/10.1533/9780857098672.2.409>
- Henle, T. (2005). Protein-bound advanced glycation endproducts (AGEs) as bioactive amino acid derivatives in foods. *Amino Acids*, 29(4), 313–322.
- Herrmann, S. S., Duedahl-Olesen, L., & Granby, K. (2014). Simultaneous determination of volatile and non-volatile nitrosamines in processed meat products by liquid chromatography tandem mass spectrometry using atmospheric pressure chemical ionisation and electrospray ionisation. *Journal of Chromatography A*, 1330, 20–29. <https://doi.org/10.1016/j.chroma.2014.01.009>
- Heshmati, A., Ghadimi, S., Khaneghah, A. M., Barba, F. J., Lorenzo, J. M., Nazemi, F., & Fakhri, Y. (2018a). Risk assessment of benzene in food samples of Iran's market. *Food and Chemical Toxicology*, 114, 278–284.
- Heshmati, A., Ghadimi, S., Mousavi Khaneghah, A., Barba, F. J., Lorenzo, J. M., Nazemi, F., & Fakhri, Y. (2018b). Risk assessment of benzene in food samples of Iran's market. *Food and Chemical Toxicology*, 114, 278–284. <https://doi.org/10.1016/j.fct.2018.02.043>
- Hikisz, P., & Jacenik, D. (2023). Diet as a source of acrolein: Molecular basis of aldehyde biological activity in diabetes and digestive system diseases. *International Journal of Molecular Sciences*, 24(7), 6579.
- Hogervorst, J. G., Schouten, L. J., Konings, E. J., Goldbohm, R. A., & van den Brandt, P. A. (2007). A prospective study of dietary acrylamide intake and the risk of endometrial, ovarian, and breast cancer. *Cancer Epidemiology and Prevention Biomarkers*, 16(11), 2304–2313.
- Hogervorst, J. G., Schouten, L. J., Konings, E. J., Goldbohm, R. A., & van den Brandt, P. A. (2008). Dietary acrylamide intake and the risk of renal cell, bladder, and prostate cancer-. *The American Journal of Clinical Nutrition*, 87(5), 1428–1438.
- Hogervorst, J. G., Schouten, L. J., Konings, E. J., Goldbohm, R. A., & van den Brandt, P. A. (2009). Lung cancer risk in relation to dietary acrylamide intake. *Journal of the National Cancer Institute*, 101(9), 651–662.
- Hou, L., Zhang, Y., & Wang, X. (2019). Characterization of the volatile compounds and taste attributes of sesame pastes processed at different temperatures. *Journal of Oleo Science*, 68(6), 551–558.
- Houessou, J. K., Benac, C., Delteil, C., & Camel, V. (2005). Determination of polycyclic aromatic hydrocarbons in coffee brew using solid-phase extraction. *Journal of Agricultural and Food Chemistry*, 53(4), 871–879.
- Houessou, J. K., Goujou, D., Heyd, B., & Camel, V. (2008). Modeling the formation of some polycyclic aromatic hydrocarbons during the roasting of Arabica coffee samples. *Journal of Agricultural and Food Chemistry*, 56(10), 3648–3656.
- HSDB. (2006, Field Update on 2012). *Ethyl Carbamate*. National Library of Medicine, Hazardous Substances Data Bank. Retrieved 20 September 2019 from <https://toxnet.nlm.nih.gov>
- Hsieh, I.-M., & Malmali, M. (2023). Combined chlorine dioxide–membrane distillation for the treatment of produced water. *Desalination*, 551, 116396.
- Hu, G., Hernandez, M., Zhu, H., & Shao, S. (2013a). An efficient method for the determination of furan derivatives in apple cider and wine by solid phase extraction and high performance liquid chromatography—Diode array detector. *Journal of Chromatography A*, 1284, 100–106. <https://doi.org/10.1016/j.chroma.2013.02.002>
- Hu, Z., Cheng, P., Guo, M., Zhang, W., & Qi, Y. (2013b). A novel approach of periodate oxidation coupled with HPLC-FLD for the quantitative determination of 3-chloro-1, 2-propanediol in water and vegetable oil. *Journal of Agricultural and Food Chemistry*, 61(27), 6614–6621.
- Huang, M.-C., Chen, H.-C., Fu, S.-C., & Ding, W.-H. (2013). Determination of volatile N-nitrosamines in meat products by microwave-assisted extraction coupled with dispersive micro solid-phase extraction and gas chromatography – Chemical ionisation mass spectrometry. *Food Chemistry*, 138(1), 227–233. <https://doi.org/10.1016/j.foodchem.2012.09.119>
- Huang, M., Liu, P., Song, S., Zhang, X., Hayat, K., & Xia, S.,...Gu, F. (2011). Contribution of sulfur-containing compounds to the colour-inhibiting effect and improved antioxidant activity of Maillard reaction products of soybean protein hydrolysates. *Journal of the Science of Food and Agriculture*, 91(4), 710–720.
- Huang, S., Dai, C., Zhou, Y., Peng, H., Yi, K., & Qin, P.,...Zhang, X. (2018). Comparisons of three plant species in accumulating polycyclic aromatic

- hydrocarbons (PAHs) from the atmosphere: A review. *Environmental Science and Pollution Research*, 25, 16548–16566.
- Hurrell, R. F. (1980). Interaction of Food Components During Processing. In G. G. Birch & K. J. Parker (Eds.), *Food and Health: Science and Technology* (pp. 369–388). Springer Netherlands. https://doi.org/10.1007/978-94-009-8718-0_22
- IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2013). Some chemicals present in industrial and consumer products, food and drinking-water. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, 101, 9.
- Ianni, A., Bennato, F., Martino, C., Grotta, L., & Martino, G. (2020). Volatile flavor compounds in cheese as affected by ruminant diet. *Molecules*, 25(3), 461.
- Ingenbleek, L., Lautz, L., Dervilly, G., Darney, K., Astuto, M., Tarazona, J., ... Verger, P. (2020). Risk assessment of chemicals in food and feed: principles, applications and future perspectives. In *Environmental Pollutant Exposures and Public Health*, pp 1–38. <https://doi.org/10.1039/9781839160431-00001>
- IOFI. (2012). Guidelines for the preparation of smoke flavorings. In *Code of Practice of the International Organization of the Flavor Industry* (Version 1.3 ed.), Geneva, Switzerland. <https://iofi.org/>
- Ismail, I., Hwang, Y.-H., Bakhsh, A., Lee, S.-J., Lee, E.-Y., Kim, C.-J., & Joo, S.-T. (2022). Control of sous-vide physicochemical, sensory, and microbial properties through the manipulation of cooking temperatures and times. *Meat science*, 188, 108787.
- Iwasaki, M., Kataoka, H., Ishihara, J., Takachi, R., Hamada, G. S., & Sharma, S., ... Tsugane, S. (2010). Heterocyclic amines content of meat and fish cooked by Brazilian methods. *Journal of Food Composition and Analysis*, 23(1), 61–69.
- Jaeger, H., Janositz, A., & Knorr, D. (2010). The Maillard reaction and its control during food processing. The potential of emerging technologies. *Pathologie Biologie*, 58(3), 207–213.
- Jędrkiewicz, R., Kupska, M., Glowacz, A., Gromadzka, J., & Namieśnik, J. (2016). 3-MCPD: A worldwide problem of food chemistry. *Critical Reviews in Food Science and Nutrition*, 56(14), 2268–2277.
- Ji, L., Zhang, Y., Song, W., Cai, L., Wang, Y., & Guo, J. (2020). Analysis on antibacterial activities and volatile compounds of Maillard reaction products derived from squid skin. E3S Web of Conferences,
- Jiang, K., Huang, C., Liu, F., Zheng, J., Ou, J., Zhao, D., & Ou, S. (2022). Origin and fate of acrolein in foods. *Foods*, 11(13), 1976.
- Jiao, Z., Dong, Y., & Chen, Q. (2014). Ethyl carbamate in fermented beverages: Presence, analytical chemistry, formation mechanism, and mitigation proposals. *Comprehensive Reviews in Food Science and Food Safety*, 13(4), 611–626.
- Jin, F., Xu, J., Liu, X.-R., Regenstein, J. M., & Wang, F.-J. (2019). Roasted tree peony (*Paeonia ostii*) seed oil: Benzoic acid levels and physicochemical characteristics. *International Journal of Food Properties*, 22(1), 499–510.
- Jo, C.-H., Sim, Y.-E., Lee, H. M., Ryeom, T., & Myung, S.-W. (2008). Heterocyclic amines in several types of cooked meat and chicken dishes which form part of the Korean diet. *Food Science and Technology Research*, 14(2), 169–175.
- Joint, F., & Organization, W. H. (1995). Application of risk analysis to food standards issues: report of the Joint FAO/WHO expert consultation. In *Joint FAO/WHO Expert Consultation on the Application of Risk Analysis to Food Standards Issues*. Geneva, World Health Organization, pp. 39–39, (WHO/FNU/FOS/95.3).
- Kafouris, D., Koukkidou, A., Christou, E., Hadjigeorgiou, M., & Yiannopoulos, S. (2020). Determination of polycyclic aromatic hydrocarbons in traditionally smoked meat products and charcoal grilled meat in Cyprus. *Meat Science*, 164, 108088.
- Kamankesh, M., Mohammadi, A., Hosseini, H., & Modarres Tehrani, Z. (2015). Rapid determination of polycyclic aromatic hydrocarbons in grilled meat using microwave-assisted extraction and dispersive liquid–liquid microextraction coupled to gas chromatography–mass spectrometry. *Meat science*, 103, 61–67. <https://doi.org/10.1016/j.meatsci.2015.01.001>
- Kanekanian, A. (2010). Thermal processing of food: Potential health benefits and risks-symposium proceedings. *International Journal of Dairy Technology*, 63(1), 145–145.
- Karangwa, E., de Dieu Habimana, J., Jingyang, Y., Murekatete, N., Zhang, X., Masamba, K., ... Muhoza, B. (2017). Sensory characteristics of maillard reaction products obtained from sunflower protein hydrolysates and different sugar types. *International journal of food engineering*, 13(3), 20160006. <https://doi.org/10.1515/ijfe-2016-0006>
- Kathuria, D., Hamid, Gautam, S., & Thakur, A. (2023). Maillard reaction in different food products: Effect on product quality, human health and mitigation strategies. *Food Control*, 153, 109911. <https://doi.org/10.1016/j.foodcont.2023.109911>
- Katritzky, A. R., Ramsden, C. A., Joule, J. A., & Zhdankin, V. V. (2010). *Handbook of heterocyclic chemistry*. Elsevier.
- Khorshidian, N., Asli, M. Y., Arab, M., & Hosseini, H. (2015). Acrolein formation in foods and its impact on health. *Journal of Clinical Excellence*, 4 (Special Issue), 175–189.
- Khorshidian, N., Yousefi, M., Shadnough, M., Siadat, S. D., Mohammadi, M., & Mortazavian, A. M. (2020). Using probiotics for mitigation of acrylamide in food products: A mini review. *Current Opinion in Food Science*, 32, 67–75.
- Kim, W., Jeong, Y. A., On, J., Choi, A., Lee, J.-Y., Lee, J., & G., ... Pyo, H. (2015). Analysis of 3-MCPD and 1, 3-DCP in various foodstuffs using GC-MS. *Toxicological Research*, 31(3), 313.
- Kislov, V., Sadovnikov, A., & Mebel, A. (2013). Formation mechanism of polycyclic aromatic hydrocarbons beyond the second aromatic ring. *The Journal of Physical Chemistry A*, 117(23), 4794–4816.
- Kittel, K. M., & Deibler, K. D. (2002). The Contribution of Halogenated Aroma Compounds to Food Flavor. In *Heteroatomic Aroma Compounds*, Chapter 17, pp 269–280. ACS Publications. <https://doi.org/10.1021/bk-2002-0826.ch017>
- Kocadağlı, T., Methven, L., Kant, A., & Parker, J. K. (2021). Targeted precursor addition to increase baked flavour in a low-acrylamide potato-based matrix. *Food Chemistry*, 339, 128024.
- Koh, B.-K. (2007). Color difference and acrylamide content of cooked food. *American Journal of Food Technology*, 2(4), 318–322.
- Kounoun, A., Louajri, A., Cacciola, F., Baaboua, A. E., Mondello, L., & Bougtaib, H., ... Maadoudi, M. E. (2022). Development of a new HPLC method for rapid histamine quantification in fish and fishery products without sample clean-up. *European Food Research and Technology*, 248(6), 1679–1689. <https://doi.org/10.1007/s00217-022-03995-z>
- Koyama, N., Yasui, M., Oda, Y., Suzuki, S., Satoh, T., & Suzuki, T., ... Honma, M. (2011). Genotoxicity of acrylamide in vitro: Acrylamide is not metabolically activated in standard in vitro systems. *Environmental and Molecular Mutagenesis*, 52(1), 11–19.
- Krishnakumar, T., & Visvanathan, R. (2014). Acrylamide in food products: A review. *Journal of Food Processing & Technology*, 5(7), 1.
- Krol, B., & Tinbergen, B. (1974). Proceedings of the International Symposium on Nitrite in Meat Products. *The Central Institute for Nutrition and Food Research TNO, Zeist, the Netherlands, Pudoc, Wageningen*, pp. 268.
- Kusonić, D., Bijelić, K., Kladar, N., Torović, L., & Srđenović Čonić, B. (2023). Health risk assessment of ethyl carbamate in fruit spirits. *Food Additives & Contaminants: Part B*, 16(4), 393–403. <https://doi.org/10.1080/19393210.2023.2262956>
- Lachenmeier, D. W., Reusch, H., Sproll, C., Schoeberl, K., & Kuballa, T. (2008). Occurrence of benzene as a heat-induced contaminant of carrot juice for babies in a general survey of beverages. *Food Additives and Contaminants*, 25(10), 1216–1224.
- Lachenmeier, D. W., Schwarz, S., Teipel, J., Hegmanns, M., Kuballa, T., Walch, S. G., & Breitling-Utzmann, C. M. (2018). Potential antagonistic effects of acrylamide mitigation during coffee roasting on furfuryl alcohol, furan and 5-hydroxymethylfurfural. *Toxics*, 7(1), 1.
- Lancioti, R., Patrignani, F., Lucci, L., Guerzoni, M. E., Suzzi, G., Belletti, N., & Gardini, F. (2007). Effects of milk high pressure homogenization on biogenic amine accumulation during ripening of ovine and bovine Italian cheeses. *Food Chemistry*, 104(2), 693–701. <https://doi.org/10.1016/j.foodchem.2006.12.017>
- Lane, M. M., Gamage, E., Du, S., Ashtree, D. N., McGuinness, A. J., Gauci, S., ... Srour, B. (2024). Ultra-processed food exposure and adverse health outcomes: umbrella review of epidemiological meta-analyses. *Bmj*, 384, e077310. <https://doi.org/10.1136/bmj-2023-077310>
- Laskin, B., Voznyuk, O., & Blinov, I. (2018). Nitrosation of dimethylamine with dinitrogen trioxide. *Russian Journal of Applied Chemistry*, 91(6), 996–1001.
- Lea, P. J., Sodek, L., Parry, M. A., Shewry, P. R., & Halford, N. G. (2007). Asparagine in plants. *Annals of Applied Biology*, 150(1), 1–26.

- Lee, K.-J., Lee, G.-H., Kim, H., Oh, M.-S., Chu, S., Hwang, I., & J.,... Park, H.-M. (2015). Determination of heterocyclic amines and acrylamide in agricultural products with liquid chromatography-tandem mass spectrometry. *Toxicological Research*, 31(3), 255.
- Lee, L. W., Tay, G. Y., Cheong, M. W., Curran, P., Yu, B., & Liu, S. Q. (2017). Modulation of the volatile and non-volatile profiles of coffee fermented with *Yarrowia lipolytica*: II. *Roasted Coffee. LWT*, 80, 32–42.
- Lee, T., Park, H., Puligundla, P., Koh, G.-H., Yoon, J., & Mok, C. (2020). Degradation of benzopyrene and acrylamide in roasted coffee beans by corona discharge plasma jet (CDPJ) and its effects on biochemical and sensory properties. *Food Chemistry*, 328, 127117. <https://doi.org/10.1016/j.foodchem.2020.127117>
- Lehner, N. D. M., Crane, J. T., Mottet, M. P., & Fitzgerald, M. E. (2009). Chapter 25 - Biohazards: Safety Practices, Operations and Containment Facilities. In *Planning and Designing Research Animal Facilities* (pp. 347–363). Academic Press. <https://doi.org/10.1016/B978-0-12-369517-8.00025-6>
- Lepaumier, H., Picq, D., & Carrette, P.-L. (2009). New amines for CO₂ capture. I. Mechanisms of amine degradation in the presence of CO₂. *Industrial & Engineering Chemistry Research*, 48(20), 9061–9067.
- Li, C., Li, C., Yu, H., Cheng, Y., Xie, Y., Yao, W.,... Qian, H. (2020a). Chemical food contaminants during food processing: sources and control. *Critical reviews in food science and nutrition*, 61(9), 1545–1555. <https://doi.org/10.1080/10408398.2020.1762069>
- Li, G., Zhong, Q., Wang, D., & Gao, H. (2017). A survey of ethyl carbamate in beer from Chinese market. *Food Control*, 79, 254–257. <https://doi.org/10.1016/j.foodcont.2017.03.039>
- Li, L., Wang, L., Liu, J., Yang, J., Wu, W., & Zhang, B.,... Wei, C. (2020b). Effect of reaction conditions on the volatile pyrazines components of defatted flaxseed meal in the Maillard reaction system. *Journal of the American Oil Chemists' Society*, 97(12), 1385–1399. <https://doi.org/10.1002/aocs.12412>
- Li, Y.-F., Lin, Z.-Z., Hong, C.-Y., & Huang, Z.-Y. (2021). Histamine detection in fish samples based on indirect competitive ELISA method using iron-cobalt co-doped carbon dots labeled histamine antibody. *Food Chemistry*, 345, 128812. <https://doi.org/10.1016/j.foodchem.2020.128812>
- Li, Y., Liu, X., Meng, L., & Wang, Y. (2018). Qualitative and quantitative analysis of furosin in fresh and processed ginsengs. *Journal of Ginseng Research*, 42(1), 21–26. <https://doi.org/10.1016/j.jgr.2016.12.004>
- Liao, H., Zhu, M., & Chen, Y. (2020). 4-Hydroxy-2-nonenal in food products: A review of the toxicity, occurrence, mitigation strategies and analysis methods. *Trends in Food Science & Technology*, 96, 188–198.
- Lim, H.-H., & Shin, H.-S. (2012). Simple determination of acrolein in surface and drinking water by headspace SPME GC-MS [journal article]. *Chromatographia*, 75(15), 943–948. <https://doi.org/10.1007/s10337-012-2274-9>
- Lim, H.-S., & Lee, K.-G. (2011). Development and validation of analytical methods for ethyl carbamate in various fermented foods. *Food Chemistry*, 126(3), 1373–1379. <https://doi.org/10.1016/j.foodchem.2010.11.110>
- Lina, G., & Min, Z. (2022). Formation and release of cooked rice aroma. *Journal of Cereal Science*, 107, 103523. <https://doi.org/10.1016/j.jcs.2022.103523>
- Liu, G., Wright, M. M., Zhao, Q., Brown, R. C., Wang, K., & Xue, Y. (2016). Catalytic pyrolysis of amino acids: comparison of aliphatic amino acid and cyclic amino acid. *Energy conversion and management*, 112, 220–225.
- Liu, P., Li, Z., Bennett, A., Lin, H., Sarathy, S. M., & Roberts, W. L. (2019). The site effect on PAHs formation in HACA-based mass growth process. *Combustion and Flame*, 199, 54–68.
- Loeppky, R., Gnewuch, C., Hazlitt, L., & McKinley, W. (1979). *N-Nitrosamine Fragmentation and N-Nitrosamine Transformation.*, 101, 109–123.
- Loomis, D., Guyton, K. Z., Grosse, Y., El Ghissassi, F., Bouvard, V., & Benbrahim-Tallaa, L.,... Straif, K. (2017). Carcinogenicity of benzene. *The Lancet Oncology*, 18(12), 1574–1575.
- Lund, M. N. (2021). Reactions of plant polyphenols in foods: Impact of molecular structure. *Trends in Food Science & Technology*, 112, 241–251. <https://doi.org/10.1016/j.tifs.2021.03.056>
- Ma, L., Liu, G., Cheng, W., Liu, X., Liu, H., & Wang, Q.,... Brennan, M. A. (2020). Formation of malondialdehyde, 4-hydroxy-hexenal and 4-hydroxy-nonenal during deep-frying of potato sticks and chicken breast meat in vegetable oils. *International Journal of Food Science & Technology*, 55(4), 1833–1842.
- Mabrouk, A. F. (1979). Flavor of browning reaction products [In Food Taste Chemistry]. ACS Symposium series American Chemical Society, Washington D.C.
- Makhoul, N., & Al-Zohouri, J. (2019). Determination of Benzene in some Beverages under certain conditions. *Research Journal of Pharmacy and Technology*, 12(1), 37–39.
- Manariotis, I. D., Karapanagioti, H. K., & Chryssikopoulos, C. V. (2011). Degradation of PAHs by high frequency ultrasound. *Water research*, 45(8), 2587–2594. <https://doi.org/10.1016/j.watres.2011.02.009>
- Mandal, D. (2019). Food preservative chemistry: Effects and side effects. *Journal of the Indian Chemical Society*, 96(12), 1519–1528.
- Marć, M. (2020). Emissions of selected monoaromatic hydrocarbons as a factor affecting the removal of single-use polymer barbecue and kitchen utensils from everyday use. *Science of the Total Environment*, 720, 137485.
- Marcinkowska, M. A., & Jeleń, H. H. (2022). Role of sulfur compounds in vegetable and mushroom aroma. *Molecules*, 27(18), 6116.
- Martínez Steele, E., Buckley, J. P., & Monteiro, C. A. (2023). Ultra-processed food consumption and exposure to acrylamide in a nationally representative sample of the US population aged 6 years and older. *Preventive Medicine*, 174, 107598. <https://doi.org/10.1016/j.ypmed.2023.107598>
- Mayr, C. M., Capone, D. L., Pardon, K. H., Black, C. A., Pomeroy, D., & Francis, I. L. (2015). Quantitative analysis by GC-MS/MS of 18 aroma compounds related to oxidative off-flavor in wines. *Journal of Agricultural and Food Chemistry*, 63(13), 3394–3401.
- Mazzoni, C., Tirard, A., Boubetra, A., & Roussey, F. (2020). Proficiency-testing scheme for haloanisoles and halophenols in oak wood. *Accreditation and Quality Assurance*, 25, 173–178.
- McLaren, D. A. (2000). Use of chlorine-based sanitizers and disinfectants in the food manufacturing industry: Current and emerging technology approaches on waste minimization-Technology for efficient use of chlorine-based materials. *University of Nebraska Food Processing Center, Lincoln, Nebraska*, pp.126.
- Mehta, B. M. (2015). Nutritional and toxicological aspects of the chemical changes of food components and nutrients during heating and cooking. *Handbook of Food Chemistry*, 897, 936.
- Mendonça, R. D., Lopes, A. C., Pimenta, A. M., Gea, A., Martínez-Gonzalez, M. A., & Bes-Rastrollo, M. (2017). Ultra-processed food consumption and the incidence of hypertension in a Mediterranean cohort: The Seguimiento Universidad de Navarra project. *American Journal of Hypertension*, 30(4), 358–366. <https://doi.org/10.1093/ajh/hpw137>
- Mendonça, R. D., Pimenta, A. M., Gea, A., de la Fuente-Arrillaga, C., Martínez-Gonzalez, M. A., Lopes, A. C., & Bes-Rastrollo, M. (2016). Ultraprocessed food consumption and risk of overweight and obesity: The University of Navarra Follow-Up (SUN) cohort study. *American Journal of Clinical Nutrition*, 104(5), 1433–1440. <https://doi.org/10.3945/ajcn.116.135004>
- Mercer, C. (2006). FDA re-opens probe into benzene contamination of soft drinks. *Special Report, Beverage Daily*. <https://www.bakeryandsnacks.com/Article/2006/02/15/FDA-re-opens-probe-into-benzene-contamination-of-soft-drinks>
- Minko, I. G., Kozekov, I. D., Kozekova, A., Harris, T. M., Rizzo, C. J., & Lloyd, R. S. (2008). Mutagenic potential of DNA-peptide crosslinks mediated by acrolein-derived DNA adducts. *Mutation Research/fundamental and Molecular Mechanisms of Mutagenesis*, 637(1), 161–172.
- Minorczyk, M., Czaja, K., Starski, A., Korcz, W., Liszewska, M., Lewiński, R., Robson, M. G., Postupolski, J., & Struciński, P. (2023). Assessment of Furan and its derivatives intake with home prepared meals and characterization of associated risk for Polish infants and toddlers. *Foods*, 12(19), 3618.
- Mirza Alizadeh, A., Hashempour-Baltork, F., Mousavi Khaneghah, A., & Hosseini, H. (2021a). New perspective approaches in controlling fungi and mycotoxins in food using emerging and green technologies. *Current Opinion in Food Science*, 39, 7–15. <https://doi.org/10.1016/j.cofs.2020.12.006>
- Mirza Alizadeh, A., Hosseini, H., Meybodi, N. M., Hashempour-Baltork, F., Alizadeh-Sani, M., & Tajdar-Oranj, B.,... Khaneghah, A. M. (2022). Mitigation of potentially toxic elements in food products by probiotic bacteria: A comprehensive review. *Food Research International*, 152, 110324.
- Mirza Alizadeh, A., Hosseini, H., Mohseni, M., Eskandari, S., Sohrabvandi, S., Hosseini, M., & J.,... Nahavandi, S. (2021b). Analytic and chemometric assessments of the native probiotic bacteria and inulin effects on bioremediation of lead salts. *Journal of the Science of Food and Agriculture*, 101(12), 5142–5153.
- Moghe, A., Ghare, S., Lamoreau, B., Mohammad, M., Barve, S., McClain, C., & Joshi-Barve, S. (2015). Molecular mechanisms of acrolein toxicity:

- Relevance to human disease. *Toxicological Sciences*, 143(2), 242–255. <https://doi.org/10.1093/toxsci/kfu233>
- Mohammadi, A., Tajdar-oranj, B., Hosseini, H., Kamankesh, M., Shariatifar, N., Jazaeri, S., & Hosseini-Esfahani, F. (2023a). Probabilistic dietary exposure and carcinogenic risk of heterocyclic aromatic amines formed in the main groups of fast foods: Investigation of different ages and genders. *Journal of Food Composition and Analysis*, 120, 105344. <https://doi.org/10.1016/j.jfca.2023.105344>
- Mohammadi, M., Hosseini, H., Shahraz, F., Hosseini, S. M., Mirza Alizadeh, A., Taghizadeh, M.,...Shojaee-Aliabadi, S. (2023b). Effect of sage seed gum film incorporating Zataria multiflora Boiss essential oil on the storage quality and biogenic amine content of refrigerated Otolithes rubber fillets. *International Journal of Biological Macromolecules*, 238, 123711. <https://doi.org/10.1016/j.ijbiomac.2023.123711>
- Mohammadi, M., Mirza Alizadeh, A., & Mollakhalili Meybodi, N. (2021). Off-flavors in fish: A review of potential development mechanisms, identification and prevention methods. *Journal of Human Environment and Health Promotion*, 7(3), 120–128.
- Mohammed, S., Obiri, S., Ansa-Asare, O. D., Dartey, G., Kuddy, R., & Appiah, S. (2019). Assessment of concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in vegetables from farms in Accra. *Ghana. Environmental Monitoring and Assessment*, 191(7), 417.
- Mohan, A., Roy, A., Duggirala, K., & Klein, L. (2022). Oxidative reactions of 4-oxo-2-Nonenal in meat and meat products. *LWT*, 165, 113747. <https://doi.org/10.1016/j.lwt.2022.113747>
- Moldoveanu, S. (2010). Pyrolysis of amino acids and small peptides. *Techniques and Instrumentation in Analytical Chemistry*, 28, 527–578.
- Monteiro, C. A., Cannon, G., Lawrence, M., Costa Louzada, M., & Machado, p. (2019a). *Ultra-processed foods, diet quality, and health using the NOVA classification system* (p. 48). FAO.
- Monteiro, C. A., Cannon, G., Levy, R. B., Moubarac, J. C., Louzada, M. L., & Rauber, F.,...Jaime, P. C. (2019b). Ultra-processed foods: What they are and how to identify them. *Public Health Nutrition*, 22(5), 936–941. <https://doi.org/10.1017/s1368980018003762>
- Monteiro, C. A., Moubarac, J. C., Levy, R. B., Canella, D. S., Louzada, M., & Cannon, G. (2018). Household availability of ultra-processed foods and obesity in nineteen European countries. *Public Health Nutrition*, 21(1), 18–26. <https://doi.org/10.1017/s1368980017001379>
- Monteiro, S., Bundaleski, N., Malheiro, A., Cabral, M., & Teodoro, O. M. (2022). Cross contamination of 2, 4, 6-Trichloroanisole in cork stoppers. *Journal of Agricultural and Food Chemistry*, 70(22), 6747–6754.
- Morsi, R., El-Tahan, N., & El-Tobgy, K. (2012). Probability of benzene forming in Egyptian non-alcohol carbonated soft drinks. *Australian Journal of Basic and Applied Sciences*, 6(3), 271–278.
- Mortzfeld, F. B., Hashem, C., Vranková, K., Winkler, M., & Rudroff, F. (2020). Pyrazines: Synthesis and industrial application of these valuable flavor and fragrance compounds. *Biotechnology Journal*, 15(11), 2000064.
- Motarjemi, Y. (2013). *Encyclopedia of food safety*, 1st Edition, pp 2304. Hardback ISBN: 9780123786128. Academic Press.
- Mucci, L. A., Adami, H. O., & Wolk, A. (2006). Prospective study of dietary acrylamide and risk of colorectal cancer among women. *International Journal of Cancer*, 118(1), 169–173.
- Muchiri, M., McCartney, A., & Methven, L. (2020). Sensory profile and consumer preference of novel probiotic yoghurt enriched with orange sweet potato (*Ipomoea batatas*). *African Journal of Food, Agriculture, Nutrition and Development*, 20(5), 16471–16489.
- Murkovic, M. (2007). Analysis of heterocyclic aromatic amines. *Analytical and Bioanalytical Chemistry*, 389(1), 139–146.
- Nadeem, H. R., Akhtar, S., Ismail, T., Sestili, P., Lorenzo, J. M., Ranjha, M. M. A., & N.,...Aadil, R. M. (2021). Heterocyclic aromatic amines in meat: Formation, isolation, risk assessment, and inhibitory effect of plant extracts. *Foods*, 10(7), 1466.
- Nagao, M., & Tsugane, S. (2016). Cancer in Japan: Prevalence, prevention and the role of heterocyclic amines in human carcinogenesis. *Genes and Environment*, 38, 1–8.
- Naila, A., Flint, S., Fletcher, G., Bremer, P., & Meerdink, G. (2010). Control of biogenic amines in food—existing and emerging approaches. *Journal of Food Science*, 75(7), R139–R150.
- Nateghi, L., Hosseini, E., & Fakheri, M. A. (2024). The effect of cold atmospheric plasma pretreatment on oil absorption, acrylamide content and sensory characteristics of deep-fried potato strips. *Food Chemistry: X*, 21, 101194. <https://doi.org/10.1016/j.fochx.2024.101194>
- National Research Council. (1988). *Frontiers in chemical engineering: research needs and opportunities*. National Academies Press. <https://doi.org/10.17226/1095>
- Nematollahi, A., Mollakhalili Meybodi, N., & Mousavi Khaneghah, A. (2021). An overview of the combination of emerging technologies with conventional methods to reduce acrylamide in different food products: Perspectives and future challenges. *Food Control*, 127, 108144. <https://doi.org/10.1016/j.foodcont.2021.108144>
- Nerin, C., Aznar, M., & Carrizo, D. (2016). Food contamination during food process. *Trends in Food Science & Technology*, 48, 63–68.
- Neuwirth, C., Mosesso, P., Pepe, G., Fiore, M., Malfatti, M., & Turteltaub, K.,... Mally, A. (2012). Furan carcinogenicity: DNA binding and genotoxicity of furan in rats in vivo. *Molecular Nutrition & Food Research*, 56(9), 1363–1374.
- Ng, T. K. W., Appukutty, M., Shyam, S., Voon, P. T., & Selvaduray, K. R. (2019). Chapter 65 - Cooking Oils in Health and Sports. In D. Bagchi, S. Nair, & C. K. Sen (Eds.), *Nutrition and Enhanced Sports Performance* (Second Edition) (pp. 751–756). Academic Press. <https://doi.org/10.1016/B978-0-12-813922-6.00065-5>
- Nielsen, C. J., Bossi, R., Bunkan, A. J. C., Dithmer, L., Glasius, M., Hallquist, M.,... Maguta, M. M. (2012). Atmospheric Degradation of Amines (ADA): summary report from atmospheric chemistry studies of amines, nitrosamines, nitramines and amides. CLIMIT project no. 208122, University of Oslo. ISBN 978-82-992954-7-5.
- NTP. (2016). *Report on Carcinogens, : N-Nitrosamines*. <http://ntp.niehs.nih.gov/go/roc>
- Olaniran, A. O., Hiralal, L., Mokoena, M. P., & Pillay, B. (2017). Flavour-active volatile compounds in beer: Production, regulation and control. *Journal of the Institute of Brewing*, 123(1), 13–23.
- Osório, V. M., & de Lourdes Cardeal, Z. (2011). Determination of acrolein in french fries by solid-phase microextraction gas chromatography and mass spectrometry. *Journal of Chromatography A*, 1218(21), 3332–3336. <https://doi.org/10.1016/j.chroma.2010.11.068>
- Ozel, M. Z., Gogus, F., Yagci, S., Hamilton, J. F., & Lewis, A. C. (2010). Determination of volatile nitrosamines in various meat products using comprehensive gas chromatography–nitrogen chemiluminescence detection. *Food and Chemical Toxicology*, 48(11), 3268–3273. <https://doi.org/10.1016/j.fct.2010.08.036>
- Özşarac, N., Kolsarici, N., Demirok Soncu, E., & Haskaraca, G. (2019). Formation of heterocyclic aromatic amines in doner kebab cooked with different methods at varying degrees of doneness. *Food Additives & Contaminants: Part A*, 36(2), 225–235.
- Paik, Y., Kim, H.-S., Joo, Y.-S., Lee, J. W., & Lee, K.-W. (2024). Evaluation of polycyclic aromatic hydrocarbon contents in marine products in South Korea and risk assessment using the total diet study. *Food Science and Biotechnology*. <https://doi.org/10.1007/s10068-023-01491-y>
- Palacios, A. (2006). Organoleptic defects caused by uncontrolled malolactic fermentation. In R. Morenzoni (Ed.), *Malolactic Fermentation in Wine-Understanding the Science and the Practice* (16) *Lactobacillus: The Next Generation of Malolactic Fermentation Starter Cultures-An Overview* (pp. 7.1–7.7). Lallemand, Montre'al.
- Pang, J., & Zhang, F. (2021). Carbohydrates. In J. Kan & K. Chen (Eds.), *Essentials of Food Chemistry* (pp. 123–195). Springer Singapore. https://doi.org/10.1007/978-981-16-0610-6_4
- Park, J.-E., Seo, J.-E., Lee, J.-Y., & Kwon, H. (2015). Distribution of seven N-nitrosamines in food. *Toxicological Research*, 31(3), 279.
- Patel, A. B., Shaikh, S., Jain, K. R., Desai, C., & Madamwar, D. (2020). Polycyclic aromatic hydrocarbons: Sources, toxicity, and remediation approaches. *Frontiers in Microbiology*, 11, 562813.
- Pegg, R. B., & Shahidi, F. (2006). Processing of nitrite-free cured meats. In *Advanced Technologies for Meat Processing* (pp. 513–534). CRC Press. <https://doi.org/10.1201/9781420017311>
- Pegg, R. B., & Shahidi, F. (2008). *Nitrite curing of meat: The N-nitrosamine problem and nitrite alternatives*. 280 pages, Wiley-Blackwell, John Wiley & Sons.
- Peivasteh-Roudsari, L., Karami, M., Barzegar-Bafrouei, R., Samiee, S., Karami, H., Tajdar-Oranj, B.,...Mousavi Khaneghah, A. (2022). Toxicity, metabolism, and mitigation strategies of acrylamide: a comprehensive review. *International Journal of Environmental Health Research*, 1–29. <https://doi.org/10.1080/09603123.2022.2123907>

- Pekmezci, H., & Basaran, B. (2024). Dietary acrylamide exposure and health risk assessment of pregnant women: A case study from Türkiye. *Food Science & Nutrition*, 12(2), 1133–1145.
- Pereira, V., Pereira, A. C., Pérez Trujillo, J. P., Cacho, J., & Marques, J. C. (2015). Amino acids and biogenic amines evolution during the estufagem of fortified wines. *Journal of Chemistry*, 2015(1), 494285.
- Pickenhagen, W., Ho, C.-T., & Spanier, A. M. (1996). Contribution of low-and nonvolatile materials to the flavor of foods, *Allured Pub Corp*, 242 pages, ISBN: 9780931710506.
- Pischetsrieder, M., & Henle, T. (2012). Glycation products in infant formulas: Chemical, analytical and physiological aspects. *Amino Acids*, 42, 1111–1118.
- Poulsen, M. W., Hedegaard, R. V., Andersen, J. M., de Courten, B., Bügel, S., Nielsen, J.,... Dragsted, L. O. (2013). Advanced glycation endproducts in food and their effects on health. *Food and Chemical Toxicology*, 60, 10–37. <https://doi.org/10.1016/j.fct.2013.06.052>
- Pradipta, A. R., & Tanaka, K. (2021). Biofunctional chemistry and reactivity of biogenic acrolein for cancer diagnosis and therapy. *Chemical Communications*, 57(77), 9798–9806.
- Pripis-Nicolau, L., De Revel, G., Bertrand, A., & Maujean, A. (2000). Formation of flavor components by the reaction of amino acid and carbonyl compounds in mild conditions. *Journal of Agricultural and Food Chemistry*, 48(9), 3761–3766.
- Pugajeva, I., Rozentale, I., Viksna, A., Bartkiene, E., & Bartkevics, V. (2016). The application of headspace gas chromatography coupled to tandem quadrupole mass spectrometry for the analysis of furan in baby food samples. *Food Chemistry*, 212, 20–26. <https://doi.org/10.1016/j.foodchem.2016.05.159>
- Puget, S., Beno, N., Chabanet, C., Guichard, E., & Thomas-Danguin, T. (2010). Tap water consumers differ from non-consumers in chlorine flavor acceptability but not sensitivity. *Water Research*, 44(3), 956–964.
- Quan, W., Li, Y., Jiao, Y., Xue, C., Liu, G., & Wang, Z.,... Chen, J. (2020). Simultaneous generation of acrylamide, β -carboline heterocyclic amines and advanced glycation ends products in an aqueous Maillard reaction model system. *Food Chemistry*, 332, 127387.
- Qureshi, T. M., Vermeer, C., Vegarud, G. E., Abrahamson, R. K., & Skeie, S. (2013). Formation of biogenic amines and vitamin K contents in the Norwegian autochthonous cheese Gamalost during ripening [journal article]. *Dairy Science & Technology*, 93(3), 303–314. <https://doi.org/10.1007/s13594-013-0123-8>
- Rafiee, M., Yazdanbakhsh, A., Hatami, H., & Jalilvand, H. (2022). Investigating perchlorate concentration in drinking water and its relationship with the frequency of hypothyroidism among infants in Damavand City. *Journal of Human Environment and Health Promotion*, 8(3), 154–160.
- Ragavan, K., Rastogi, N. K., & Srivastava, A. K. (2017). Chapter 21: Industrial Food Processing Contaminants. In *Food Toxicology*, D. Bagchi & A. Swaroop (Eds.), pp. 395. CRC Press. <https://doi.org/10.1201/9781315371443>
- Rauber, F., da Costa Louzada, M. L., Steele, E. M., Millett, C., Monteiro, C. A., & Levy, R. B. (2018). Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). *Nutrients*, 10(5). <https://doi.org/10.3390/nu10050587>
- Ripain, I. H. A., & Ngah, N. (2021). A brief review on the thiazole derivatives: Synthesis methods and biological activities. *Malays. J. Anal. Sci.*, 25, 257–267.
- Roesler, J., Martinot, S., McEnally, C., Pfefferle, L., Delfau, J.-L., & Vovelle, C. (2003). Investigating the role of methane on the growth of aromatic hydrocarbons and soot in fundamental combustion processes. *Combustion and Flame*, 134(3), 249–260.
- Rudneva, I., & Omel'chenko, S. (2021). Nitrosamines in aquatic ecosystems: Sources, formation, toxicity, environmental risk (Review). 2. content in aquatic biota, biological effects and risk assessment. *Water Resources*, 48, 291–299.
- Ryu, D., Choi, B., Kim, N., & Koh, E. (2016). Validation of analytical methods for ethyl carbamate in nine food matrices. *Food Chemistry*, 211, 770–775. <https://doi.org/10.1016/j.foodchem.2016.05.131>
- Sadeghi, M., Raeisi, M., Ghahrechi, M., Rezaie, N., & Pahlevanzadeh, B. (2019). Chemical Quality of the Leading Bottled Water Brands Distributed in Gorgan. *Iran. Journal of Human, Environment, and Health Promotion*, 5(2), 66.
- Sadighara, P., Pirhadi, M., Sadighara, M., Shavaly-Gilani, P., Zirak, M. R., & Zeinali, T. (2022). Benzene food exposure and their prevent methods: a review. *Nutrition & Food Science*, 52(6), 971–979.
- Saeed, Y., Wang, J. Q., & Zheng, N. (2017). Furosine induces DNA damage and cell death in selected human cell lines: A strong toxicant to kidney Hek-293 cells [journal article]. *Food Science and Biotechnology*, 26(4), 1093–1101. <https://doi.org/10.1007/s10068-017-0131-1>
- Şahin, T., Dalğa, S., & Ölmez, M. (2022). Polycyclic aromatic hydrocarbons (PAHs) and their importance in animal nutrition. In book: *Animal Husbandry*. IntechOpen, <https://doi.org/10.5772/intechopen.101816>.
- Sahoo, B. M., Ravi Kumar, B. V., Banik, B. K., & Borah, P. (2020). Polyaromatic hydrocarbons (PAHs): Structures, synthesis and their biological profile. *Current Organic Synthesis*, 17(8), 625–640.
- Salviano dos Santos, V. P., Medeiros Salgado, A., Guedes Torres, A., & Signori Pereira, K. (2015). Benzene as a chemical hazard in processed foods. *International journal of food science*, 2015(1), 545640.
- Sarwar Gilani, G., Wu Xiao, C., & Cockell, K. A. (2012). Impact of Antinutritional Factors in Food Proteins on the Digestibility of Protein and the Bioavailability of Amino Acids and on Protein Quality. *British Journal of Nutrition*, 108(S2), S315–S332. <https://doi.org/10.1017/S0007114512002371>
- Scanlan, R. A. (2003). Nitrosamines In B. Caballero (Ed.), *Encyclopedia of Food Sciences and Nutrition (Second Edition)* (pp. 4142–4147). Academic Press. <https://doi.org/10.1016/B0-12-227055-X/00831-2>
- Senoussi, A., Rapisarda, T., Schadt, I., Chenchouni, H., Saoudi, Z., & Senoussi, S.,... Carpino, S. (2022). Formation and dynamics of aroma compounds during manufacturing-ripening of Bouhezza goat cheese. *International Dairy Journal*, 129, 105349.
- Fard SM, Afshar PG, & Adeli Milani M. (2020). A comparison of the quality characteristics of the virgin and refined olive oils supplied in Tarom Region, Iran (2019). *Journal of Human Environment and Health Promotion*, 6(2), 83–90.
- Shahidi, F. (2012). *Flavor of meat and meat products*. 301 pages. Springer New York, NY. <https://doi.org/10.1007/978-1-4615-2177-8>
- Shahidi, F., & Hossain, A. (2022). Role of Lipids in Food Flavor Generation. *Molecules*, 27(15), 5014. <https://www.mdpi.com/1420-3049/27/15/5014>
- Shahidi, F., & Pegg, R. B. (1992). Nitrite-free meat curing systems: Update and review. *Food Chemistry*, 43(3), 185–191.
- Shahidi, F., Pegg, R. B., & Shamsuzzaman, K. (1991). Color and oxidative stability of nitrite-free cured meat after gamma irradiation. *Journal of Food Science*, 56(5), 1450–1452.
- Shahidi, F., Samaranyaka, A., & Pegg, R. (2014). Cooking of meat| Maillard reaction and browning. In M. Dikeman & C. Devine (Eds.), *Encyclopedia of meat sciences (2nd ed)*, pp. 391–403. Academic Press.
- Shakil, M. H., Trisha, A. T., Rahman, M., Talukdar, S., Kobun, R., Huda, N., & Zzaman, W. (2022). Nitrites in cured meats, health risk issues, alternatives to nitrites: A review. *Foods*, 11(21), 3355.
- Shapla, U. M., Soleyman, M., Alam, N., Khalil, M. I., & Gan, S. H. (2018). 5-Hydroxy-methylfurfural (HMF) levels in honey and other food products: Effects on bees and human health [journal article]. *Chemistry Central Journal*, 12(1), 35. <https://doi.org/10.1186/s13065-018-0408-3>
- Sharma, R. K., Chan, W. G., Seeman, J. I., & Hajaligol, M. R. (2002). Pyrolysis of α -amino acids. *Fuel Chemistry Division Preprints*, 47(1), 398–399.
- Shen, G., Tao, S., Wei, S., Zhang, Y., Wang, R., & Wang, B.,... Chen, Y. (2012). Emissions of parent, nitro, and oxygenated polycyclic aromatic hydrocarbons from residential wood combustion in rural China. *Environmental Science & Technology*, 46(15), 8123–8130.
- Shen, M., Liu, Q., Jia, H., Jiang, Y., Nie, S., Xie, J.,... Xie, M. (2016). Simultaneous determination of furan and 2-alkylfurans in heat-processed foods by automated static headspace gas chromatography-mass spectrometry. *LWT - Food Science and Technology*, 72, 44–54. <https://doi.org/10.1016/j.lwt.2016.04.030>
- Shen, Y., Hu, L.-T., Xia, B., Ni, Z.-J., Elam, E., & Thakur, K.,... Wei, Z.-J. (2021). Effects of different sulfur-containing substances on the structural and flavor properties of defatted sesame seed meal derived Maillard reaction products. *Food Chemistry*, 365, 130463.
- Shibata, A., Uemura, M., Hosokawa, M., & Miyashita, K. (2018). Acrolein as a major volatile in the early stages of fish oil TAG oxidation. *Journal of Oleo Science*, 67(5), 515–524.
- Shin, H.-S., & Jung, D.-G. (2006). Determination of chlorine dioxide in water by gas chromatography–mass spectrometry. *Journal of Chromatography A*, 1123(1), 92–97. <https://doi.org/10.1016/j.chroma.2006.04.089>
- Shinkaruk, S., Floch, M., Prida, A., & i, Darriet, P., & Pons, A. (2019). Identification of Diallylpyrazines off-flavors in oak wood. *Journal of Agricultural and Food Chemistry*, 67(36), 10137–10144.

- Shuyun, L., Hanju, S., Gang, M., Tao, Z., Lei, W., Hui, P., ... Lingyan, G. (2022). Insights into flavor and key influencing factors of Maillard Reaction of Products: A recent update. *Frontiers in Nutrition*, 2014, 9, 973677.
- Silva, M. (2005). 2.2.2. - Quantitation by HPLC of Amines as Dansyl Derivatives. In I. Molnár-Perl (Ed.), *Journal of Chromatography Library* (Vol. 70, pp. 445–470). Elsevier. [https://doi.org/10.1016/S0301-4770\(05\)80018-1](https://doi.org/10.1016/S0301-4770(05)80018-1)
- Šimko, P. (2005). Factors affecting elimination of polycyclic aromatic hydrocarbons from smoked meat foods and liquid smoke flavorings. *Molecular Nutrition & Food Research*, 49(7), 637–647.
- Singh, L., Varshney, J. G., & Agarwal, T. (2016). Polycyclic aromatic hydrocarbons' formation and occurrence in processed food. *Food Chemistry*, 199, 768–781. <https://doi.org/10.1016/j.foodchem.2015.12.074>
- Singla, R. K., Dubey, A. K., Ameen, S. M., Montalto, S., & Parisi, S. (2018). Analytical Methods for the Determination of Maillard Reaction Products in Foods. An Introduction. In R. K. Singla, A. K. Dubey, S. M. Ameen, S. Montalto, & S. Parisi (Eds.), *Analytical Methods for the Assessment of Maillard Reactions in Foods* (pp. 1–14). Springer International Publishing. https://doi.org/10.1007/978-3-319-76923-3_1
- Slabizki, P. (2016). Identification and quantification of cork off-flavor compounds in natural cork stoppers by multidimensional gas chromatographic methods, Doctoral dissertation, Dissertation, Duisburg, Essen, Universität Duisburg-Essen.
- Smoker, M., Tran, K., & Smith, R. E. (2010). Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Shrimp. *Journal of Agricultural and Food Chemistry*, 58(23), 12101–12104. <https://doi.org/10.1021/jf1029652>
- Snowdon, E. M., Bowyer, M. C., Grbin, P. R., & Bowyer, P. K. (2006). Mousy off-flavor: A review. *Journal of Agricultural and Food Chemistry*, 54(18), 6465–6474.
- Song, S., Zhang, X., Xiao, Z., Niu, Y., Hayat, K., & Eric, K. (2012). Contribution of oxidized tallow to aroma characteristics of beeflike process flavour assessed by gas chromatography–mass spectrometry and partial least squares regression. *Journal of Chromatography A*, 1254, 115–124.
- Srouf, B., Kordahi, M. C., Bonazzi, E., Deschasesaux-Tanguy, M., Touvier, M., & Chassaing, B. (2022). Ultra-processed foods and human health: From epidemiological evidence to mechanistic insights. *Lancet Gastroenterol Hepatol*, 7(12), 1128–1140. [https://doi.org/10.1016/s2468-1253\(22\)00169-8](https://doi.org/10.1016/s2468-1253(22)00169-8)
- Stadler, R. H., & Lineback, D. R. (2008). *Process-induced food toxicants: Occurrence, formation, mitigation, and health risks*. John Wiley & Sons.
- Steppeler, C., Haugen, J.-E., Rødbotten, R., & Kirkhus, B. (2016). Formation of malondialdehyde, 4-hydroxynonenal, and 4-hydroxyhexenal during in vitro digestion of cooked beef, pork, chicken, and salmon. *Journal of Agricultural and Food Chemistry*, 64(2), 487–496.
- Stevens, J. F., & Maier, C. S. (2008). Acrolein: Sources, metabolism, and biomolecular interactions relevant to human health and disease. *Molecular Nutrition & Food Research*, 52(1), 7–25.
- Stevens, J. F., & Maier, C. S. (2011). Acrolein. *Molecular Nutrition and Food Research*, 55(9), 1275.
- Stuart, G. R., Holcroft, J., de Boer, J. G., & Glickman, B. W. (2000). Prostate mutations in rats induced by the suspected human carcinogen 2-amino-1-methyl-6-phenylimidazo [4, 5-b] pyridine. *Cancer Research*, 60(2), 266–268.
- Sulukan, E., Ghosigharehagaji, A., Baran, A., Yildirim, S., Bolat, İ., & Ceyhan, S. B. (2021). A versatile toxicity evaluation of ethyl carbamate (urethane) on zebrafish embryos: Morphological, physiological, histopathological, immunohistochemical, transcriptional and behavioral approaches. *Toxicology Letters*, 353, 71–78.
- Taghizadeh, S. F., Iranmanesh, O., Tsitsimpikou, C., Tsatsakis, A., Karimi, G., & Rezaee, R. (2024). Determination of 3 monochloropropane-1,2-diol (3-MCPD) level in chocolate: A probabilistic health risk assessment for Iranian consumers. *Journal of Food Composition and Analysis*, 125, 105800. <https://doi.org/10.1016/j.jfca.2023.105800>
- Tamanna, N., & Mahmood, N. (2015). Food processing and maillard reaction products: effect on human health and nutrition. *International journal of food science*, 2015(1), 526762.
- Tan, H., Sen, A., Wheeler, W., Cornell, J., & Wei, C. (1987). A kinetic study of the reaction of aqueous chlorine and chlorine dioxide with amino acids, peptides and proteins. *Journal of Food Science*, 52(6), 1706–1711.
- Taylor, A. J., & Linforth, R. S. (2002). *Food flavour technology*. Volume 9 of Sheffield Food Technology Series. 302 pages. Sheffield, Sheffield Academic Press.
- Taylor, J., Wohlers, D., & Amata, R. (2004). *Toxicological profile for chlorine dioxide and chlorite*. Agency for Toxic Substances and Disease Registry, Public Health Service (ATSDR), U.S. Department of Health and Human Services, Atlanta, 30333, 143.
- Teixidó, E., Santos, F. J., Puignou, L., & Galceran, M. T. (2006). Analysis of 5-hydroxymethylfurfural in foods by gas chromatography–mass spectrometry. *Journal of Chromatography A*, 1135(1), 85–90. <https://doi.org/10.1016/j.chroma.2006.09.023>
- Teng, J., Hu, X., Tao, N., & Wang, M. (2018). Impact and inhibitory mechanism of phenolic compounds on the formation of toxic Maillard reaction products in food. *Frontiers of Agricultural Science and Engineering*, 5(3), 321–329.
- Trinetta, V., Vaidya, N., Linton, R., & Morgan, M. (2011). Evaluation of chlorine dioxide gas residues on selected food produce. *Journal of food science*, 76(1), 11–15. <https://doi.org/10.1111/j.1750-3841.2010.01911.x>
- Tu, N. T. M., Linh, D. T., Hoa, V. T., Chi, T. T. T., Trung, N. Q., & Ngoan, L. T. (2019). Heterocyclic amines in food processing and its food safety issues with emphasizing healthy diet for people: A mini review. *Southeast Asian Journal of Sciences*, 7(1), 89–93.
- van Rooijen, C., Bosch, G., van der Poel, A. F. B., Wierenga, P. A., Alexander, L., & Hendriks, W. H. (2014). Quantitation of Maillard Reaction Products in Commercially Available Pet Foods. *Journal of Agricultural and Food Chemistry*, 62(35), 8883–8891. <https://doi.org/10.1021/jf502064h>
- Velisek, J., Calta, P., Dolezal, M., Crews, C., & Hasnip, S. (2003). 3-Chloropropane-1, 2-diol in models simulating processed foods: precursors and agents causing its decomposition. *Czech Journal of Food Sciences-UZPI (Czech Republic)*, 21(5), 153–161.
- Vernin, G. (1982). Heterocyclic compounds in flavors and fragrances part III. *Pyridine and Derivatives. Perfumer & Flavorist*, 7, 23–35.
- Vikström, A. C., Abramsson-Zetterberg, L., Naruszewicz, M., Athanassiadis, I., Granath, F. N., & Törnqvist, M. Å. (2011). In vivo doses of acrylamide and glycidamide in humans after intake of acrylamide-rich food. *Toxicological Sciences*, 119(1), 41–49. <https://doi.org/10.1093/toxsci/kfq323>
- Vinci, R. M., Canfyn, M., De Meulenaer, B., de Schaetzen, T., Van Overmeire, I., De Beer, J., & Van Loco, J. (2010). Determination of benzene in different food matrices by distillation and isotope dilution HS-GC/MS. *Analytica Chimica Acta*, 672(1), 124–129. <https://doi.org/10.1016/j.aca.2010.04.053>
- Vizzier-Thaxton, Y., Ewing, M., & Bonner, C. (2010). Generation and detection of trihalomethanes in chicken tissue from chlorinated chill water. *Journal of Applied Poultry Research*, 19(2), 169–173.
- Vojvodić, S., Srdjenović Čonić, B., & Torović, L. (2023). Benzoates and in situ formed benzene in food supplements and risk assessment. *Food Additives & Contaminants: Part B*, 16(4), 321–331. <https://doi.org/10.1080/19393210.2023.2241145>
- Vranova, J., & Ciesarova, Z. (2009). Furan in food—a review. *Czech J Food Sci*, 27(1), 1–10.
- Wamhoff, H., & Gribble, G. W. (2012). Chapter 3 - Wine and Heterocycles. In A. R. Katritzky (Ed.), *Advances in Heterocyclic Chemistry* (Vol. 106, pp. 185–225). Academic Press. <https://doi.org/10.1016/B978-0-12-396531-8.00003-1>
- Wang, H.-T., Hu, Y., Tong, D., Huang, J., Gu, L., & Wu, X.-R., ... Tang, M.-S. (2012). Effect of carcinogenic acrolein on DNA repair and mutagenic susceptibility. *Journal of Biological Chemistry*, 287(15), 12379–12386.
- Wang, H.-Y., Qian, H., & Yao, W.-R. (2011). Melanoidins produced by the Maillard reaction: Structure and biological activity. *Food Chemistry*, 128(3), 573–584.
- Wang, H., Feng, F., Guo, Y., Shuang, S., & Choi, M. M. F. (2013). HPLC-UV quantitative analysis of acrylamide in baked and deep-fried Chinese foods. *Journal of Food Composition and Analysis*, 31(1), 7–11. <https://doi.org/10.1016/j.jfca.2013.02.006>
- Wang, J., Yuan, C., Gao, X., Kang, Y., Huang, M., & Wu, J., ... Zhang, Y. (2020a). Characterization of key aroma compounds in Huangjiu from northern China by sensory-directed flavor analysis. *Food Research International*, 134, 109238.
- Wang, L., Fan, S., Yan, Y., Yang, L., Chen, S., & Xu, Y. (2020b). Characterization of potent odorants causing a pickle-like off-odor in Moutai-aroma type Baijiu by comparative aroma extract dilution analysis, quantitative measurements, aroma addition, and omission studies. *Journal of Agricultural and Food Chemistry*, 68(6), 1666–1677.
- Wang, Y., Jia, A., Wu, Y., Wu, C., & Chen, L. (2015). Disinfection of bore well water with chlorine dioxide/sodium hypochlorite and hydrodynamic cavitation. *Environmental Technology*, 36(4), 479–486.

- Wang, Y., Tuccillo, F., Lampi, A. M., Knaapila, A., Pulkkinen, M., & Kariluoto, S.,... Sandell, M. (2022a). Flavor challenges in extruded plant-based meat alternatives: A review. *Comprehensive Reviews in Food Science and Food Safety*, 21(3), 2898–2929.
- Wang, Y., Xie, J., Zhang, C., Xu, Y., & Yang, X. (2022b). Effect of lipid on formation of Maillard and lipid-Maillard meaty flavour compounds in heated cysteine-xylose-methyl linoleate system. *Flavour and Fragrance Journal*, 37(5), 274–284.
- Wang, Z., Wang, J., Richter, H., Howard, J. B., Carlson, J., & Levendis, Y. A. (2003). Comparative study on polycyclic aromatic hydrocarbons, light hydrocarbons, carbon monoxide, and particulate emissions from the combustion of polyethylene, polystyrene, and poly (vinyl chloride). *Energy & Fuels*, 17(4), 999–1013.
- Watanabe, T., Idehara, T., Yoshimura, Y., & Nakazawa, H. (1998). Simultaneous determination of chlorine dioxide and hypochlorite in water by high-performance liquid chromatography. *Journal of Chromatography A*, 796(2), 397–400. [https://doi.org/10.1016/S0021-9673\(97\)01009-1](https://doi.org/10.1016/S0021-9673(97)01009-1)
- Weber, J., & Sharypov, V. (2009a). Ethyl Carbamate in Foods and Beverages – A Review. In E. Lichtfouse (Ed.), *Climate Change, Intercropping, Pest Control and Beneficial Microorganisms*, (pp. 429–452). Springer Netherlands. https://doi.org/10.1007/978-90-481-2716-0_15
- Weber, J., & Sharypov, V. (2009b). Ethyl carbamate in foods and beverages: A review. *Environmental Chemistry Letters*, 7(3), 233–247.
- Weerawatanakorn, M., Wu, J.-C., Pan, M.-H., & Ho, C.-T. (2015). Reactivity and stability of selected flavor compounds. *Journal of Food and Drug Analysis*, 23(2), 176–190.
- Wenzl, T., Lachenmeier, D. W., & Gökmen, V. (2007). Analysis of heat-induced contaminants (acrylamide, chloropropanols and furan) in carbohydrate-rich food. *Analytical and Bioanalytical Chemistry*, 389(1), 119.
- Wenzl, T., Szilagyi, S., Rosen, J., & Karasek, L. (2008). Validation of an Analytical Method to Determine the Content of Acrylamide in Roasted Coffee. EUR 23403 EN. Luxembourg: OPOCE. JRC46263. <https://doi.org/10.2787/54267>
- Westling, M., Danielsson-Tham, M.-L., Jass, J., Nilsen, A., Öström, Å., & Tham, W. (2016). Contribution of Enterobacteriaceae to sensory characteristics in soft cheeses made from raw milk. *Procedia Food Science*, 7, 17–20.
- Whitfield, F. B., Mottram, D. S., Brock, S., Puckey, D. J., & Salter, L. J. (1988). Effect of phospholipid on the formation of volatile heterocyclic compounds in heated aqueous solutions of amino acids and ribose. *Journal of the Science of Food and Agriculture*, 42(3), 261–272.
- Wilson, K. M., Mucci, L. A., Cho, E., Hunter, D. J., Chen, W. Y., & Willett, W. C. (2009). Dietary acrylamide intake and risk of premenopausal breast cancer. *American Journal of Epidemiology*, 169(8), 954–961.
- Wu, F., Lv, P., Yang, N., Jin, Y., Jin, Z., & Xu, X. (2018). Preparation of Maillard reaction flavor additive from germinated wheat and its effect on bread quality. *Cereal Chemistry*, 95(1), 98–108.
- Wu, J., Liu, Y., Zhao, H., Huang, M., Sun, Y., Zhang, J., & Sun, B. (2021). Recent advances in the understanding of off-flavors in alcoholic beverages: Generation, regulation, and challenges. *Journal of Food Composition and Analysis*, 103, 104117.
- Xiang, J., Liu, F., Wang, B., Chen, L., Liu, W., & Tan, S. (2021a). A literature review on maillard reaction based on milk proteins and carbohydrates in food and pharmaceutical products: Advantages, disadvantages, and avoidance strategies. *Foods*, 10(9), 1998.
- Xiang, J., Liu, F., Wang, B., Chen, L., Liu, W., & Tan, S. (2021b). A Literature Review on Maillard Reaction Based on Milk Proteins and Carbohydrates in Food and Pharmaceutical Products: Advantages, Disadvantages, and Avoidance Strategies. *Foods*, 10(9). <https://doi.org/10.3390/foods10091998>
- Xiao, Y., Huang, Y., Chen, Y., Zhu, M., He, C., & Li, Z.,... Liu, Z. (2022). Characteristic fingerprints and change of volatile organic compounds of dark teas during solid-state fermentation with Eurotium cristatum by using HS-GC-IMS, HS-SPME-GC-MS. *E-Nose and Sensory Evaluation. LWT*, 169, 113925.
- Xie, D., Wan, Z., Shen, J., Zheng, Z., Wang, Z., Xiao, C., & Kang, H. (2014). Study on semicarbazide content difference from different organizations chicken generated by sodium hypochlorite. *Journal of Food Safety and Quality*, 5(11), 3394–3399.
- Xiong, Z., Li, B., Li, L., Wan, L., Peng, X., & Yin, Y. (2017). Effect of selected mercapto flavor compounds on acrylamide elimination in a model system. *Molecules*, 22(6), 888.
- Yang, J., Pan, Z., Takeoka, G., Mackey, B., Bingol, G., Brandl, M., & T.,... Wang, H. (2013). Shelf-life of infrared dry-roasted almonds. *Food Chemistry*, 138(1), 671–678.
- Yang, N., Liu, C., Liu, X., Degen, T. K., Munchow, M., & Fisk, I. (2016). Determination of volatile marker compounds of common coffee roast defects. *Food Chemistry*, 211, 206–214.
- Yao, W., Zhang, Y., Jia, X., & Huang, Z. (2014). Selective catalytic transfer dehydrogenation of alkanes and heterocycles by an iridium pincer complex. *Angewandte Chemie*, 126(5), 1414–1418.
- Yarahmadi, T., Hassanzadaza, H., Chamandoost, S., & Aminzadeh, M. (2016). Quality assessment of some high consumption foods in Zanjan City. *Journal of Human Environment and Health Promotion*, 1(3), 143–148.
- Yasuhara, A., Tanaka, Y., Hengel, M., & Shibamoto, T. (2003). Gas chromatographic investigation of acrylamide formation in browning model systems. *Journal of Agricultural and Food Chemistry*, 51(14), 3999–4003.
- Yaylayan, V. (2006). Precursors, formation and determination of furan in food. *Journal Für Verbraucherschutz und Lebensmittelsicherheit*, 1(1), 5–9.
- Yeo, H., Balagiannis, D. P., Koek, J. H., & Parker, J. K. (2022). Comparison of odorants in beef and chicken broth—focus on Thiazoles and Thiazolines. *Molecules*, 27(19), 6712.
- Yin, N., Shoeman, D. W., Klammer, K. A., & Csallany, A. S. (2020). 4-Hydroxynonenal (HNE), a toxic aldehyde in fried chicken from fast food restaurants and a grocery store. *Food and Nutrition Sciences*, 11(2), 82–97.
- Yousefi, M., Shariatifar, N., Tajabadi Ebrahimi, M., Mortazavian, A. M., Mohammadi, A., & Khorshidian, N.,... Hosseini, H. (2019). In vitro removal of polycyclic aromatic hydrocarbons by lactic acid bacteria. *Journal of Applied Microbiology*, 126(3), 954–964.
- Yu, L. L., Wang, S., & Sun, B.-G. (2014). *Food safety chemistry: Toxicant occurrence, analysis and mitigation*. CRC Press.
- Yu, S., Ge, Y., Zhang, L., Li, Y., Zhang, W., Liu, C., & Peng, S. (2024). Dietary exposure assessment of perchlorate and chlorate in infant formulas marketed in Shanghai, China. *Science in One Health*, 3, 100062. <https://doi.org/10.1016/j.soh.2024.100062>
- Zamora, R., Lavado-Tena, C. M., & Hidalgo, F. J. (2020). Oligomerization of reactive carbonyls in the presence of ammonia-producing compounds: A route for the production of pyridines in foods. *Food Chemistry*, 304, 125284.
- Zha, F., Gao, K., Rao, J., & Chen, B. (2021). Maillard-driven chemistry to tune the functionality of pea protein: Structure characterization, site-specificity, and aromatic profile. *Trends in Food Science & Technology*, 114, 658–671.
- Zhang, Y., Li, X., Lu, X., Sun, H., & Wang, F. (2021). Effect of oilseed roasting on the quality, flavor and safety of oil: A comprehensive review. *Food Research International*, 150, 110791.
- Zhao, D., Shi, D., Sun, J., Li, A., Sun, B., & Zhao, M.,... Huang, M. (2018a). Characterization of key aroma compounds in Gujinggong Chinese Baijiu by gas chromatography-olfactometry, quantitative measurements, and sensory evaluation. *Food Research International*, 105, 616–627.
- Zhao, F., Yim, H., Hu, W., Cheng, G., Zhang, W., & Cui, S.,... Cui, W. (2017). Determination of chlorine dioxide and its by-products in food by ion chromatography. *Journal of Food Safety and Quality*, 8(11), 4212–4215.
- Zhao, L., Lyu, C., & Li, Y. (2021). Analysis of factors influencing plant-microbe combined remediation of soil contaminated by polycyclic aromatic hydrocarbons. *Sustainability*, 13(19), 10695.
- Zhao, T., Chen, S., Li, H., & Xu, Y. (2018b). Identification of 2-hydroxymethyl-3, 6-diethyl-5-methylpyrazine as a key retronasal burnt flavor compound in soy sauce aroma type Baijiu using sensory-guided isolation assisted by multivariate data analysis. *Journal of Agricultural and Food Chemistry*, 66(40), 10496–10505.
- Zhao, X., Du, G., Zou, H., Fu, J., Zhou, J., & Chen, J. (2013). Progress in preventing the accumulation of ethyl carbamate in alcoholic beverages. *Trends in Food Science & Technology*, 32(2), 97–107.
- Zhao, Y., Luo, X., Li, J., Xu, M., & Tu, Y. (2015). Effect of basic alkali-pickling conditions on the production of lysinoalanine in preserved eggs. *Poultry science*, 94. <https://doi.org/10.3382/ps/pev184>
- Zhou, C., Zhan, G., Pan, D., Zhou, G., Wang, Y., He, J., & Cao, J. (2022a). Characterizing the spoilage mechanism of “three sticks” of Jinhua ham. *Food Science and Human Wellness*, 11(5), 1322–1330.
- Zhou, K., Liu, Y., Li, W.-Q., Liu, G.-L., Wei, N., Sun, Y.-M., & Xu, Z.-L. (2017). An improved HPLC-FLD for fast and simple detection of ethyl carbamate in soy sauce and prediction of precursors [journal article].

Food Analytical Methods, 10(12), 3856–3865. <https://doi.org/10.1007/s12161-017-0948-5>

Zhou, Y. J., Zhang, Y. X., & Dong, X. W. (2022b). Determination of heterocyclic amines in braised sauce beef and the effects of different cooking conditions on the formation of heterocyclic amines. *Journal of the Science of Food and Agriculture*, 102(2), 617–627.

Zhuang, Y., Dong, J., He, X., Wang, J., Li, C., Dong L, L., & Wang, S. (2022). Impact of heating temperature and fatty acid type on the formation of lipid oxidation products during thermal processing. *Frontiers in Nutrition*, 9, 913297. <https://doi.org/10.3389/fnut.2022.913297>

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.