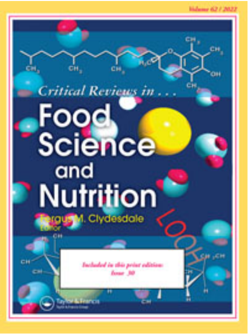

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REVIEW

Food additives: From functions to analytical methods

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ABSTRACT
Food additives refer to all kinds of trace substances used in food or food processing to preserve flavor or enhance food taste, appearance, or other qualities. At present, artificial synthetic food additives have gradually replaced the natural food additives and many problems related to food additives, involving the abuse of food additives, excessive additives or even toxic additives. Obviously, food additives can bring people great sensory enjoyment and commercial convenience, but they may also cause potential risks to human health. So, it is of high significance to conduct quantitative analysis on the content of food additives. According to their functions and the regulatory requirements of food additives, this review starts from the classification and structures of various food additives involving colorants, preservatives, antioxidants, sweeteners, emulsifiers, stabilizers, thickeners, gelling agents. It then summarizes and discusses analytical methods for quantification of food additives including modern immunoassays and other biotechnological methods. The proposed review aspires to fill in the knowledge gap of food additives between academia and industry by covering all kinds of analytical methods for quantifying food additives.

KEYWORDS
analytical methods; food additives; food additives regulation; molecular structure and technique

Introduction

Food additives are substances added to food to preserve flavor or enhance its taste, appearance, or other qualities (Ishidate et al. 1984), and are inevitable in packaged food. The proper use of food additives plays an important role in modern food industry. Firstly, food additives not only function in food preservation, but also help to enhance certain qualities of food such as color, flavor and flexibility, as well as improving the nutrition of food. For example, proper food nutrition enhancers can be added to make up nutrition loss during food processing. They effective prevent malnutrition and nutrient deficiency and promoting nutrition balance (Wiley and Nee 2020). Secondly, the use of food additives such as defoaming agents, stabilizers and coagulants in food is conducive to the operations during food processing. For instance, when gluconate lactone as tofu coagulant is used, the mechanization and automation of tofu production can be easily realized. Additionally, food additives benefit the commercial convenience by extending the shelf life and working in the manufacturing process, through packaging, or during storage or transport.

Although food additives bring so many benefits, the improper use of food additives will do harm for human health. Therefore, it is of great importance to discuss and summarize the analytical methods for food additives to provide guidance for regulatory management of food additives.

Previous literature provided some analytic methods for food. For example, Poms et al. reported a review on methods for allergen analysis in food (Poms, Klein, and Anklam 2004), but it concentrated in the aspect of allergen detection. Other reviews also mentioned analytic methods in food additives based on safety, action and detection. Carocho et al. analyzed several types of food additives in terms of safety and toxicity (Carocho et al. 2014); Carocho and Ferreira provided an overview of the potential benefits and adverse effects of antioxidants, a kind of additives, which analyzed the mechanisms of action and detection methodologies of antioxidants (Carocho and Ferreira 2013). There was another article written by Yamjala et al. that mentioned technological methods in analysis of azo dyes for coloring food (Yamjala, Nainar, and Ramisetti 2016), however, it lacked the analysis for other food additives. Since there are few reviews covering the topic of analytical methods for food additives in perspectives of functions and analytical techniques, meanwhile, food additives have vital relationship with human health (Roca-Saavedra et al. 2018), it is of great significance to make a review on the analysis of food additives.

Aiming to fill in the knowledge gap between academia research of food additives and product development in food industry, we propose the first review on the analysis of food additives from the respective of molecular structure and

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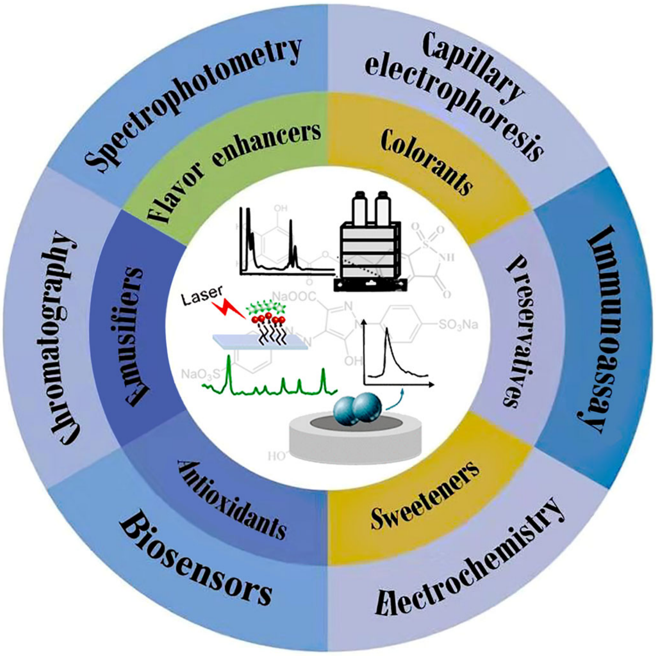

Figure 1. The overall schematic presentation of analytical methods for food additives: from functions to detection techniques.

Figure 2. The general classification of food additives using E-number from E100 to E1599.

modern quantification techniques. This review will start from the classification of food additives, then cover analysis of food additives based on all aspects of analytical methods, including both traditional and modern biotechnological methods (Figure 1).

Food additives and their functions

Till now, there are more than 25,000 compounds of food additives being used all around the world (Anderson 1986). According to the compositions, food additives are generally divided into two major categories of natural additives and synthetic additives. Wherein, natural food additives are mainly produced by purifying the ingredients from plant or animal sources. While chemically synthesized additives are based on chemical raw materials, from which organic or inorganic matter can be extracted and purified. Additionally, based on their functions, food additives can be divided into several groups such as antioxidants, bleach, sweeteners, preservatives, colorants, thickeners and so on. Food additives from different group may have overlap due to multiple effects.

To regulate food additives and inform consumers, additives were classified and assigned unique numbers in different countries. The numbering method in European Union gives each additive a unique number called an "E number", which is used in Europe for all approved additives. This numbering scheme has now been adopted and extended by the Codex Alimentarius Commission to internationally identify all additives, regardless of whether they are approved for use (Codex Alimentarius Commission 1989). Using this method, the additives can be easily classified into groups that have different functions (Figure 2). Food additives mentioned in following contents are all contained in Table 1, where the E-number, main usage and maximum dosage can be referred. Below section details different food additives and their functions.

Colorants

Colorants are a kind of additives that added to food to remedy colors lost during preparation, enhance perception of flavor or to make food look more attractive (Coultate and Blackburn 2018). Colorants present in both natural and synthetic forms, where natural food colors refer to naturally available dyes obtained from vegetables, animals or minerals. For instance, curcumin is mainly used for coloring food like beverages, sauces and confectionery, which can be added only lower than 0.01 g/kg. Additionally, canthaxanthin used to dye tanning pills, candies, and carbonated drinks has the maximum dosage from 0.001 to 0.03 g/kg. On the other hand, synthetic food colors are popularly also known as artificial food colors, which are manufactured chemically. Wherein, quinoline yellow used for coloring cold fruits, ice creams, sweets, and beverage products should be controlled under 0.1 g/kg in food processing. Tartrazine mainly added in soups, ice creams, sweets, gum and mustard yogurt has maximum dosage from 0.015 to 0.018 g/kg.

Preservatives

Preservatives are used to prevent or inhibit spoilage of food due to contamination of fungi, bacteria and other microorganisms and keep food safe for longer time (Carocho, Morales, and Ferreira 2018). Similar to food colors, preservatives can also be divided into two main groups of artificial and natural ones. Commonly used artificial preservatives include sorbic acid, which is used in dairy products, soybean products, processed vegetables, cooked meat products and

Table 1. Typical representatives of four food additives with E-number (not given: —).

Category		Common substance (E-number)	Mainly used	Maximum dosage range (g/kg)
Colorants	Natural food colors	Natural carotene (E160a)	Dairy products, frozen drinks, processed fruits, dried vegetables and soybean products	—
		Anthocyanins (E163)	Jams, sugar confectioneries, jellies, soft drinks and frozen products	—
		Curcumin (E100)	Beverages, sauces and confectionery	< 0.01
		Canthaxanthin (E161g)	Tanning pills, fruit-spreads, candies, sirups, sauces, carbonated drinks	0.001 ∼ 0.03
	Artificial food colors	Tartrazine (E102)	Soups, sauces, ice creams, ice lollies, sweets, chewing gum, marzipan, jam, jelly, marmalade and mustard yogurt etc.	0.015 ∼ 0.018
		Quinoline yellow (E104)	Cold fruits, ice creams, cake, chocolate, bread, cheese sauces and beverage products etc.	< 0.1
		Sunset yellow FCF (E110)	Jam, dairy products, cocoa products, starch desserts, compound condiments, beverage products	0.005 ∼ 0.0887
		Carmoisine (E122)	Beverage, wine, candy, green plum, bayberry, sandwich, ice cream etc.	0.005 ∼ 0.015
		Ponceau 4R (E124)	Beverage, wine, soda, candy, pastry, soya drink, ice cream, yogurt	0.001 ∼ 0.01
		Allura red (E129)	Candy coating, fried chicken, meat enema, western ham, jelly, biscuit sandwich	0.004 ∼ 0.0085
Preservatives	Natural preservative	Nisin (E234)	Meat, dairy products, vegetable protein products, canned goods, coffee beverage, tea, soy sauce	0.15 ∼ 0.5
		Natamycin (E235)	Yogurt, cheese, raw ham, dried sausage, cakes	< 0.1
		Lysozyme (E1105)	Cheese, drink, baby food, meat and fish products	—
	Artificial preservative	Sorbic acid (E200) and potassium sorbate (E202)	Dairy products, soybean products, processed vegetables, cooked meat products, aquatic products, etc.	0.075 ∼ 2.0
		Benzoic acid (E210) and sodium benzoate (E211)	Condiments, pickled products, beverage products, fruit wine	0.2 ∼ 2.0
		P-hydroxybenzoates (E214-219)	Jam and sauce products, carbonated drinks, etc	0.012 ∼ 0.5
		Sodium nitrite (E250)	Soybean products, meat products, aquatic products, pastry and puffed foods, etc.	1.0 ∼ 10
		Propionic acid (E280) and sodium propionate (E281)	Soybean products, wet flour products, bread, pastry, vinegar and soy sauce, etc.	0.25 ∼ 2.5
Antioxidants		Ascorbic acid and its salts (E300-302)	Peeled fresh fruits and vegetables, wheat flour, fruits and vegetables products	0.2 ∼ 5.0
		Tocopherol (E306) and its geometric isomers (E307-309)	Meat, fish, nuts, vegetables, fruits, beverages and canned food	—
		Propyl gallate (E310)	Nuts and canned seeds, gum-based candy, grilled meat, fried noodles, etc.	0.1 ∼ 0.4
		Tert-butyl hydroquinone (E319)	Moon cakes, instant rice noodles products, biscuits, baked food fillings	0.2
		Butyl hydroxyanisole (E320)	Fat, oil and emulsified fat products, coarse grain, instant rice noodles products, etc.	0.2
		Butylated hydroxytoluene (E321)	Fried noodles, gum-based candy, air-dried aquatic products, etc.	0.2 ∼ 0.4
Sweeteners	Natural sweetener	Sorbitol (E420)	Dairy products, jams, wet flour products, baked products, beverages and soybean products, etc.	0.5 ∼ 30
		Mannitol (E421)	Candy, chewing gum	0.2
		Thaumatin (E957)	Candied fruits, candy, biscuits, canned meat, etc.	—
		Stevioside (E960)	Flavor fermented milk, candy, condiments, canned fruits, flavored sirup and tea products	0.17 ∼ 10.0
		Maltitol, maltitol sirup (E965)	Processing fruits, frozen surimi products, soybean products, etc.	—
		Lactitol (E966)	Dairy products, Spices	—
		Xylitol (E967)	Dairy products, tea products, alcoholic drinks, seasonings, starch products, processed fruits and vegetables, etc.	—
	Artificial sweetener	Aspartame (E951)	Dairy products, frozen fruits and vegetables, cereals and starch desserts	0.3 ∼ 4.0
		Cyclamate (E952)	Canned fruits, jams, mixed wine, instant noodle food and condiments	0.65 ∼ 8.0
		Saccharin and its salts (E954)	Frozen drinks, dehydrated mango, dried figs, cold fruits, cooked beans and dried fruits	0.15 ∼ 5.0
		Sucralose (E955)	Prepared dairy products, jams, sufu, coarse cereals products, Baked products, etc.	0.25 ∼ 5.0
		Neotame (E961)	Dairy products, frozen fruits and vegetables, cereals and starch desserts	0.01 ∼ 0.35
Emulsifiers, stabilizers, thickeners		Polyglycerol esters (E475)	Soy milk drinks, ice-creams, spreads, breads, cakes, toffee, chocolate	5 ∼ 10
		Sorbitan esters (E491-495)	Milk, ice-creams, breads, cakes, biscuits, soya products, dried yeast, drinks	0.05 ∼ 10
		Sodium alginic acid (E400)	Milk products, cheese, margarine, freezing drinks	10

(*continued*)

Table 1. Continued.

Category	Common substance (E-number)	Mainly used	Maximum dosage range (g/kg)
	Agar (E406)	Ice cream, low-fat spreads, dairy products, salad dressings, mayonnaise	—
	Pectin (E440)	Jam, jelly, cheese, candy, sauce, yoghurt	3.0
	Gellan gum (E418)	Pudding, jelly, sugar, drinks, dairy products, jam products, bread	—
Flavor enhancers	Monosodium glutamate (E621)	Soup, sausage, fish cake, chili sauce, canned food, puffed food, jelly	0.2 ~ 0.5
	Guanylic acid (E626)	Meat, ham, bacon, soy sauce, food condiments	0.5
Glazing agents	Carnauba wax (E903)	Candy, dried food, baked goods, marshmallows, sugar products, fruit juice, broth sauce	—
	Shellac (E904)	Apples, oranges, gum sugar base, roasted coffee, chocolate, wafer biscuits	0.2

aquatic products. The maximum dosage of sorbic acid is 0.075 to 2.0 g/kg in food processing. Benzoic acid and its salts, are commonly used in preserving condiments, pickled products, beverage products and fruit wine, which have the maximum additive amount from 0.2 to 2.0 g/kg. The natural preservatives involving nisin, which is added to meat, dairy products, vegetable protein products, canned goods, coffee beverage, tea and soy sauce. The maximum additive amount of nisin is 0.15 to 0.5 g/kg. Moreover, the maximum dosage of natamycin should be controlled lower than 0.1 g/kg in food processing.

Antioxidants

There is some overlap between preservatives and antioxidants because they perform the similar effect on the food preservation. Antioxidants mainly prevent or inhibit the oxidation process to keep the food from spoilage (Lorenzo et al. 2018). Natural antioxidant additives are commonly added to meat, fish, nuts, vegetables, fruits, beverages and canned food. For example, the additive amount of ascorbic acid as well as its salt-like ascorbate and its geometric isomers should be controlled from 0.2 to 5.0 g/kg. The artificial antioxidants are often added to oils, cheese, and chips to suppress the formation of hydroperoxides (Carocho, Morales, and Ferreira 2018). For instance, the phenol derivatives of propyl gallate should be controlled in dosage from 0.1 to 0.4 g/kg. Moreover, tert-butyl hydroquinone has the maximum dosage of 0.2 g/kg; and butyl hydroxyanisole should be controlled lower than 0.2 g/kg too.

Sweetener

Sweetener, a sugar substitute, is a food additive that provides a sweet taste like that of sugar while containing significantly less food energy, making it a zero-calorie or low-calorie sweetener (Martyn et al. 2018). Natural sweeteners like sorbitol, xylitol, and mannitol are derived from sugars, which are widely used in dairy products, tea products, alcoholic drinks, seasonings, candy, starch products, processed fruits and vegetables. Wherein, the maximum dosage of sorbitol is from 0.5 to 3.0 g/kg; the additive amount of mannitol should be controlled under 0.2 g/kg. Artificial sweetener such as aspartame, cyclamate, saccharin sodium and sucralose are mainly used in fruits, jams, beverages, desserts and dairy products. The maximum dosage of aspartame is from 0.3 to 4.0 g/kg; cyclamate has maximum dosage from 0.65 to 8.0; and saccharin sodium is from 0.15 to 5.0 g/kg.

Emulsifiers, stabilizers, thickeners and gelling agents

Since many functions of food additives are overlapped, and thickeners and gelling agents have nearly the same functions (Abid et al. 2018). Therefore, emulsifiers, stabilizers, thickeners and gelling agents are categorized as one group from E400 to E499 in the E-number classification (Figure 2). Emulsifiers, also called emulgents, act as an interface between the conflicting components in water and oil (McClements and Jafari 2018), and are used in creams and sauces, bakery, and dairy products. Examples of emulsifiers are polyglycerol esters, which has the maximum dosage range from 5 to 10 g/kg. Stabilizers are substances or chemicals that allow food ingredients, which do not mix well, to remain in a homogenous state after blending (Tekin Pulatsü, Sahin, and Sumnu 2018). The common food stabilizer includes agar, alginic acid and its sodium, potassium, ammonium and calcium salts. Thickeners or thickening agents are substances added to food preparations for increasing their viscosity without changing other properties like taste, for example, pectin has the maximum dosage of lower than 3.0 g/kg. Gelling agents like konjac, karaya gum, and gellan gum are incorporated into foods to produce specific structure, flow, stability and eating qualities desirable for consumers.

Glazing agents, flavor enhancer

Other additives like glazing agents which fall into this category, have other functions for improving whipping, leavening and color permanence (Teixeira 2018). One glazing agent called shellac has the maximum dosage range of lower than 0.2 g/kg in food processing. Additionally, the food flavor enhancers like monosodium glutamate and guanylic acid function in enhancing the existing flavor (Abdel-Moemin, Regenstein, and Abdel-Rahman 2018), where monosodium glutamate has the maximum dosage from 0.2 to 0.5 g/kg and guanylic acid should be lower than 0.5 g/kg.

Food additives are intensively used and provide functions in improving food quality. However, the vast majority of food safety incidents caused by illegal activities, especially the abuse and illegal use of food additives have caught public concern worldwide. Therefore, the regulation and measurement of food additives are two most effective methods to standardize the market action and enhance the level of food safety.

Regulation of food additives

The improper use of both natural and synthetic food additives will do harm for human body (Carocho, Morales, and Ferreira 2015). For instance, boric acid was widely used as a food preservative from the 1870s to the 1920s, but was banned in World War I as it was demonstrated to be toxic in animal and human studies. Safrole, naturally occurs in sassafras and sweet basil, was firstly used as a food spice to flavor root beer until it showed to be carcinogenic. Such cases suggest that only additives with stable safety should be used in foods. Therefore, a series of standards regarding the topic of food additives safety should be covered to introduce new safe additives and bans those questionable ones.

Assessment

In order to apply the same standard for food additives, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) has been meeting annually since 1956 to update and revise its related standards (Wissgott and Bortlik 1996). According to laws, regulations and standards, illegal food additives or the abuse of food additives are usually assessed in two ways: component identification and content determination. The former aims at finding out whether additives are illegally utilized and the latter is to know if additives are excessive. From this point of view, how to determine food composition and additive content is an important issue to guide the laws and make sure foods are safe to the community (Figure 3). Thus, it is of great importance to establish reliable and sensitive analytical methods for the inspection of food additives.

Food additives regulations among different countries

The regulations of food additives among China, the United States, the European Union, Australia and New Zealand are listed and compared in Table 2. Moreover, Table 2 also separately lists flavoring agents, processing acids, nutritive substances and coloring agents due to different food regulations in different countries.

China

The functional range of food additives is the largest in Chinese food regulation, which defines food additives as both chemosynthetic and natural substances added to food for quality, color, fragrance and taste improvement; or for food preservation and processing technology. Therefore, coloring agents, sweeteners, flavoring agents, preservatives, antioxidants, processing acids, nutritive additives, gum-based substances all belong to food additives. Wherein, China provides more detailed regulations for flavoring agents, where flavorings, flavoring adjunct and process flavoring are 3 subtypes of flavoring agents. They are classified according to their functions and final effects for the food, where flavorings are the concentrated and prepared mixture for producing flavor; flavoring adjunct has no influence in final flavor but functions in producing, preserving and applying flavorings; and process flavorings are used to attain certain characteristics of flavor.

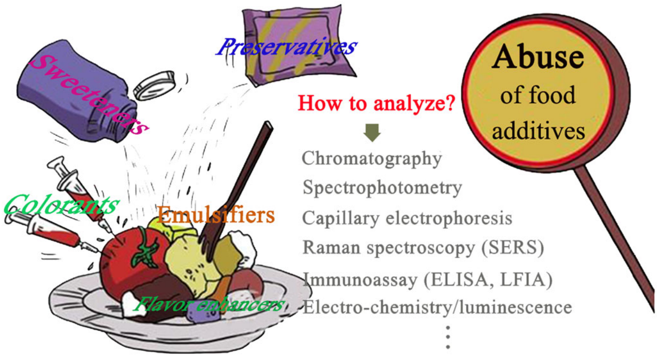

Figure 3. The scheme of food additives abuse and the related analytical methods.

The United States

The United States divided substances directly added to food into 4 types, where food additives, coloring agents, prior-sanctioned substances and GRAS substances are in equative classifications. Food additives are substances intendedly used and directly or indirectly becoming a component or affecting food characteristics. Therefore, any substances intendedly used in producing, manufacturing, packing, processing, packaging or transporting food may be considered as food additives.

The European Union

The European Union defines food additives as substances not normally consumed as food itself but added intentionally for technological purposes. However, substances without technological effect but used for imparting flavor, taste or nutrition should are not defined as food additives. Additionally, food ingredients used for technological function do not fall within food additives. The approval process for new additives requires pre-market applications including administrative, risk assessment, toxicological and risk management data.

Australia and New Zealand

In Australia and New Zealand food regulations, food additives are distinguished from processing acids and nutritive substances. The food additives are substances added to food to achieve technological functions and not normally used for consuming, where the by-products or food additives itself may remain in final food product.

Analysis of food additives

At present, traditional detection methods for analyzing food additives mainly include chromatography such as liquid

Table 2. Regulations of food additives in China, USA, EU, Australia and New Zealand.

		China	USA	EU	Australia & New Zealand
Food additives	Definition of food additives	An artificially chemosynthetic or natural substance added to food [1] to improve food quality, color, fragrance and taste; [2] for food preservation; [3] for processing technology.	A substance intendedly used and directly or indirectly becoming a component or affecting food characteristics.	Substances not normally consumed as food itself but added intentionally for technological purposes.	Substances added to food to achieve technological functions and not normally used for consuming.
	Distinguishable regulations		[1] Direct food additives: A subcategory of food additives approved by the USFDA. [2] Food additives, Prior-sanctioned substances, color additives and GRAS substances are in equative classification.	Food additives not including [1] substances used for imparting flavor and/or taste or for nutritional purposes [2] food ingredients used for technological function.	[1] The by-products or food additives itself may remain in the food. [2] food additives are distinguished from processing acids and nutritive substances.
	Categories of food additives	Coloring agents, sweeteners, flavoring agents, preservatives, antioxidants, processing acids, nutritive additives, gum-based substances.	Preservatives, flavoring agents, processing acids, nutritive additives, sweeteners.	Preservatives, flavoring agents, processing acids, nutritive additives, sweeteners, coloring agents.	Flavoring agents, sweeteners, coloring agents, preservatives, antioxidants.
	Approval process for new additives	Pre-market application is required.	Pre-market application in form of a food or color additives petition is required.	Pre-market application is required, including administrative, risk assessment, toxicological and risk management data.	Pre-market application is required, including technical information, safety information and dietary exposure of food additives.
Flavoring agents	Classification	[1] Flavoring agents belong to food additives. [2] Flavoring agents include 3 components: Flavorings, flavoring adjunct and process flavoring.	Regulated as both direct food additives and GRAS substances.	Regulated as food additives.	Regulated as food additives.
	Definition	[1] Flavorings are not directly used for consumption but as concentrated and prepared mixture for producing flavor. [2] Flavoring adjunct is required for producing, preserving and applying flavorings but have no influence in final flavor. 3] Process flavorings are used to attain certain characteristic of odor and flavor.	No specific definition	Flavoring substances obtained from chemical synthesis or isolation, and natural flavoring substances, functioning in improving or modifying the odor and/or taste of food for the benefit of the consumer.	Intense preparations used in small amount and not for consuming, adding to food to impart taste and/or odor
Processing acids	Classification	Regulated as food additives.	Belonging to food additives as "secondary direct food additives".	Regulated as food additives.	Distinguished from food additives.
	Definition	A substance only functions in fulfilling certain technological purpose during food production process rather than consumed as a food ingredient.	A substance has a technical effect in food during processing but not intends to have an ongoing technical effect in the food.	Any substances not consumed as food but is intentionally used in processing of raw materials, food or ingredients to [1] fulfill a certain technological purpose during processing and treatment; [2] may result in presence in final product.	The substances used in processing raw materials, food or ingredients to [1] fulfill a certain technological purpose during processing but not in the final food; [2] manufacture of food in processing at the lowest level necessary to achieve certain functions.
Nutritive substances	Classification	Regulated as food additives.	Regulated as food additives.	Regulated as food additives.	Distinguished from food additives.
	Definition	No specific definition	No specific definition	No specific definition	A substance not consumed as a food or used as food ingredients, but is intentionally added to food to achieve a nutritional purpose.
Coloring agents	Classification	Regulated as food additives.	Distinguished from food additives.	Regulated as food additives.	Regulated as food additives.
	Definition	No specific definition	Substances that are capable of imparting color when added or applied to food.	No specific definition	No specific definition

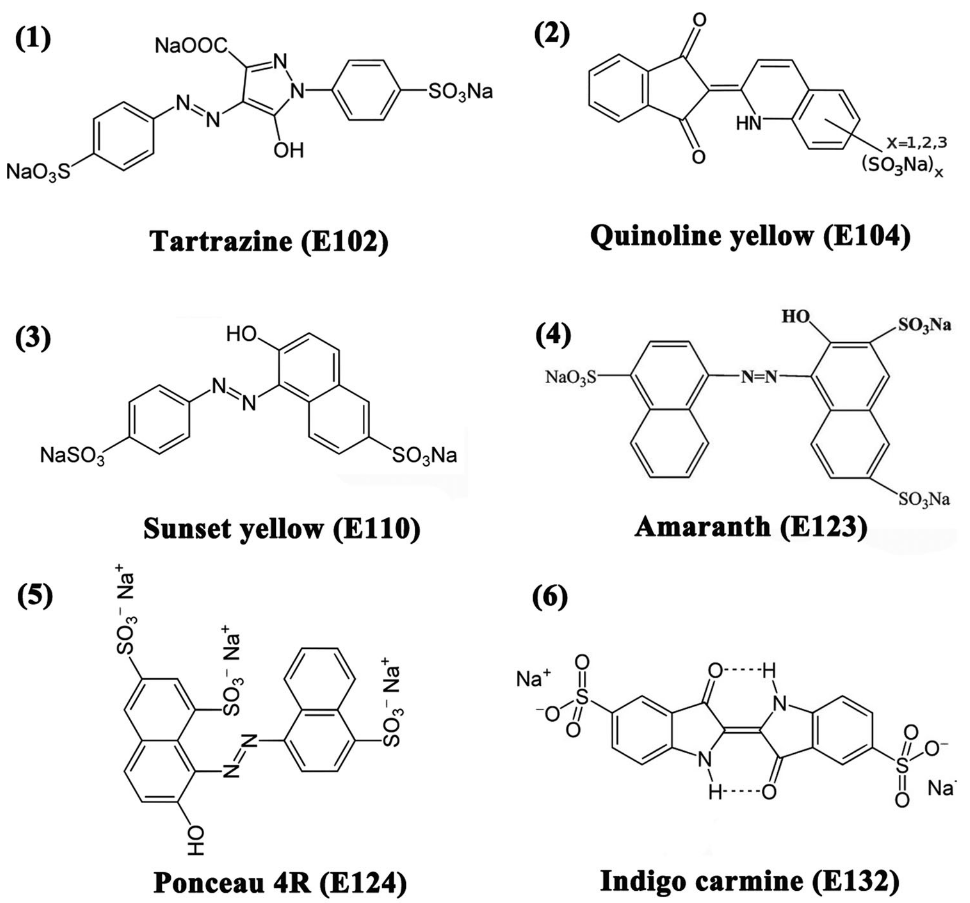

Figure 4. Chemical structures of the representative synthetic food colorants (from **1** to **6**: tartrazine (E102), quinoline yellow (E104), sunset yellow FCF (E110), amaranth (E123), ponceau 4 R (E124) and indigo carmine (E132)).

chromatography, gas chromatography and mass/liquid chromatography. These methods behave advantages of high sensitivity, good stability and reproducibility, but still suffer shortcomings such as professional operations, complex sample pretreatment, relative long test period and high cost (Taghdisi et al. 2019). Besides, spectrophotometry like Uv-*vis* absorbance and fluorescence spectroscopy possess simple operation and good sensitivity, however, the stability is a great concern, and the interference sources are complicated (Nguyen and Waterhouse 2019). High performance capillary electrophoresis exhibits simple operation, high accuracy and sensitivity but requires high quality of electrophoresis paint (Papetti and Colombo 2019). Recently, ion chromatography has been intensively used in analysis of food additives, which can determine low level of components even at high substrate concentration, thus simplify or eliminate sample pretreatment process and achieve simultaneous determination of multiple components (Meher, Labhsetwar, and Bansiwal 2018).

With the development of nanotechnology, many newly developed analytical methods such as surface enhanced Raman spectroscopy (SERS), fluorescence assay, electrochemical or electroluminescence assay, enzyme-linked immunosorbent assay (ELISA), lateral flow immunoassay (LFIA) and their related biosensors have been constructed to analyze food additives, which have greatly improved the performance of the analytical methods. These newly developed methods can also realize quantitative and qualitative detection of food additives with simple operations, rapid detection, high sensitivity and good specificity. The following section will discuss different analytical methods for five classes of food additives respectively, including colorants, preservatives, sweeteners, antioxidants, emulsifiers as well as their application and properties.

Then, different analytical methods including biosensors are comprehensively summarized and their detection performance for food additives, especially for the additives with low concentration, are compared and evaluated.

Analysis of food colorants

Food colorants, also known as dyes or pigments that impart color when it is added to food or drink, are usually divided into natural ones and artificial ones. Compared with natural pigments, artificial pigments have the advantages of high stability, good color uniformity, low microbial pollution and cost of production. Because of the advantages, artificial pigments such as tartrazine (E102), quinoline yellow (E104), sunset yellow FCF (E110), amaranth (E123), ponceau 4 R (E124) and indigo carmine (E132) are widely applied in food industry. However, continuous intake of synthetic colorants may do certain toxicity to human (Amchova, Kotolova, and Ruda-Kucerova 2015). Experiments demonstrated that a high dosage of the dye such as amaranth might increase the incidence of malignant tumors in rats. Therefore, the synthetic pigments allowed in some countries are regulated with strictly limited dosage.

Moreover, all these synthetic pigments include functional group like –OH, $–NH_2$ or benzene ring ($–C_6H_5$), which are optically or electrochemically active from the chemical structure (Figure 4). It means that the substances are easily activated to an excited state under light or electricity, resulting in specific optical or electrical signals. From this perspective, the detection of colorants is more favored with optical or electrochemical methods.

Tartrazine

Tartrazine (E102), known as lemon yellow, is a kind of water-soluble azo dye and often used in the coloring of food and beverage. Studies have shown that intake of tartarzine can cause a series of changes in biochemical markers and it does great harm to asthma patients and children at higher doses (Elekima et al. 2019). The acceptable daily intake (ADI) for tartrazine is allocated as 7.5 mg/kg/day by JECFA in 1964, but many countries have banned or restricted tartrazine (Walton et al. 1999). To regulate food safety, many electrochemical and optical methods have been developed to analyze tartrazine in food.

For instance, He et al. prepared TiO_2-reduced graphene oxide composite-modified electrodes for the sensitive detection of tartrazine (He et al. 2018a). The new method showed that the composites increased the electrochemical active area and enhanced the sensitivity with a LOD of 8.0 nmol L^{-1} (S/N = 3). The method was successfully applied for the detection of trace tartrazine in carbonated beverage samples. Similarly, de Lima et al. reported the differential pulse voltammetry method for tartrazine detection using gold nanoparticles and Nickel(II)-phthalocyanine-tetrasulfonic (de Lima et al. 2019). In this work, a large and well-defined redox peak of tartrazine was obtained with the LOD of 0.055 μmol L^{-1}. The results demonstrated the excellent accuracy and reliability for the detection of tartrazine in juice samples. Besides, Tiwari et al. described the diffuse reflectance Fourier transform infrared (DRS-FTIR) spectroscopy for the detection of tartrazine (Tiwari and Deb 2019). Based on the prior extraction of tartrazine with modified silver nanoparticles, the method achieved linear calibrations in the range of 1 to 160 ng mL^{-1} with a LOD of 2.44 ng mL^{-1}. The above developed methods proved to be good alternative techniques, providing low cost and reliable results for the control of harmful food additives. As those electrochemical and optical methods are sensitive to environment, great attention should be paid on the influence of nanomaterials and the substrates on the signal outputs.

Sunset yellow

Sunset yellow (E110), a water-soluble synthetic azo dye, is often used in combination with amaranth to give a brown coloring in chocolates. Under EU and WHO/FAO guidelines, the daily acceptable intake is 0 ~ 4 mg/kg. It was reported that sunset yellow behaved no carcinogenicity, genotoxicity, or developmental toxicity in the amounts at which it is used (Joshi and Pancharatna 2019). However, it was banned or restricted as a food additive in countries like Norway, Finland and Sweden due to its lack of evidence for food safety.

In recent years, several analytical methods have been reported for the determination of sunset yellow, especially the electrochemical sensor and assays based on SERS. For example, Tran et al. developed an electrochemical sensor for sunset yellow measurement by modifying graphite flakes on the glassy carbon electrode (Tran et al. 2019). By using differential pulse voltammetry, sunset yellow can be detected with the linear range of 50 ~ 1000 nM with the calculated LOD of 19.2 nM. The recoveries of the method are 93.35 ~ 107.7% in commercial soft drinks, which suggests its accuracy and stability in the analysis of sunset yellow. Furthermore, Li et al. constructed a method by using bimetallic nanoparticles functionalized graphene for the electrode modification (Li et al. 2019a). Following that, the differential pulse voltammetry was adopted for the determination of sunset yellow. Further study revealed that the oxidation mechanism of sunset yellow is pH dependent and the electrochemical process is adsorption-controlled, which suggested that the morphology of modified material is extremely important to achieve high sensitivity of detection. The Co-Ni modified electrode showed the linear range of 0.008 ~ 10.0 μM and the LOD of 2.0 nM for sunset yellow. The nanomaterials based electrochemical methods increased active area and enhanced electron transfer efficiency, behaving accurate and sensitive determination of the used dyes in soft drinks without laborious pretreatment.

Besides, Ai et al. synthesized flower-shaped silver nanoparticles as SERS substrates for the simultaneous detection of sunset yellow, tartrazine, food blue and acid red (Ai et al. 2018). The SERS substrate behaved high SERS activity and the four different food colorants can be distinguished by principle component analysis. The LODs of the four colorants were measured to be 10^{-7} mol L^{-1}. Based on gold nanorods, Ou et al. reported a SERS method for the detection of sunset yellow and allura red in beverages (Ou et al. 2018). Based on the substrate, it showed strong peak at 1592 cm^{-1} and 1219 cm^{-1} for sunset yellow and allura red. With little sample preparation, the method can realize the convenient, cost efficient and quick detection of sunset yellow and allura red as low to 0.10 mg L^{-1}. Generally, the above SERS methods have demonstrated great advantages in terms of simplicity and sensitivity in the analysis of colorants, however, the stability and the background interference may be the main restrictions for their wide applications.

Amaranth

Amaranth (E123) usually appears as a trisodium salt in the drinks, candy and pastries. Excessive intake of amaranth can have adverse effects on health, such as high genotoxicity and cytotoxicity. Since 1976, it has been banned in the United States by the Food and Drug Administration as a suspected carcinogen. However, its use is legal in some other countries like United Kingdom and China but the maximum amount is strictly limited due to the potential risks to health (Oplatowska-Stachowiak and Elliott 2017). According to the hygienic standard of food additives by FAO/WHO in 1994, the daily acceptable intake of amaranth is less than 0.5 mg/kg. Therefore, it is critical to measure the amount of amaranth in food to control food quality and ensure consumer's health.

So far, many optical or electrochemical techniques are used for the determination of amaranth in food. For example, Li et al. reported a molecularly imprinted polymer based electrochemical sensor for the selective and sensitive detection of amaranth (Li et al. 2019b). The polymer ensured the selectivity and the electrochemical method attributed to the sensitivity. The method showed a linear relationship for amaranth in the range of 0.006–10 μM, and the limit of detection (LOD) of 2 nM. The proposed sensor can distinguish amaranth from other structurally similar substances like sunset yellow and tartrazine. He et al. developed a kind of manganese dioxide-graphene nanocomposites modified glassy carbon electrode for amaranth analysis based on ionic liquids (He et al. 2018b), revealing that the oxidation of amaranth is an adsorption-controlled and irreversible electrode process involving two-electron and one-proton. The method showed a range of 0.02 μM$\sim$10 μM and a LOD value of 1.0 nM (S/N = 3) for amaranth in soda samples. The above electrochemical methods provided a rapid, simple, low-cost and effective approach to analyze amaranth in food samples.

For the optical methods, Liu et al. presented a novel fluorescence nanosensor for selective and sensitive determination of amaranth using carbon dots. The method showed a linear range of 0.2 $\sim$ 30 μM for amaranth with the LOD of 0.021 μM (Liu et al. 2019). It reported that amaranth can efficiently and sensitively quench the C-dots fluorescence at 523 nm by the inner filter effect and non-radiative energy transfer mechanisms. The proposed sensor has several advantages such as simplicity in design, fabrication and operation, and rapid response. Moreover, by simulating the theoretical spectrum and their characteristic peaks with density functional theory (DFT), Zou et al. presented a surface-enhanced Raman spectroscopy method for the rapid and quantitative detection of amaranth based on silver nanorods array substrates (Zou et al. 2018). The substrates showed characteristic peaks of amaranth located at 1345 cm^{-1} and 1361 cm^{-1} with the linear ranges from 1.0 to 100.0 mg L^{-1} and the LOD of 1.0 mg L^{-1}. Those optical methods are simple, sensitive, rapid and effective, but the stability and accuracy still remain to be developed due to the potential background interference.

Indigo carmine

As a kind of synthetic colorant, indigo carmine (E132) is an organic salt derived from indigo by sulfonation. Recent studies show that indigo carmine might cause irritations vomiting and diarrhea to human beings and the ADI value for indigo carmine is 5.0 mg kg^{-1} d^{-1} (Europe Food Safety Authority (EFSA)), 2014). Moreover, it is difficult to extract them completely from the food samples for analysis, thus poses great challenges to the food safety supervision. Therefore, it is an urgent to develop effective methods for the sensitive detection of indigo carmine.

For example, Manjunatha et al. discussed the electrochemical behavior of indigo carmine at poly (glycine) modified carbon paste electrode by cyclic voltammetry (Manjunatha 2018). The method showed the oxidation potential of indigo carmine at 407 mV with the LOD of 110 nM under differential pulse voltammetry, which can be applied to the detection of indigo carmine in real samples. Furthermore, by coupling flow injection analysis and boron-doped diamond electrode, Deroco et al. developed a multiple pulse amperometry method for indigo carmine detection with a well-defined oxidation peak at around 0.67 V (Deroco et al. 2018). The oxidation process involves the transfer of two electrons and two protons, yielding the oxidized species dehydroindigo. The method showed the indigo carmine concentration ranges of 70.0 $\sim$ 1000 nM with LOD of 40.0 nM, which was applied in commercial candies at a 95% confidence level. These electrochemical methods can be considered of great analytical interest with shorter analysis time and lower cost of instrumentation.

Chen et al. created an $Au-AuO_x$ substrate by in situ oxidation – reduction cycle for the SERS detection of indigo carmine (Chen et al. 2018). The novel substrate greatly improved the SERS performance through both electromagnetic and chemical enhancements. For indigo carmine, the substrate could exhibit a characteristic peak at 1582 cm^{-1}, which further showed a range of 10^{-7} to 10^{-3} M in soft drink sand ice cream. Besides, Li et al. proposed a resonance Rayleigh scattering technique for indigo carmine analysis using acridine orange (Li et al. 2016). In this work, the weak scattering intensity of acridine orange can be enhanced with the presence of indigo carmine, with a linear range of 2 $\sim$ 32 μM and the LOD of 2.4×10^{-8} M. Without any significant interference, the method can achieve sensitive and selective determination of trace level of indigo carmine.

From the electrochemical methods to the scattering techniques, it can be seen that the characteristic signal and good robustness are the indispensible part in analytical methods. Fortunately, the above methods show specific signal toward the analyte and possess the advantages like convenient operations, rapid detection, high sensitivity and reproducibility, showing their potential applications in indigo carmine detection in foodstuffs.

Other colorants

Other commonly used colorants include ponceau 4 R (E124), azorubine (E122), quinoline yellow (E104), and allura red (E129). They contain azo groups as their chromophore in the molecular structure, which can produce characteristic reduction peak by cathodic voltammetric determination. Meanwhile, the –OH on aromatic ring can also make them electrochemically oxidizable by using anodic voltammetry (Lipskikh et al. 2018). For example, Silva et al. described an electrochemical sensor based on ionic liquid and carbon black combined with chitosan film (Silva, Wong, and Fatibello-Filho 2019). In this work, an oxidation peak at

+0.9 V could be observed corresponding to Ponceau 4 R, which was recorded as calibration signal for measurements. Particularly, the oxidation signal of Ponceau 4 R was greatly improved by the constructed film, yielding the LODs of 0.9 nM. By coupling with molecularly imprinted technique (MIT), Piri et al. developed a simple electrochemical sensor for azorubine determination in water sample (Piri et al. 2018). The method behaved a detection linear range of 1~12 mg L^{-1} and a LOD of 0.57 mg L^{-1}. The molecularly imprinted polymer can greatly induce the interference from food samples, making it more accurate and selective to azorubine. The MIP coupled electrochemical method can greatly enhance the selectivity of electrochemical sensor, however, the poor conductivity of the polymer can in turn restrict its sensitivity.

Besides, Sivasankaran et al. investigated the fluorescence quenching behavior of quinoline yellow toward copper nanoclusters (Sivasankaran et al. 2019). The blue fluorescence of copper nanoclusters can be selectively quenched by quinoline yellow, and the fluorescence intensity decreased with the increase of quinoline yellow concentration. The results showed a linear range from 5.50 to 0.20 μM with the LOD of 0.11 μM. Yao et al. reported a fast and quantitative SERS method for allura red detection in candy samples (Yao et al. 2018). The SERS substrate of silver nanorod array was firstly developed with highly sensitive and reproducible, which serves characteristic peaks of allura red at 488, 589, 751, 1221, 1270, 1326, 1495, and 1578 cm^{-1}, respectively. The intensity at 1221 cm^{-1} was used to determine allura red with the linear range of 0.8 ~ 100 mg L^{-1} as well as a LOD of 0.05 mg L^{-1}. The robust fluorescence and SERS detection can make them perfect methods in fast preliminary testing of foods, providing potential application in food safety control field. Those optical methods may suffer from the instability caused by either food matrices or substrate materials. Take SERS-based assays for an example, the food matrices can lead to strong fluorescence, and the uniform SERS substrates pose crucial influence on the stability of SERS signal. Hence, it is a favorable strategy to develop various substrates for different food additives according to their functions and structures.

Analysis of preservatives

Microbial, enzyme or chemical changes can easily cause food spoilage due to the high nutrient content in foods. Fortunately, introducing food preservatives can prevent or delay food spoilage. The commonly used preservatives include benzoic acid, sorbic acid, propionic acid and their salts, P-hydroxy phenyl acid polymer and sodium nitrite (Figure 5). The work mechanism of these preservatives lies in inhibiting growth of the bacteria or their specific enzymes.

Antioxidants can also act as preservatives, and antioxidants like BHA, BHT, TBHQ and PG will be discussed in a separate section because they have similar chemical structures and are usually used in food together. Besides, the artificial preservatives may have more obvious harm to human's health than the natural preservatives, which would behave adverse effect on children's behavior (Anand and Sati 2013). Thus, many methods have been developed to analyze preservatives for food safety supervision and risk assessment. Amongst, due to the lack of active groups, unique polarity and molecular charge, chromatography and capillary electrophoresis are the most popular methods for the analysis of preservatives.

Benzoic acid and sodium benzoate

Benzoic acid (E200) and sodium benzoate (E211) are used as preservatives mainly in pickled products and beverages. The maximum amount used in foods ranges from 0.2 to 2.0 g/kg under the China National Standards GB 2760-2014. Excessive benzoic acid will destroy the VB_1 in food and make the calcium insoluble, which can destroy the absorption of calcium by the human body. Furthermore, long-term intake of such preservatives will increase the risk of cancer (Javanmardi et al. 2019). Therefore, it is necessary to ensure a relative low level of these preservatives in food to meet regulatory standards.

Timofeeva et al. proposed a simple and highly available microextraction method coupled with high performance liquid chromatography for benzoic and sorbic acids detection in beverages and sauce samples (Timofeeva et al. 2019). Air-assisted dispersive liquid-liquid microextraction procedure with organic phase solidification was developed as a new method for pretreatment, which made it eco-friendly, simple and easy to operate with relatively low LODs. The microextraction recoveries of benzoic and sorbic acids ranged from 93% to 105% and 96% to 101%, respectively. The method showed linear detection ranges of 0.1 ~ 150 mg L^{-1} and 0.05 ~ 100 mg L^{-1} for benzoic acid and sorbic acid with LODs of 0.03 mg L^{-1} and 0.02 mg L^{-1}, respectively.

Moreover, microfluidic device is widely used in food analysis, and the paper-based device has the advantages such as lightweight and low in cost. For example, Öztekin exploited a silica capillary instead of a column to achieve rapid sample separation (~3 min) and analysis of benzoic acid (Öztekin 2018). The method exhibited a detection linear range of 0.005 ~ 0.4 mM and a LOD of 0.405 mg L^{-1}. Besides, Liu et al. developed a microfluidic paper-based analytical device via an integrated microfluidic platform for benzoic acid detection (Liu et al. 2018). In the work, twenty-one food samples were measured to analyze benzoic acid with the deviations of concentration measurements below 6.6%. The reported capillary electrophoresis methods provided a compact and reliable tool for the analysis of benzoic acid, suggesting the advantages such as simple procedures, low cost and good reproducibility. Obviously, the sensitivity of this method remains to be improved.

Parabens

Parabens, known as *p*-hydroxybenzoates (E214-219), are intensively used in food, cosmetic and pharmaceutical products. Some animal studies have reported adverse reproductive effects of parabens (Jagne, White, and Jefferson 2016).

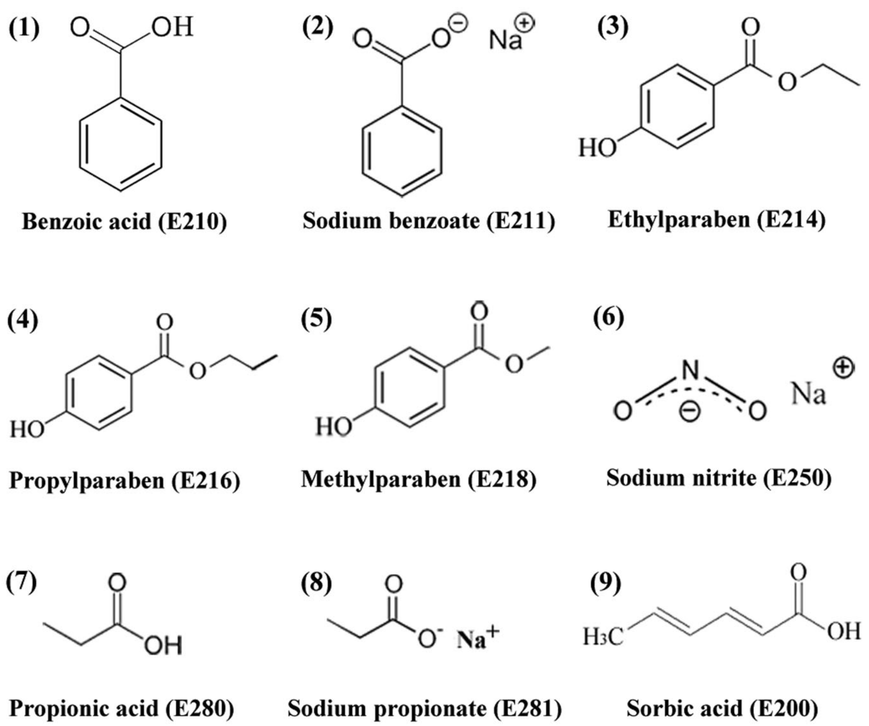

Figure 5. Chemical structures of the representative synthetic preservatives (from **1** to **9**: benzoic acid (E210), sodium benzoate (E211), ethylparaben (E214), propylparaben (E216), methylparaben (E218), sodium nitrite (E250), propionic acid (E280) and sodium propionate (E281) and sorbic acid (E200)).

As such, possible detrimental health effects to human could be caused with the use of foods, cosmetics, and pharmaceutical products. To address the concern, many regulatory agencies have established exposure limits for the use of parabens in those products. Therefore, it is necessary to monitor parabens in such products to control and verify the safety.

Most of the analytical methods for parabens are chromatography technique coupled with certain separation system. For example, Becerra-Herrera et al. reported the gas chromatography mass spectrometry for the simultaneous detection of parabens like *n*-butylparaben, methylparaben (E218), ethylparaben (E214), propylparaben (E216) coupling with rotating disk adsorptive extraction (Becerra-Herrera et al. 2018). The method showed recoveries of 79%~91% with relative standard deviations less than 10% and LODs lower than 0.05 $\mu g\ L^{-\ 1}$ for the analytes. The proposed method was very suited to the detection of parabens with fast extraction and low volume of derivatizing agent. Van Overmeire et al. reported a liquid chromatography-tandem mass spectrometry for the simultaneous determination of four parabens (methyl-, ethyl-, propyl-, and butyl-paraben) (Van Overmeire et al. 2019). Using negative electrospray ionization, the four parabens were analyzed with LODs of $0.1 \sim 0.2\ ng\ g^{-1}$ and LOQs of $0.2 \sim 0.5\ ng\ g^{-1}$, which could be an alternative to conduct simultaneous detection of parabens in food matrices.

Nitrite

Nitrite, mostly sodium nitrite (E250), is used for curing meat because it prevents bacterial growth and gives the product a desirable pink-red fresh color. Unfortunately, nitrite could bind with hemoglobin to reduce the oxygen transport capability of blood in human body with adverse effects. Moreover, nitrite can be readily converted to potent carcinogenic *N*-nitrosamines by reacting with the amino acids of proteins. The lethal level of nitrite is about 22 mg/kg (body weight), and the maximum allowed nitrite concentration in meat products is 200 ppm (Parthasarathy and Bryan 2012). Hence, a variety of analytical methods, especially chromatography and capillary electrophoresis methods have been developed for nitrite analysis.

For example, Lin et al. constructed a new capillary liquid chromatography based on polymer-based monolithic column (Lin, Hsu, and Fuh 2019). Without derivatization process, the proposed method obtained comparable LOD/LOQ values of 1.50/4.25 and 1.25/4.00 $\mu g\ g^{-1}$ for nitrite and nitrate. Moreover, for more than 200 analyses, the separation performance showed no noticeable decline, which suggested it is an acceptable method to monitor the occurrence of nitrite and nitrate in vegetables. Antczak-Chrobot et al. reported an ion chromatographic method to determine nitrite and nitrate in sugar by-products (Antczak-Chrobot, Bąk, and Wojtczak 2018). The method needn't to enzymatically converted nitrate to nitrite, behaving recoveries of nitrate and nitrite better than 90% and 96%. The detection linear ranges for nitrite and nitrate are $0.05 \sim 15.0\ mg\ L^{-1}$ and $0.1 \sim 50\ mg\ L^{-1}$ as well as LODs of $0.015\ mg\ L^{-1}$ and $0.046\ mg\ L^{-1}$, respectively. Owing to the simplicity, the small volume of samples and short time of analysis, the technique is suitable for routine control of nitrite and nitrate concentration. Tezcan proposed a sample stacking-capillary electrophoresis method for nitrate contents determination (Tezcan 2018). The measurement could be completed in less than 3 min without requiring any preliminary preparation method. The nitrate concentration in commercial milk samples ranged from 0.20 to 1.50 mg L^{-1} with the LOD of 0.03 mg L^{-1} (S/N = 3), showing the desirable separation performance and detection sensitivity of electrophoresis technique.

Other preservatives

Other preservatives such as sorbic acid (E200) and potassium sorbate (E202), propionic acid (E280) and propionates (E281-283) are also reported to be detected by many analytical methods. For instance, by coupling capillary electrophoresis with UV spectrophotometric method, de Jesus et al. realized the simultaneous detection of propionate and sorbate with the separation time less than 5 min (de Jesus et al. 2018). In this work, propionate and sorbate were detected at 235 nm and 250 nm with the LOQs of 4.3 and 1.5 mg kg^{-1} in bread. The method was demonstrated to be quick, simple, and easy for the simultaneous determination of propionate and sorbate. Further, Guadalupe et al. proposed a simple method for propionate and sorbate analysis by capillary electrophoresis with capacitively coupled contactless conductivity detection (Guadalupe et al. 2018). The separation of analytes can be achieved within 7 min with good resolution. The method behaved LOQs of 0.11 and 0.21 g kg^{-1}, as well as the recoveries varied from 88% to 94% and 86% to 102% for propionate and sorbate. The capillary electrophoresis method is appropriate for the analysis of inorganic and organic compounds that lack a strong chromophore group, such as propionate and sorbate.

Analysis of antioxidants

Food antioxidants are substances that can prevent or slow damage to food caused by free radicals and unstable molecules in food produces. Commonly, the antioxidants used in food produces include tocopherols (E306-309), propyl gallate (PG, E310), *tert*-butyl hydroquinone (TBHQ, E319), butylated hydroxyanisole (BHA, E320) and butylated hydroxytoluene (BHT, E321), which can prevent food from turning rancid and assure excellent quality and pleasant appearance, odor, and taste for the consumer (Figure 6). It has been reported that high doses of antioxidants like BHA and BHT do harmful effects on animals and may induce the promotion of cancer (Williams, Iatropoulos, and Whysner 1999). Thus, it is important to determine and quantify the unavoidable additives in food samples.

Most of the antioxidants possess phenolic hydroxyl group, which could act as an active electron donor to scavenge free radicals. Besides the GC-MS or LC-MS (Kibi et al. 2019), the food antioxidants can be electrochemical active and are easy to be determined by the electrochemical methods due to their specific structure. Moreover, from the constitute their excellent electrochemical properties in terms of high electron transfer rate for diverse redox systems, low noise and high sensitivity, these features have enabled expanding the application scope of electrochemical methods in antioxidants analysis. In this section, electrochemistry related methods will be introduced because they are more sensitive and more suitable for on-site analysis of antioxidants.

Tocopherols

Tocopherols are a kind of natural compounds in seed oils found to have vitamin E activity, which provide rich information about the identity and the quality of vegetable oils. Amongst, α-, γ- and δ-tocopherol usually serve as antioxidants and are widely used in foods. Particularly, it is of great value to analyze tocopherols for the quality control of edible oils and for oil admixtures verification (Lechner, Reiter, and Lorbeer 1999). Among various detection methods, the low cost, high sensitivity and simple operations of the electrochemical detection platform make it an attractive alternative to determine tocopherols.

For instance, Riman et al. proposed an electrochemical detector for HPLC by using the pencil graphite as disposable working electrode (Riman et al. 2019). The electrochemical detector in combination of HPLC exhibited nanomolar concentrations of tocopherols. The combined method was highly applicable to separate and detect the tocopherols, showing linear detection ranges of $0 \sim 500$ nM with LODs of 2.2, 1.2, 0.8 nM for α-, γ- and δ-tocopherol. Moreover, the proposed detector behaved excellent electrochemical performance identical to that of commercial UV-VIS HPLC detector. Similarly, Sýs et al. developed a new electrochemical method for the determination of the sum of tocopherols (Sýs et al. 2017). Based on extraction of tocopherols into glassy carbon paste electrode, the detection was conducted by square wave stripping voltammetry. Within 5 min and 15 min accumulation, the method showed different linear ranges of $0.5 \sim 40\ \mu M$ and $0.05 \sim 10\ \mu M$ as well as the LODs of 0.1 μM and 0.033 μM, respectively. The electrochemical method can be recommended as an alternative for analysis of the total quantity of tocopherols in food samples.

Propyl gallate

Propyl gallate (PG, E310) is widely employed in foodstuffs and plays an important role in preserving food products such as fried foods, edible fats and oils as a common antioxidant. However, it was reported that high doses of PG may cause potential health hazards such as apoptosis and DNA cleavage (Vikraman et al. 2013). The ADI recommended by JECFA is $0 \sim 1.4$ mg/kg body weight and the maximum level in food is 200 mg kg^{-1}. Therefore, it is of great importance to develop analytical methods for quantitative determination of PG.

For example, Wu et al. proposed an electrochemical biosensor for the simultaneous determination of BHA and PG in foodstuffs with well-defined oxidation peak at 624 and 655 mV (Wu et al. 2016). By modifying spiny Au-Pt nanotubes and horseradish peroxidase onto electrode, it behaved synergetic catalase-like activity toward BHA and PG. The method showed a wide linear range of $0.3 \sim 50$ mg L^{-1} and $0.1 \sim 100$ mg L^{-1} for BHA and PG with LODs of 0.046 mg L^{-1} and 0.024 mg L^{-1}. Moreover, BHA and PG were demonstrated by a simple visual detection method, which

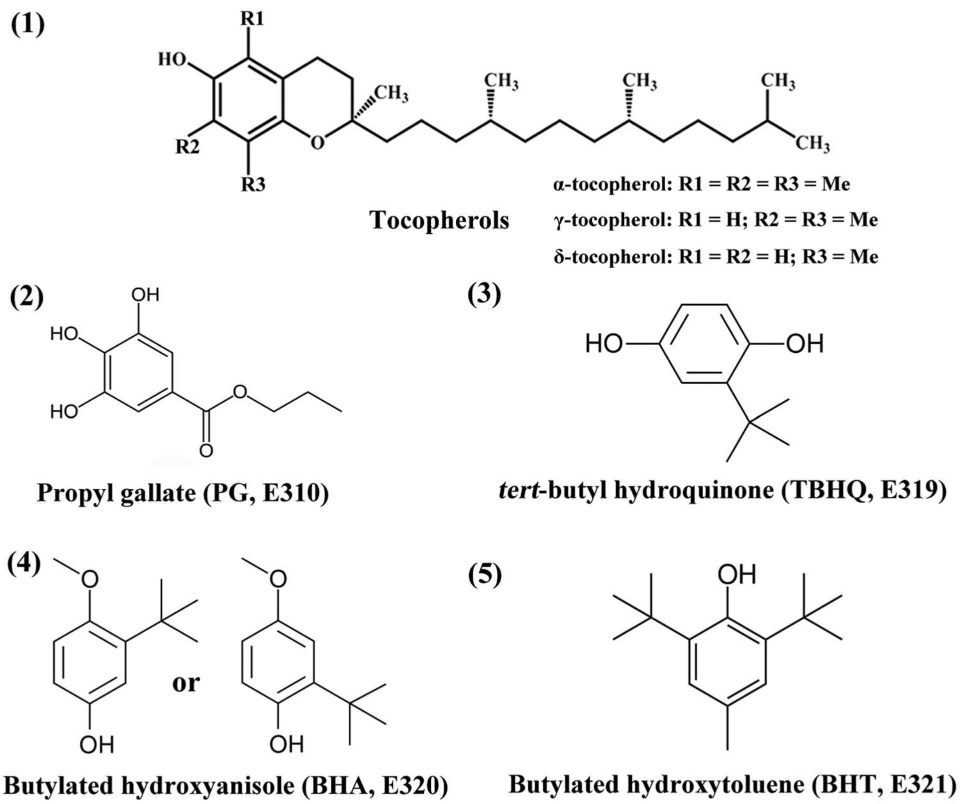

Figure 6. Chemical structures of food antioxidants (from **1** to **5**: α-, γ- and δ- tocopherol (E307-309), propyl gallate (PG, E310), *tert*-butyl hydroquinone (TBHQ, E319), butylated hydroxyanisole (BHA, E320) and butylated hydroxytoluene (BHT, E321)).

involved Au-Pt nanotubes as catalyst and TMB as indicator. Due to the strong oxidation resistance of BHA and PG, TMB could be less oxidized and result in the decrement of optical density. Both the electrochemical and visual detection methods revealed the rich electron in the structure of BHA and PG.

Using nickel nanoparticles modified electrode, Sivasankaran and Kumar developed an electrochemical sensor for the analysis of PG (Sivasankaran and Kumar 2019). Simply, nickel nanoparticles modified surface improved the oxidation peak current of PG molecules. The method could achieve two linear detection ranges for PG from 4.0×10^{-4} M to 1.0×10^{-3} M and from 2.0×10^{-6} to 3.0×10^{-4} M with the calculated LOD of 5.85×10^{-8} M. Finally, the method was verified by standard spectrophotometry for quantification of PG in spiked food samples. The electrochemical sensor behaved good selectivity, sensitivity and stability toward PG detection, which is helpful for regulating and reducing the risk of overuse of PG in foods.

Tert-butyl hydroquinone

Tert-butyl hydroquinone (TBHQ, E319) is known as an artificial antioxidant with two phenolic hydroxyl groups and a *tert*-butyl group. The chemical structure indicates the stability and strong oxidation resistance of TBHQ. Thus, TBHQ is widely adopted as an antioxidant in unsaturated vegetable oils and many edible animal fats. Study has shown that excessive use of TBHQ may do genotoxicity and carcinogenicity for man (Van Esch 1986). FDA sets a maximum limit for TBHQ of 200 mg/kg in foods and the limit of TBHQ in fats and oils is no more than 0.02%. Here, new developed electrochemical methods with simple operations and rapid detection will be introduced.

For example, Yue et al. developed an electrochemical sensor for selective detection of TBHQ by integrating molecularly imprinted polymer, PdAu nanoparticles and reduced graphene oxide together to form the sensing interface (Yue et al. 2019). The sensor showed favorable accuracy and satisfactory precision for the analysis of TBHQ, behaving the linear range of $0.5 \sim 60\,\text{mg L}^{-1}$ and a LOD of $0.046\,\text{mg L}^{-1}$. The detection results were further verified by HPLC with good recoveries ranging from 99.4 to 108.5% in spiked edible oil samples. Besides, Cao et al. designed a ratiometric electrochemical sensor for TBHQ detection based on MnO_2 and reduced graphene oxide (Cao et al. 2019). Wherein, MnO_2 acted as the inner reference electrochemical oxidation peak at 0.572 V, and the oxidation peak for TBHQ is about -0.06 V. The sensor showed two linear ranges of $1.0 \sim 50.0\,\mu\text{M}$ and $100.0 \sim 300.0\,\mu\text{M}$ with a LOD of $0.8\,\mu\text{M}$. The ratiometric method can avoid the interference of other antioxidants in matrix samples and achieve rapid and accurate detection of TBHQ in edible oil.

Butylated hydroxyanisole

Butylated hydroxyanisole (BHA, E320) consists of a mixture of two isomers, 2-*tert*-/3-*tert*-butyl-4-hydroxyanisole, which is widely used in fat, oil and emulsified fat products as an antioxidant. It was reported that BHA increased the incidences of hyperplasia of the forestomach, and the higher dose induced a significant increase in the incidence of papilloma and squamous cell carcinoma for rats (Ito et al. 1983). FDA suggests that the levels of BHA are limited to 2 ~ 1000 mg kg^{-1}. So, it is essential to develop simple and sensitive analytical methods for BHA.

Bavol et al. reported an electrochemical method for the simultaneous of BHA, PG and TBHQ using flow injection analysis coupled with multiple-pulse amperometry (Bavol et al. 2018). Without preliminary separation, the method could realize continuous application of three potential pulses at a single-injection step. As a result, it provided low LOQs of 0.85 μM, 1.45 μM, and 2.51 μM for BHA, PG and TBHQ, respectively. Aghdam et al. developed a new microfluidic-based method based on a miniaturized chemical analysis system for antioxidants detection in edible oils (Aghdam et al. 2019). The method showed recoveries of 93.2 ~ 102% and 95.4–97% for BHA in sunflower oil and olive oil. Without any pretreatment, the detection linear range for BHA was 10 ~ 100 μM and the LOD was 1.4 μM. Squissato et al. presented an effective voltammetry method for the direct detection of BHA, PG, TBHQ and BHT in biodiesel (Squissato, Richter, and Munoz 2019). In the work, partial least square regression was applied to resolve overlapped signals. Owing to the PLS approach, there is no need to modify electrode to achieve the separation of the peaks.

The above electrochemical methods, including can be easily applied in the detection of food samples without high demands on instrumentation, which showed great potential in food analysis when applying a simple extraction procedure or an analysis model.

Butylated hydroxytoluene

Butylated hydroxytoluene (BHT, E321) is another kind of synthetic phenolic antioxidant commonly applied in food and pharmaceutical industries. Usually, BHT is used in combination with BHA to enhance the antioxidant activity. Neverthless, long-term exposure to BHT will cause chronic poisoning, causing adverse effects like metabolic disorders (Branen 1975). The new developed detection of BHT mainly focused on all kinds of electrochemical methods.

For example, Emam et al. developed a molecularly imprinted electrochemical gas sensor to analyze BHT (Emam et al. 2018). The electrochemical sensor was constructed via three steps: (1) modify a thin layer of graphene onto the substrate, (2) facilitate polymer template and target molecule by electrochemical polymerization and (3) remove the target molecules to produce molecularly imprinted cavities. The method can achieve good sensitivity and selectivity for BHT with the LOD of 0.02 ppb. Karimi-Maleh et al. suggested a voltammetric method for the detection of ferulic acid and BHT (Karimi-Maleh et al. 2019). The strategy was based on the twofold modification of electrode, NiO-embedded single-wall carbon nanotube and *n*-methyl-3-butylimidazolium bromide. The method can resolve the oxidation signal of BHT with a LOD of 0.1 μM, which was favorable for the direct analysis of BHT in corn milk, wheat flour, and corn cider samples.

Other antioxidants

Other antioxidants like natural ones (tea polyphenols, ascorbic acid) and artificial ones (dodecyl gallate, octyl gallate) are also used in food stuffs. Due to the safety concerns, people are more favorable to natural antioxidants like ascorbic acid and tea polyphenols. The artificial ones are more likely to cause long-term toxicity for human health (Van der Heijden, Janssen, and Strik 1986). Therefore, many researchers showed intense attention on antioxidants analysis, especially for the synthetic ones.

Pedroso et al. proposed an electrochemical sensor for dodecyl gallate detection based on molecularly imprinted polymer film (Pedroso et al. 2017). Electropolymerized molecularly imprinted polymers (MIPs) were synthesized after modifying carbon nanotubes on electrode. Using square wave voltammetry, the sensor showed linear range from 0.50 to 8.0 nM with a LOD of 0.22 nM and a LOQ of 0.67 nM. In this work, carbon nanotubes increased the active surface area and enhance the electron transfer and the MIPs ensured the selectivity for the recognition of dodecyl gallate in complex matrix. Sivasankaran et al. fabricated a glassy carbon electrode chemically modified with gold nanoparticles for octyl gallate detection (Sivasankaran et al. 2016). By combining the advantages of gold nanoparticles and self-assembled monolayer of dodecane thiol, the sensitivity of the proposed method is largely improved. The method behaved a linear detection range of 1.2 ~ 0.2 μM and a LOD of 8.3 nM, which was demonstrated to be applicable in food samples such as margarine, butter and sunflower oil.

Analysis of sweeteners

Obesity epidemic is a global health problem which has caused wide attention recently, and low-calorie foods with sweet taste are favored by the individuals of all ages. Thus, low and no-calorie sweeteners with similar sweet taste as sugar has played a critical part in food industry. Wherein, artificial sweeteners like acesulfame (E950), aspartame (E951), cyclamate (E952), saccharin (E954), sucralose (E955) and neotame (E961) are non-caloric replacements used to enhance sweet tastes for food. However, the safety of artificial sweeteners has been controversial. Therefore, it is of great significance to develop new methods for artificial sweeteners analysis to control food quality and ensure consumer's health.

The sweeteners can be divided into three groups based on their different charging states in solution: positively charged (aspartame and neotame), negatively charged (acesulfame K and cyclamate Na), and uncharged (saccharin and sucralose) (Figure 7). Also, as the sweeteners show diversiform structures, various methods ranging from chromatography to electrochemical methods and then to optical methods have been proposed.

Acesulfame, cyclamate and saccharin

Acesulfame (E950), cyclamate (E952) and saccharin (E954) are often used in the form of sodium or calcium salt, which are non-glucose, low-calorie products with a highly sweet taste. Since they are chemically synthesized and they may create potential health risks, their presence in food will

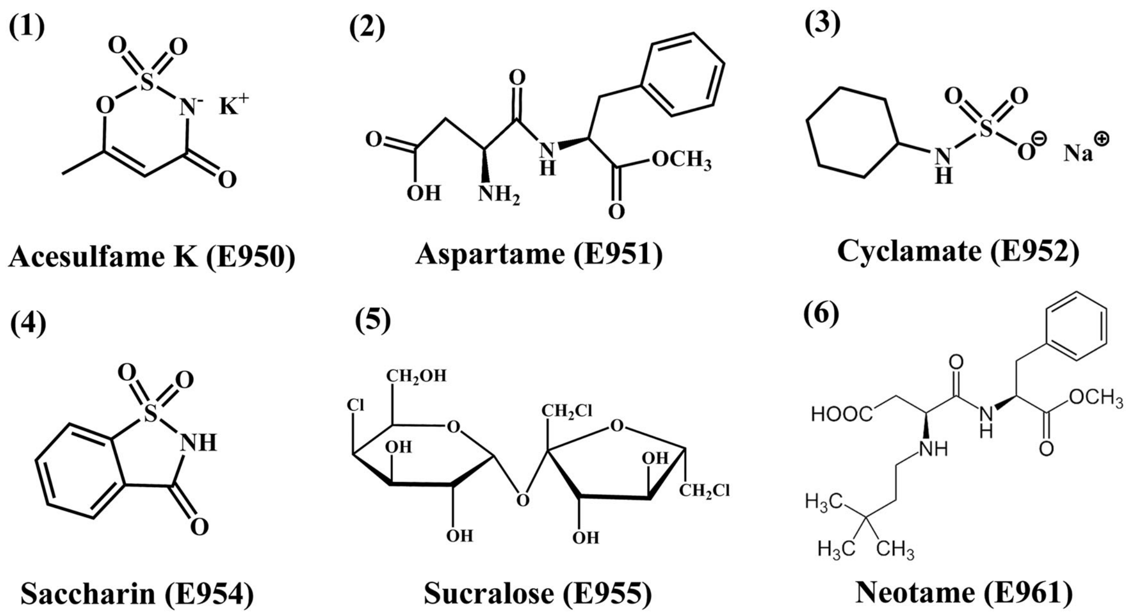

Figure 7. Chemical structures of sweeteners (from **1** to **6:** acesulfame K (E950), aspartame (E951), cyclamate (E952), saccharin (E954), sucralose (E955) and neotame (E961)).

cause consumers' mistrust. Consequently, many governments set maximum ADI value for acesulfame and saccharin. Therefore, it is encouraging to investigate the level of these sweeteners using effective methods.

Liu et al. proposed a sweetness sensor to detect the negatively charged sweeteners like acesulfame K (Liu et al. 2020). In the sensor, lipid polymer membranes act as the taste-sensing part, and the potential change in membrane caused by target adsorption was defined as outputs. The method can well predict acesulfame K in a concentration of $0.2 \sim 0.7$ mM with $R^2 = 0.99$ when coexist with salty substances, which suggested it was useful for the evaluation of acesulfame K food and beverages. Based on nanodiamond paste modified with 0.1 pM of α, β, and γ-cyclodextrin, Stefan-van Staden et al. designed three sensors for pattern recognition of aspartame, acesulfame K and cyclamate Na (Stefan-van Staden, Moscalu-Lungu, and van Staden 2019). Nanodiamond makes the sensor channel more stable than nano-graphite and the modified cyclodextrins give the selectivity of analytes. All the three targets can be detected at the $\sim$ pM levels with no sampling and fast screening, revealing the high sensitivity of the sensors in food samples. Besides, Seyinde et al. adopted a reverse phase HPLC method for quantitative determination of saccharin (Seyinde, Ejidike, and Ayejuyo 2019). This work simply reported the use of ahypersil C-18 column and an eluent consisting of 10% acetic acid in water. Based on the method. the saccharin content in beverages was found to be 1.23 ± 0.03 mg mL^{-1}, which showed acceptable analytical linearity, precision and accuracy.

Aspartame and neotame

Aspartame (E951) and neotame (E961) are two artificial sweeteners with similar chemical structures. Chemically, neotame owns a 3,3-dimethylbutyl group attached to the amino group of the aspartic acid portion of the molecule. However, it is used not as widely as aspartame in food products. Both of the two sweeteners remain safety controversy, and their safety has been studied extensively since their discovery with research that includes animal studies, clinical and epidemiological research (O'Donnell 2012). In this sense, it is relevant to develop new analytical methods to verify quality control and monitoring of these compounds in food matrixes.

For instance, Le et al. proposed the electrochemical oxidation of a binary mixture of caffeic acid (CAF) and aspartame (ASP) on preanodized screen-printed carbon electrodes to form copolymer of poly(CAF-ASP) (Le, Su, and Cheng 2019). Using the DPV method, the copolymer modified electrode was applied to ASP determination resulting with a linear range from 0.05 to 10 μM as well as a LOD of 0.0076 μM and a LOQ of 0.0256 μM. The proposed electrochemical platform showed easy operations in analyzing ASP in drink samples, offering potential applications in the food industry. Bathinapatla et al. presented a highly sensitive electrochemical sensor for the detection of neotame using DPV with a modified glassy carbon electrode (Bathinapatla et al. 2015). By fabricating the electrode with copper nanoparticles decorated multiwalled carbon nanotubes, it behaved an obvious oxidation peak of neotame at a potential of 1.3 V. The peak currents of DPV plots showed a linear ranged from 0.05 to 2.0 mM for the detection of neotame. The detection results in food samples were verified by capillary electrophoresis method with a 96% confidence level, revealing that it is a promising alternative in analysis of sweeteners.

Sucralose

Sucralose (E955) is an artificial sweetener and a kind of commonly used sugar substitute, which is used as a replacement for, or in combination with other artificial like aspartame and acesulfame potassium. Usually, sucralose is applied in products such as candy, breakfast bars and soft drinks.

Despite being generally recognized as safe by regulatory agencies including the FDA and the Joint FAO/WHO Expert Committee Report on Food Additives, based on information from clinical studies, high doses of sucralose could do effects on various organs but on illnesses such as obesity, diabetes, and cancer remain yet-unknown (Rodero, de Souza Rodero, and Azoubel 2009). Therefore, it is necessary to analyze the content of sucralose to control the food quality.

Voss et al. described a silylation derivatization method and gas chromatography mass spectrometry (GC-MS) for detection of sucralose in groundwater samples (Voss, Newman, and Miller-Schulze 2019). In the work, a deuterium-labeled internal standard was employed to account for reaction and sample processing imprecision. As such, this proposed method is robust for sucralose analysis with the LOD of 21.8 ng L^{-1}. The quality control measures are competitive with previously published methods such as GC-MS, HPLC-MS/MS for the quantification of sucralose by derivatization. Encouragingly, Heider et al. reported a service-learning approach related with analytical techniques to allow students to learn analytical skills toward sucralose in water (Heider et al. 2018). As sucralose neither absorb light in the visible or UV region, nor electrochemically active or photoluminesce, and the water matrix precludes the use of infrared spectroscopy due to water interferes in the OH region. Students finally chose reversed-phase liquid chromatography with mass spectrometry to measure sucralose. From this point, the analytical skills from the molecular structure to the properties and to the techniques are thirstily required to design a method for the analysis of food additives.

Analysis of other food additives

Together with the food additives discussed above, other additives are commonly detected include emulsifiers, stabilizers, flavor enhancers and so forth. Amongst, the favored detection methods are chromatography, spectrophotometry, electrophoresis, optical and electrochemical methods. Based on the differences in the structure and property of food additives, they are often analyzed by the fitting technique or their coupled ones to achieve the best results.

For example, Oellig et al. presented a high-performance thin-layer chromatography method coupled with fluorescence detection for the detection of acetic acid esters (E472a), lactic acid esters (E472b), citric acid esters (E472c), and mono- and diacetyl tartaric acid esters (E472e) (Oellig, Link, and Schwack 2020). Under UV 366 nm, direct visual comparison of the emulsifier pattern was obtained, which can be developed for sensitive and selective screening of E472. The visual fingerprint was demonstrated to be very valuable and suitable for a fast and simple quality control of emulsifier in food samples. Using Fourier transform infrared spectroscopy (FTIR), Clarke developed a new method to measure sodium alginate in fish meat products (Clarke 2017). After drying and extracting the sample, FTIR was adopted to directly quantify the amount of sodium alginate with partial least squares (PLS) and principal component analysis (PCA) models. The results reveal that FTIR can be applied for the rapid detection of sodium alginate in fish and other meat products. Devi et al. reported an amperometric immunosensor for the detection of monosodium glutamate based on Au@MoS_2/chitosan nanocomposites modified electrode (Devi et al. 2019). In the method, the nanocomposites acted as a conductive matrix and the anti-glutamate antibody was immobilized on to its surface to discern the glutamate. It showed a detection range of $0.05 \sim 200\ \mu M$ with the LOD and LOQ of 0.03 and 0.1 μM. By combining amperometric method with immunoassay, the sensor behaved satisfactory selectivity, reproducibility and stability.

Many methods have been explored to determine food additives with the prospect of good selectivity, sensitivity and stability (Jiang et al. 2019; Nair et al. 2020; Xie et al. 2019). However, most of them may suffer from the weakness like time-consuming, complex pretreatment, complicated operations and high cost. It seems that high analytical performance (e.g. sensitivity and stability) will make other performance such as convenience and low cost compromised. To compare the performance of analytical methods in food additive analysis, Table 3 summarized the detection parameters such as linear range, limit of detection (LOD) and limit of quantification (LOQ), as well as their advantages and disadvantages.

Prospects and challenges

With the development of novel materials, especially the functional nanomaterials, the performance of analytical techniques has been greatly improved. As we discussed above, all the analytical methods showed remarkable advancement in the analysis of food additives. However, there are still many remaining challenges to be solved such as complex sample pretreatment, high-cost, time-consuming and tedious operations and relatively low detection efficiency. For the food additives, the complexity may come from three aspects: (a) a large variety of food additives make them complex; (b) various foods using food additives make the matrices complex; (c) the similar structures of food additive make them complex to be identified specifically. The limitations of analytical techniques are dependent on detection principles themselves and could be greatly influenced by the performance of materials. Thus, it is an effective means to develop methodology and new functional materials to improve the technique performance.

For example, to meet the challenges of detection accuracy, most commonly used techniques like mechanical, microwave and thermal approach are applied to extract the analytes and minimize interferences from food samples. Those careful processing procedures will inevitably include laborious and time-consuming operations, which seems to be contradictory to the convenience of analytical methods. However, if we analyze the food additives starting from their structure, they may fall into an optimal detection method. Like this, a certain food additive such as sucralose is neither optically nor electrochemically active, and its structure

Table 3. Comparison of analytical methods for food additives detection (not given: —).

Methods	Food additives	Advantage	Disadvantage	References	Examples	Performance Linear range:	LOD	LOQ
HPLC	preservative	Good selectivity, high sensitivity, recovery and reproducibility	Expensive equipment, high cost of inspection, long cycle and inability to meet batch inspection	Timofeeva et al. (2019)	benzoic acids	linear range: 0.1–150 mgL^{-1} (correlation coefficient: 0.998)	0.03 mgL^{-1}	0.1 mgL^{-1}
					sorbic acids	linear range: 0.05–100mgL^{-1} (correlation coefficient: 0.998)	0.02 mgL^{-1}	0.05 mgL^{-1}
	sweeteners			————————				
	antioxidant			Riman et al. (2019)	Gentisic acids	linear range: $1 \sim 1000 nmolL^{-1}$ (correlation coefficient: 0.999)	0.4 $nmolL^{-1}$	1.3$nmolL^{-1}$
					Caffeic acids	linear range: $3 \sim 1000 nmolL^{-1}$ (correlation coefficient: 0.999)	1.1 $nmolL^{-1}$	3.6 $nmolL^{-1}$
					Dihydrocaffeic acids	linear range: $1 \sim 1000 nmolL^{-1}$ (correlation coefficient: 0.999)	0.4 $nmolL^{-1}$	1.4 $nmolL^{-1}$
GC-MS or LC-MS	sweeteners	Rapid, sensitive and accurate in quantification	Cumbersome, expensive, time-consuming, and need to be completed in lab	Voss, Newman, and Miller-Schulze (2019)	Sucralose	linear range: $99 \sim 2004 ngL^{-1}$	0.8ngL^{-1}	$0.7 \sim 1.9 ngL^{-1}$
	antioxidant			Kibi et al. (2019)Kivilompolo, Obůrka, and Hyötyläinen (2007)	phenolic antioxidants (GC-MS)	linear range: Good	$10 \sim 80\ \mu gL^{-1}$	———————
Spectrometry	colorants	High sensitivity, wide linear range, fast and convenient, suitable for on-site detection, less sample consumption	Expensive, lack of stability, require sample database.	Ntrallou, Gika, and Tsochatzis (2020)	Amaranth, ponceau 4R, sunset yellow, tartrazine, brilliant blue	————————	0.2–6.0 mgL^{-1}	———————
	preservative			————————				
	antioxidant			————————				
Capillary electrophoresis	preservative	Simple, rapid, low cost and less sample consumption	Relative low sensitivity and reproducibility	Lin, Hsu, and Fuh (2019)	NO2-(3 days)	Accuracy: $98.17 \sim 101.26\%$	0.06mgL^{-1}	0.17 mgL^{-1}
					NO3-(3 days)	Accuracy: $96.00 \sim 101.22\%$	0.05mgL^{-1}	0.16 mgL^{-1}
	sweeteners			————————				
Electrochemical method	colorants	Simple, require low volume samples, high sensitivity, low detection limit, strong anti-interference ability and high recovery rate	Relative low reproducibility and selectivity, short working life, the electrode and electrolyte are difficult to reuse.	Sierra-Rosales, Toledo-Neira, and Squella (2017)	Tartrazine	Sensitivity: 3.5$\mu A\mu molL^{-1}$	0.22$\mu molL^{-1}$	———————
					Sunset yellow	Sensitivity: 3.9 $\mu A\mu molL^{-1}$	0.12$\mu molL^{-1}$	———————
					Carmoisine	Sensitivity: 4.1 $\mu A\mu molL^{-1}$	0.11$\mu molL^{-1}$	———————
	preservative			————————				
	sweeteners			————————				
	antioxidant			————————				
ELISA	colorants	Simple operations, low cost, high sensitivity, fast and convenient.	Tedious procedures, relative low reproducibility, require antibody, and easy to be interfered by matrix.	Ntrallou, Gika, and Tsochatzis (2020)	Sudan I	————————	0.07 μgL^{-1}	———————
Surface-enhanced Raman scattering	colorants	Rapid, sensitive and simple, rapid response, low volume samples and on-site detection	Lack of stability, require either complex data processing or high-quality SERS substrate	Ntrallou, Gika, and Tsochatzis (2020)	Tartrazine, sunset yellow, brilliant Blue, acid red	————————	0.1 μgL^{-1}	———————
	sweeteners			————————				

contains rich hydroxyl groups with strong polarity. So, it may be not appropriate for optical and electrochemical methods, but the chromatography method with derivative materials is favorable for the substance. From this aspect, how to choose right method with proper functional materials for additives detection is equally important as developing new methods.

Besides, researchers have been paying increasing attention on addressing the limitations of analytical methods. By designing different strategies, analytical performances have been improved in terms of sensitivity, stability, accuracy and selectivity. For example, traditional Raman scattering is a typical optical detection method with low signal response. However, the signal intensity of Raman scattering can be greatly enhanced ($\sim 10^6$ fold) with the aid of noble metal nanomaterials like nanosilver or nanogold. The improved Raman scattering is called surface enhanced Raman scattering (SERS), which is a very popular method in food analysis due to its high robustness. Further, by combining mathematical algorithms, SERS can achieve the multicomponent detection for additives, which make the analysis simpler and more convenient. Moreover, the SERS technique can also couple with other detection methods like electrochemistry, immunoassay and microscopy to meet the specific requirements for the analysis of food additives. Hence, it is another way to strengthen the analytical performance by combining with other methods.

World Health Organization outlined an "ASSURED" criteria of "(i) Affordable, (ii) Sensitive, (iii) Specific, (iv) User-friendly, (v) Rapid and robust, (vi) Equipment-free, and (vii) Deliverable to users who need them" for point of need devices (Urdea et al. 2006). Wherein, a variety of analytical methods trend to miniaturization, integration, automation and intelligence. Theoretically, microsystems behave high efficiency, fast analysis time and low reagent consumption on separation. Thus, miniaturization and integration of already existing techniques is an alternative to the traditional techniques. Also, it is believed that the combination with effective pretreatment techniques with new analytical techniques can develop automatic and intelligent sensing techniques, which predicts a development direction of intelligent sensor to integrate artificial intelligence with sensors. While such ideas promise the application of those techniques in resource-limited field like medical treatment for extreme POC, these requirements and tactics are very important for developing analytical platforms in food additives. Only all the relevant techniques work together with the structures of analytes, can it be possible to develop more efficient methods to analyze food additives.

Disclosure statement

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References

Abdel-Moemin, A. R., J. M. Regenstein, and M. K. Abdel-Rahman. 2018. New Food Products for Sensory-Compromised Situations. *Comprehensive Reviews in Food Science and Food Safety* 17 (6):1625–39. doi: 10.1111/1541-4337.12399.

Abid, M., H. Yaich, H. Hidouri, H. Attia, and M. A. Ayadi. 2018. Effect of substituted gelling agents from pomegranate peel on colour, textural and sensory properties of pomegranate jam. *Food Chemistry* 239:1047–54. doi: 10.1016/j.foodchem.2017.07.006.

Aghdam, A. A., M. R. Majidi, H. Veladi, and Y. Omidi. 2019. Microfluidic-based separation and detection of synthetic antioxidants by integrated gold electrodes followed by HPLC-DAD. *Microchemical Journal* 149:104059. doi: 10.1016/j.microc.2019.104059.

Ai, Y.-J., P. Liang, Y.-X. Wu, Q.-M. Dong, J.-B. Li, Y. Bai, B.-J. Xu, Z. Yu, and D. Ni. 2018. Rapid qualitative and quantitative determination of food colorants by both Raman spectra and Surface-enhanced Raman Scattering (SERS). *Food Chemistry* 241:427–33. doi: 10.1016/j.foodchem.2017.09.019.

Amchova, P., H. Kotolova, and J. Ruda-Kucerova. 2015. Health safety issues of synthetic food colorants. *Regulatory Toxicology and Pharmacology : RTP* 73 (3):914–22. doi: 10.1016/j.yrtph.2015.09.026.

Anand, S. P., and N. Sati. 2013. Artificial preservatives and their harmful effects: Looking toward nature for safer alternatives. *International Journal of Pharmaceutical Sciences and Research* 4 (7):2496.

Anderson, D. M. W. 1986. Evidence for the safety of gum arabic (Acacia senegal (L.) Willd.) as a food additive-a brief review. *Food Additives and Contaminants* 3 (3):225–30. doi: 10.1080/02652038609373584.

Antczak-Chrobot, A., P. Bąk, and M. Wojtczak. 2018. The use of ionic chromatography in determining the contamination of sugar by-products by nitrite and nitrate. *Food Chemistry* 240:648–54. doi: 10.1016/j.foodchem.2017.07.158.

Bathinapatla, A., S. Kanchi, P. Singh, M. I. Sabela, and K. Bisetty. 2015. Fabrication of copper nanoparticles decorated multiwalled carbon nanotubes as a high performance electrochemical sensor for the detection of neotame. *Biosensors & Bioelectronics* 67:200–7. doi: 10.1016/j.bios.2014.08.017.

Bavol, D., A. Economou, J. Zima, J. Barek, and H. Dejmkova. 2018. Simultaneous determination of tert-butylhydroquinone, propyl gallate, and butylated hydroxyanisole by flow-injection analysis with multiple-pulse amperometric detection. *Talanta* 178:231–6. doi: 10.1016/j.talanta.2017.09.032.

Becerra-Herrera, M., V. Miranda, D. Arismendi, and P. Richter. 2018. Chemometric optimization of the extraction and derivatization of parabens for their determination in water samples by rotating-disk sorptive extraction and gas chromatography mass spectrometry. *Talanta* 176:551–7. doi: 10.1016/j.talanta.2017.08.071.

Branen, A. L. 1975. Toxicology and biochemistry of butylated hydroxyanisole and butylated hydroxytoluene. *Journal of the American Oil Chemists' Society* 52 (2):59. doi: 10.1007/BF02901825.

Cao, W., Y. Wang, Q. Zhuang, L. Wang, and Y. Ni. 2019. Developing an electrochemical sensor for the detection of tert-butylhydroquinone. *Sensors and Actuators B: Chemical* 293:321–8. doi: 10.1016/j.snb.2019.05.012.

Carocho, M., M. F. Barreiro, P. Morales, and I. C. Ferreira. 2014. Adding molecules to food, pros and cons: A review on synthetic and natural food additives. *Comprehensive Reviews in Food Science and Food Safety* 13 (4):377–99. doi: 10.1111/1541-4337.12065.

Carocho, M., and I. C. Ferreira. 2013. A review on antioxidants, prooxidants and related controversy: Natural and synthetic compounds, screening and analysis methodologies and future perspectives. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 51:15–25. doi: 10.1016/j.fct.2012.09.021.

Carocho, M., P. Morales, and I. C. Ferreira. 2015. Natural food additives: Quo vadis? *Trends in Food Science & Technology* 45 (2):284–95. doi: 10.1016/j.tifs.2015.06.007.

Carocho, M., P. Morales, and I. C. Ferreira. 2018. Antioxidants: Reviewing the chemistry, food applications, legislation and role as preservatives. *Trends in Food Science & Technology* 71:107–20. doi: 10.1016/j.tifs.2017.11.008.

Chen, H.-C., C.-H. Chen, C.-S. Hsu, T.-L. Chen, M.-Y. Liao, C.-C. Wang, C.-F. Tsai, and H. M. Chen. 2018. In situ creation of surface-enhanced raman scattering active Au-AuO x nanostructures through electrochemical process for pigment detection. *ACS Omega* 3 (12):16576–84. doi: 10.1021/acsomega.8b02677.

Clarke, A. D. 2017. Measurement of total sodium alginate in restructured fish products using fourier transform infrared spectroscopy. *EC Nutrition* 11:33–45.

Codex Alimentarius Commission. 1989. Class names and the international numbering system for food additives. *CAC/GL* :36–1989.

Coultate, T., and R. S. Blackburn. 2018. Food colorants: Their past, present and future. *Coloration Technology* 134 (3):165–86. doi: 10.1111/cote.12334.

de Jesus, F. F. S., A. G. Coelho, L. de Assis Pallos, J. A. F. da Silva, D. Daniel, and D. P. de Jesus. 2018. Simple and fast method for simultaneous determination of propionate and sorbate in bread by capillary electrophoresis with UV spectrophotometric detection. *Journal of Food Composition and Analysis* 72:93–6. doi: 10.1016/j.jfca.2018.06.010.

de Lima, L. F., C. C. Maciel, A. L. Ferreira, J. C. de Almeida, and M. Ferreira. 2019. Nickel (II) phthalocyanine-tetrasulfonic-Au nanoparticles nanocomposite film for tartrazine electrochemical sensing. *Materials Letters 262*:127186.

Deroco, P. B., R. A. Medeiros, R. C. Rocha-Filho, and O. Fatibello-Filho. 2018. Selective and simultaneous determination of indigo carmine and allura red in candy samples at the nano-concentration range by flow injection analysis with multiple pulse amperometric detection. *Food Chemistry* 247:66–72. doi: 10.1016/j.foodchem.2017.12.006.

Devi, R., S. Gogoi, S. Barua, H. S. Dutta, M. Bordoloi, and R. Khan. 2019. Electrochemical detection of monosodium glutamate in foodstuffs based on Au@MoS2/chitosan modified glassy carbon electrode. *Food Chemistry* 276:350–7. doi: 10.1016/j.foodchem.2018.10.024.

Elekima, I., O. E. Nwachuku, D. Ukwukwu, H. U. Nwanjo, and N. Nduka. 2019. Biochemical and histological changes associated with azo food dye (Tartrazine) in male albino rats. *Asian Journal of Research in Biochemistry 5*:1–14. doi: 10.9734/ajrb/2019/v5i130083.

Emam, S., A. Adedoyin, X. Geng, M. Zaeimbashi, J. Adams, A. Ekenseair, E. Podlaha-Murphy, and N. X. Sun. 2018. A molecularly imprinted electrochemical gas sensor to sense butylated hydroxytoluene in air. *Journal of Sensors* 2018:1–9. doi: 10.1155/2018/3437149.

Europe Food Safety Authority (EFSA). 2014. Scientific opinion on the re-evaluation of indigo carmine (E 132) as a food additive. *EFSA. Journal* 12 (7:3768):1–57.

Guadalupe, C., A. F. Fernanda Souza de Jesus, L. de Assis Pallos, J. Alberto Fracassi da Silva, and D. Pereira de Jesus. 2018. Capillary electrophoresis with capacitively coupled contactless conductivity detection for the determination of propionate and sorbate in bread. *Journal of Separation Science* 41 (20):3932–7. doi: 10.1002/jssc.201800705.

Heider, E. C., D. Valenti, R. L. Long, A. Garbou, M. Rex, and J. K. Harper. 2018. Quantifying sucralose in a water-treatment wetlands: Service-learning in the analytical chemistry laboratory. *Journal of Chemical Education* 95 (4):535–42. doi: 10.1021/acs.jchemed.7b00490.

He, Q., J. Liu, X. Liu, G. Li, P. Deng, and J. Liang. 2018b. Manganese dioxide Nanorods/electrochemically reduced graphene oxide nanocomposites modified electrodes for cost-effective and ultrasensitive detection of Amaranth. *Colloids and Surfaces. B, Biointerfaces* 172:565–72. doi: 10.1016/j.colsurfb.2018.09.005.

He, Q., J. Liu, X. Liu, G. Li, P. Deng, J. Liang, and D. Chen. 2018a. Sensitive and selective detection of tartrazine based on TiO_2-electrochemically reduced graphene oxide composite-modified electrodes. *Sensors* 18 (6):1911. doi: 10.3390/s18061911.

Ishidate, M., Jr, T. Sofuni, K. Yoshikawa, M. Hayashi, T. Nohmi, M. Sawada, and A. Matsuoka. 1984. Primary mutagenicity screening of food additives currently used in Japan. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 22 (8):623–36. doi: 10.1016/0278-6915(84)90271-0.

Ito, N., S. Fukushima, A. Hagiwara, M. Shibata, and T. Ogiso. 1983. Carcinogenicity of butylated hydroxyanisole in F344 rats. *Journal of the National Cancer Institute* 70 (2):343–52.

Jagne, J., D. White, and F. Jefferson. 2016. Endocrine-disrupting chemicals: Adverse effects of bisphenol A and parabens to women's health. *Water, Air, & Soil Pollution* 227 (6):182. doi: 10.1007/s11270-016-2785-3.

Javanmardi, F., J. Rahmani, F. Ghiasi, H. Hashemi Gahruie, and A. Mousavi Khaneghah. 2019. The Association between the Preservative Agents in Foods and the Risk of Breast Cancer. *Nutrition and Cancer* 71 (8):1229–40. doi:10.1080/01635581.2019.1608266. PMC:31044613

Jiang, K., D. Nie, Q. Huang, K. Fan, Z. Tang, Y. Wu, and Z. Han. 2019. Thin-layer MoS_2 and thionin composite-based electrochemical sensing platform for rapid and sensitive detection of zearalenone in human biofluids. *Biosensors & Bioelectronics* 130:322–9. doi: 10.1016/j.bios.2019.02.003.

Joshi, V., and K. Pancharatna. 2019. Food colorant Sunset Yellow (E110) intervenes developmental profile of zebrafish (Danio rerio). *Journal of Applied Toxicology: JAT* 39 (4):571–81. doi: 10.1002/jat.3747.

Karimi-Maleh, H., R. Farahmandfar, R. Hosseinpour, J. Alizadeh, and A. Abbaspourrad. 2019. Determination of ferulic acid in the presence of butylated hydroxytoluene as two phenolic antioxidants using a highly conductive food nanostructure electrochemical sensor. *Chemical Papers* 73 (10):2441–7. doi:10.1007/s11696-019-00793-y.

Kibi, M., S. Nishiumi, T. Kobayashi, Y. Kodama, and M. Yoshida. 2019. GC/MS and LC/MS-based tissue metabolomic analysis detected increased levels of antioxidant metabolites in colorectal cancer. *Kobe Journal of Medical Sciences* 65 (1):E19.

Kivilompolo, M., V. Obůrka, and T. Hyötyläinen. 2007. Comparison of GC–MS and LC–MS methods for the analysis of antioxidant phenolic acids in herbs. *Analytical and Bioanalytical Chemistry* 388 (4):881–7. doi: 10.1007/s00216-007-1298-8.

Le, A. V., Y. L. Su, and S. H. Cheng. 2019. A novel electrochemical assay for aspartame determination via nucleophilic reactions with caffeic acid ortho-quinone. *Electrochimica Acta* 300:67–76. doi: 10.1016/j.electacta.2019.01.020.

Lechner, M., B. Reiter, and E. Lorbeer. 1999. Determination of tocopherols and sterols in vegetable oils by solid-phase extraction and subsequent capillary gas chromatographic analysis. *Journal of Chromatography. A* 857 (1–2):231–8. doi: 10.1016/s0021-9673(99)00751-7.

Lin, S. L., J. W. Hsu, and M. R. Fuh. 2019. Simultaneous determination of nitrate and nitrite in vegetables by poly (vinylimidazole-co-ethylene dimethacrylate) monolithic capillary liquid chromatography with UV detection. *Talanta* 205:120082. doi: 10.1016/j.talanta.2019.06.082.

Lipskikh, O. I., E. I. Korotkova, Y. P. Khristunova, J. Barek, and B. Kratochvil. 2018. Sensors for voltammetric determination of food azo dyes-A critical review. *Electrochimica Acta* 260:974–85. doi: 10.1016/j.electacta.2017.12.027.

Liu, L., Z. Mi, H. Li, C. Li, Q. Hu, and F. Feng. 2019. Highly selective and sensitive detection of amaranth by using carbon dots-based nanosensor. *RSC Advances* 9 (45):26315–20. doi: 10.1039/C9RA04494A.

Liu, C. C., Y. N. Wang, L. M. Fu, and K. L. Chen. 2018. Microfluidic paper-based chip platform for benzoic acid detection in food. *Food Chemistry* 249:162–7. doi: 10.1016/j.foodchem.2018.01.004.

Liu, Y., X. Wu, Y. Tahara, H. Ikezaki, and K. Toko. 2020. A quantitative method for Acesulfame K using the taste sensor. *Sensors* 20 (2): 400. doi: 10.3390/s20020400.

Li, Q., J. Yang, X. Tan, Z. Zhang, X. Hu, and M. Yang. 2016. A simple and rapid resonance Rayleigh scattering method for detection of indigo carmine in soft drink. *Luminescence: The Journal of Biological and Chemical Luminescence* 31 (5):1152–7. doi: 10.1002/bio.3085.

Li, L., H. Zheng, L. Guo, L. Qu, and L. Yu. 2019a. Construction of novel electrochemical sensors based on bimetallic nanoparticle functionalized graphene for determination of sunset yellow in soft drink. *Journal of Electroanalytical Chemistry* 833:393–400. doi: 10.1016/j.jelechem.2018.11.059.

Li, L., H. Zheng, L. Guo, L. Qu, and L. Yu. 2019b. A sensitive and selective molecularly imprinted electrochemical sensor based on Pd-Cu bimetallic alloy functionalized graphene for detection of amaranth in soft drink. *Talanta* 197:68–76. doi: 10.1016/j.talanta.2019.01.009.

Lorenzo, J. M., M. Pateiro, R. Domínguez, F. J. Barba, P. Putnik, D. B. Kovačević, A. Shpigelman, D. Granato, and D. Franco. 2018. Berries extracts as natural antioxidants in meat products: A review. *Food Research International (Ottawa, ON)* 106:1095–104. doi: 10.1016/j.foodres.2017.12.005.

Manjunatha, J. G. G. 2018. A novel poly (glycine) biosensor towards the detection of indigo carmine: A voltammetric study. *Journal of Food and Drug Analysis* 26 (1):292–9. doi: 10.1016/j.jfda.2017.05.002.

Martyn, D., M. Darch, A. Roberts, H. Y. Lee, T. Yaqiong Tian, N. Kaburagi, and P. Belmar. 2018. Low-/no-calorie sweeteners: A review of global intakes. *Nutrients* 10 (3):357. doi: 10.3390/nu10030357.

McClements, D. J., and S. M. Jafari. 2018. Improving emulsion formation, stability and performance using mixed emulsifiers: A review. *Advances in Colloid and Interface Science* 251:55–79. doi: 10.1016/j.cis.2017.12.001.

Meher, A. K., N. Labhsetwar, and A. Bansiwal. 2018. An improved method for direct estimation of free cyanide in drinking water by ion chromatography-pulsed amperometry detection (IC-PAD) on gold working electrode. *Food Chemistry* 240:131–8. doi: 10.1016/j.foodchem.2017.07.041.

Nair, M. S., D. V. Nair, A. K. Johny, and K. Venkitanarayanan. 2020. Use of food preservatives and additives in meat and their detection techniques. In *Meat quality analysis*, 187–213. UK: Elsevier Science.

Nguyen, T. H., and A. L. Waterhouse. 2019. A production-accessible method: Spectrophotometric iron speciation in wine using ferrozine and ethylenediaminetetraacetic acid. *Journal of Agricultural and Food Chemistry* 67 (2):680–7. doi: 10.1021/acs.jafc.8b04497.

Ntrallou, K., H. Gika, and E. Tsochatzis. 2020. Analytical and sample preparation techniques for the determination of food colorants in food matrices. *Foods* 9 (1):58. doi: 10.3390/foods9010058.

O'Donnell, K. 2012. Aspartame, neotame and advantame. In *Sweeteners and Sugar Alternatives in Food Technology*, 117–36.

Oellig, C., K. Link, and W. Schwack. 2020. Characterization of E 472 food emulsifiers by high-performance thin-layer chromatography with fluorescence detection and mass spectrometry. *Journal of Chromatography A* 1618:460874. doi: 10.1016/j.chroma.2020.460874.

Oplatowska-Stachowiak, M, and C. T. Elliott. 2017. Food colors: Existing and emerging food safety concerns. *Critical Reviews in Food Science and Nutrition* 57 (3):524–48. doi:10.1080/10408398.2014.889652.

Ou, Y., X. Wang, K. Lai, Y. Huang, B. A. Rasco, and Y. Fan. 2018. Gold nanorods as surface-enhanced Raman spectroscopy substrates for rapid and sensitive analysis of allura red and sunset yellow in beverages. *Journal of Agricultural and Food Chemistry* 66 (11): 2954–61. doi: 10.1021/acs.jafc.8b00007.

Öztekin, N. 2018. Simultaneous determination of benzoic acid and sorbic acid in food products by capillary electrophoresis. *Food and Health* 4 (3):176–82.

Papetti, A., and R. Colombo. 2019. High-performance capillary electrophoresis for food quality evaluation. In *Evaluation technologies for food quality*, 301–77. Cambridge, UK: Elsevier.

Parthasarathy, D. K., and N. S. Bryan. 2012. Sodium nitrite: The "cure" for nitric oxide insufficiency. *Meat Science* 92 (3):274–9. doi: 10.1016/j.meatsci.2012.03.001.

Pedroso, M. M., M. V. Foguel, D. H. S. Silva, M. D. P. T. Sotomayor, and H. Yamanaka. 2017. Electrochemical sensor for dodecyl gallate determination based on electropolymerized molecularly imprinted polymer. *Sensors and Actuators B: Chemical* 253:180–6. doi: 10.1016/j.snb.2017.06.127.

Piri, S., F. Piri, M. R. Yaftian, and A. Zamani. 2018. Imprinted Azorubine electrochemical sensor based upon composition of MnO_2 and 1-naphthylamine on graphite nanopowder. *Journal of the Iranian Chemical Society* 15 (12):2713–20. doi: 10.1007/s13738-018-1459-z.

Poms, R. E., C. L. Klein, and E. Anklam. 2004. Methods for allergen analysis in food: A review. *Food Additives and Contaminants* 21 (1): 1–31. doi: 10.1080/02652030310001620423.

Riman, D., M. I. Prodromidis, D. Jirovsky, and J. Hrbac. 2019. Low-cost pencil graphite-based electrochemical detector for HPLC with near-coulometric efficiency. *Sensors and Actuators B: Chemical* 296: 126618. doi: 10.1016/j.snb.2019.05.095.

Roca-Saavedra, P., V. Mendez-Vilabrille, J. M. Miranda, C. Nebot, A. Cardelle-Cobas, C. M. Franco, and A. Cepeda. 2018. Food additives, contaminants and other minor components: Effects on human gut microbiota-a review. *Journal of Physiology and Biochemistry* 74 (1): 69–83. doi: 10.1007/s13105-017-0564-2.

Rodero, A. B., L. de Souza Rodero, and R. Azoubel. 2009. Toxicity of Sucralose in Humans: A Review. *International Journal of Morphology* 27 (1): 239–244. doi: 10.4067/S0717-95022009000100040.

Seyinde, D. O., I. P. Ejidike, and S. Ayejuyo. 2019. HPLC determination of benzoic acid, saccharin, and caffeine in carbonated soft drinks. *International Journal of ChemTech Research* 12 (4):15–23. doi: 10.20902/IJCTR.2019.120403.

Sierra-Rosales, P., C. Toledo-Neira, and J. A. Squella. 2017. Electrochemical determination of food colorants in soft drinks using MWCNT-modified GCEs. *Sensors and Actuators B: Chemical* 240: 1257–64. doi: 10.1016/j.snb.2016.08.135.

Silva, T. A., A. Wong, and O. Fatibello-Filho. 2019. Electrochemical sensor based on ionic liquid and carbon black for voltammetric determination of Allura red colorant at nanomolar levels in soft drink powders. *Talanta* 209: 120588.

Sivasankaran, U., and K. G. Kumar. 2019. Communication—Electrochemical sensing of synthetic antioxidant propyl gallate: A cost effective strategy using nanoparticles. *Journal of the Electrochemical Society* 166 (2):B92–B94. doi: 10.1149/2.0791902jes.

Sivasankaran, U., J. Radecki, H. Radecka, and K. Girish Kumar. 2019. Copper nanoclusters: An efficient fluorescence sensing platform for quinoline yellow. *Luminescence: The Journal of Biological and Chemical Luminescence* 34 (2):243–8. doi: 10.1002/bio.3601.

Sivasankaran, U., A. E. Vikraman, D. Thomas, and K. G. Kumar. 2016. Nanomolar level determination of octyl gallate in fats and oils. *Food Analytical Methods* 9 (7):2115–23. doi: 10.1007/s12161-015-0356-7.

Squissato, A. L., E. M. Richter, and R. A. Munoz. 2019. Voltammetric determination of copper and tert-butylhydroquinone in biodiesel: A rapid quality control protocol. *Talanta* 201:433–40. doi: 10.1016/j.talanta.2019.04.030.

Stefan-van Staden, R. I., A. Moscalu-Lungu, and J. F. van Staden. 2019. Pattern recognition of sweeteners in biological fluids, beverages, and ketchup using stochastic sensors. *Electroanalysis* 31:1–8.

Sýs, M., B. Švecová, I. Švancara, and R. Metelka. 2017. Determination of vitamin E in margarines and edible oils using square wave anodic stripping voltammetry with a glassy carbon paste electrode. *Food Chemistry* 229:621–7. doi: 10.1016/j.foodchem.2017.02.068.

Taghdisi, S. M., N. M. Danesh, M. A. Nameghi, M. Ramezani, M. Alibolandi, and K. Abnous. 2019. An electrochemical sensing platform based on ladder-shaped DNA structure and label-free aptamer for ultrasensitive detection of ampicillin. *Biosensors & Bioelectronics* 133:230–5. doi: 10.1016/j.bios.2019.03.044.

Teixeira, A. Z. A. 2018. Sodium content and food additives in major brands of Brazilian children's foods. *Ciência & Saúde Coletiva* 23 (12):4065–75. doi: 10.1590/1413-812320182312.21812016.

Tekin Pulatsü, E., S. Sahin, and G. Sumnu. 2018. Characterization of different double-emulsion formulations based on food-grade emulsifiers and stabilizers. *Journal of Dispersion Science and Technology* 39 (7):996–1002. doi: 10.1080/01932691.2017.1379021.

Tezcan, F. 2018. A sample stacking-capillary electrophoresis method for simultaneous determination of nitrate and thiocyanate ions of ultra-heat-treated milk samples. *Turkish Journal of Chemistry* 42 (4):1184–90. doi: 10.3906/kim-1801-15.

Timofeeva, I., D. Kanashina, K. Stepanova, and A. Bulatov. 2019. A simple and highly-available microextraction of benzoic and sorbic acids in beverages and soy sauce samples for high performance liquid chromatography with ultraviolet detection. *Journal of Chromatography. A* 1588:1–7. doi: 10.1016/j.chroma.2018.12.030.

Tiwari, S., and M. K. Deb. 2019. Modified silver nanoparticles-enhanced single drop microextraction of tartrazine in food samples coupled with diffuse reflectance Fourier transform infrared spectroscopic analysis. *Analytical Methods* 11 (28):3552–62. doi: 10.1039/C9AY00713J.

Tran, Q. T., T. T. Phung, Q. T. Nguyen, T. G. Le, and C. Lagrost. 2019. Highly sensitive and rapid determination of sunset yellow in drinks using a low-cost carbon material-based electrochemical sensor. *Analytical and Bioanalytical Chemistry* 411 (28):7539–49. doi: 10.1007/s00216-019-02155-9.

Urdea, M., L. A. Penny, S. S. Olmsted, M. Y. Giovanni, P. Kaspar, A. Shepherd, P. Wilson, C. A. Dahl, S. Buchsbaum, G. Moeller, et al. 2006. Requirements for high impact diagnostics in the developing world. *Nature* 444 (S1):73–9. doi: 10.1038/nature05448.

Van der Heijden, C. A., P. J. C. M. Janssen, and J. J. T. W. A. Strik. 1986. Toxicology of gallates: A review and evaluation. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 24 (10–11):1067–70. doi: 10.1016/0278-6915(86)90290-5.

Van Esch, G. J. 1986. Toxicology of tert-butylhydroquinone (TBHQ). *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 24 (10–11):1063–5. doi: 10.1016/0278-6915(86)90289-9.

Van Overmeire, I., K. Vrijens, T. Nawrot, A. Van Nieuwenhuyse, J. Van Loco, and T. Reyns. 2019. Simultaneous determination of parabens, bisphenols and alkylphenols in human placenta by ultra-high performance liquid chromatography-tandem mass spectrometry. *Journal of Chromatography. B, Analytical Technologies in the Biomedical and Life Sciences* 1121:96–102. doi: 10.1016/j.jchromb.2019.05.012.

Vikraman, A. E., Z. Rasheed, L. Rajith, L. A. Lonappan, and G. K. Krishnapillai. 2013. MWCNT-modified gold electrode sensor for the determination of propyl gallate in vegetable oils. *Food Analytical Methods* 6 (3):775–80. doi: 10.1007/s12161-012-9485-4.

Voss, S., E. Newman, and J. P. Miller-Schulze. 2019. Quantification of sucralose in groundwater well drinking water by silylation derivatization and gas chromatography-mass spectrometry. *Analytical Methods* 11 (21):2790–9. doi: 10.1039/C9AY00442D.

Walton, K., R. Walker, J. J. van de Sandt, J. V. Castell, A. G. Knapp, G. Kozianowski, M. Roberfroid, and B. Schilter. 1999. The application of in vitro data in the derivation of the acceptable daily intake of food additives. *Food and Chemical Toxicology: An International Journal Published for the British Industrial Biological Research Association* 37 (12):1175–97. doi: 10.1016/s0278-6915(99)00107-6.

Wiley, D., and C. N. Y. Nee. 2020. Food ingredients. In *Food and Society*, 377–91.Elsevier: UK.

Williams, G. M., M. J. Iatropoulos, and J. Whysner. 1999. Safety assessment of butylated hydroxyanisole and butylated hydroxytoluene as antioxidant food additives. *Food and Chemical Toxicology*: An International Journal Published for the British Industrial Biological Research Association 37 (9–10):1027–38. doi: 10.1016/S0278-6915(99)00085-X.

Wissgott, U., and K. Bortlik. 1996. Prospects for new natural food colorants. *Trends in Food Science & Technology* 7 (9):298–302. doi: 10.1016/0924-2244(96)20007-X.

Wu, L., W. Yin, K. Tang, D. Li, K. Shao, Y. Zuo, J. Ma, J. Liu, and H. Han. 2016. Enzymatic biosensor of horseradish peroxidase immobilized on Au-Pt nanotube/Au-graphene for the simultaneous determination of antioxidants. *Analytica Chimica Acta* 933:89–96. doi: 10.1016/j.aca.2016.06.020.

Xie, Y., T. Chen, Y. Guo, Y. Cheng, H. Qian, and W. Yao. 2019. Rapid SERS detection of acid orange II and brilliant blue in food by using Fe_3O_4@Au core–shell substrate. *Food Chemistry* 270:173–80. doi: 10.1016/j.foodchem.2018.07.065.

Yamjala, K., M. S. Nainar, and N. R. Ramisetti. 2016. Methods for the analysis of azo dyes employed in food industry-A review. *Food Chemistry* 192:813–24. doi: 10.1016/j.foodchem.2015.07.085.

Yao, Y., W. Wang, K. Tian, W. M. Ingram, J. Cheng, L. Qu, H. Li, and C. Han. 2018. Highly reproducible and sensitive silver nanorod array for the rapid detection of Allura Red in candy. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy* 195:165–71. doi: 10.1016/j.saa.2018.01.072.

Yue, X., X. Luo, Z. Zhou, and Y. Bai. 2019. Selective electrochemical determination of tertiary butylhydroquinone in edible oils based on an in-situ assembly molecularly imprinted polymer sensor. *Food Chemistry* 289:84–94. doi: 10.1016/j.foodchem.2019.03.044.

Zou, Q., Y. Yao, W. Wang, J. Li, C. Yan, and C. Han. 2018. Study on detection of pigment Amaranth based on surface-enhanced Raman scattering. In 2018 Cross Strait Quad-Regional Radio Science and Wireless Technology Conference (CSQRWC), pp. 1–3. IEEE. doi: 10.1109/CSQRWC.2018.8455384.