Proceedings of CONF-MSS 2026 Symposium: Advanced Composite Materials and Polymer Chemistry
DOI: 10.54254/2755-2721/2026.AD32848

Applied Chemical Analysis of Food Additives: Classification, Functions and Safety

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Abstract. Food additives are extensively employed in the modern food industry and perform irreplaceable functions in food preservation, antisepsis, sensory improvement, quality stabilization and the improvement of processing efficiency. With the continuous advancement of the food industry, the varieties and applications of food additives are constantly expanding, and their safety has aroused widespread public concern. From the perspective of applied chemistry, this paper systematically examines the classification, functional mechanisms and safety evaluation of food additives by using the literature analysis method. The results demonstrate that scientific classification helps clarify the applicable scenarios of different additives; their functional mechanisms are based on definite chemical principles; and legally approved food additives are safe when used in accordance with national and international standards. The main risks originate from misuse, overuse and illegal additives rather than standard-approved products. This study provides a theoretical reference for the rational application and standardized supervision of food additives.

Keywords: Food additives, Applied chemical analysis, Classification, Functional mechanism

1. Introduction

Along with the industrialization and globalization of the food supply chain, food additives have become indispensable components in food production, storage and transportation [1]. Extensive research has been carried out on the fundamental properties and applications of food additives worldwide. Li summarized the mainstream classification systems of food additives adopted domestically and internationally, and proposed that functional classificationis more conducive to the regulation of practical production and industrial applications [1]. Wang and Zhang analyzed the chemical mechanisms of typical preservatives and antioxidants, and verified their efficacy and safety through sufficient experimental data [2]. Liu established a quantitative risk assessment model for food additives from the perspective of applied chemistry, which offered a feasible method for objective safety evaluation [3].

At present, three core issues remain to be systematically clarified: firstly, the scientific and systematic classification of food additives; secondly, the in-depth exploration of functional mechanisms based on applied chemistry; thirdly, an objective and comprehensive safety assessment integrated with actual exposure levels. To address these problems, this study adopts the literature analysis method to systematically review and integrate authoritative research papers, national

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standards and international regulatory documents. The significance of this study lies in providing theoretical support for the scientific application of food additives, helping the public establish rational cognition, and offering a reference for the standardized and sustainable development of the food industry.

2. Classification of food additives

In line with the Chinese national food safety standard GB 2760-2014 and the classification criteria formulated by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), food additives are mainly categorized according to their functional properties, which is the most widely applied classification system in the global food industry [4]. From the viewpoint of applied chemistry, such classification also reflects the differences in chemical structures and action mechanisms.

2.1. Preservatives

Preservatives are additives that are designed to inhibit the growth and reproduction of microorganisms and prevent food spoilage and deterioration [2]. Based on chemical properties, they can be divided into organic acid preservatives (e.g., sodium benzoate, potassium sorbate), ester preservatives (e.g., parabens) and inorganic preservatives (e.g., nitrites).

2.2. Antioxidants

Antioxidants can delay or prevent oxidative deterioration of food, protecting lipids, pigments and vitamins from oxidative damage [3]. They are classified into natural antioxidants (e.g., vitamin C, vitamin E, tea polyphenols) and synthetic antioxidants (e.g., BHA, BHT, TBHQ).

2.3. Colorants

Colorants are used to improve or restore food color, and can be divided into natural colorants (e.g., carotene, chlorophyll) and synthetic colorants (e.g., tartrazine, carmine). Synthetic colorants feature bright color and high stability, while natural colorants are more consistent with the trend of healthy consumption [1].

2.4. Sweeteners

Sweeteners provide sweetness for food products and are divided into nutritive sweeteners (e.g., sucrose, high fructose corn syrup) and non-nutritive sweeteners (e.g., aspartame, sucralose, steviol glycosides). Non-nutritive sweeteners have high sweetness intensity and low calorie content, and are widely used in sugar-free and low-calorie foods [5].

2.5. Thickeners, stabilizers and emulsifiers

These additives improve the physical state of food, maintain uniform and stable texture, and enhance mouthfeel [6]. Typical examples include xanthan gum, guar gum, lecithin and sodium caseinate.

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2.6. Nutritional enhancers

Nutritional enhancers are used to supplement deficient nutrients in foods, such as vitamins, minerals and amino acids, so as to improve the nutritional value of food and meet the dietary needs of different groups [4].

Other categories include flavor enhancers, acidity regulators, anti-caking agents and flour treatment agents. Although this classification covers the mainstream types of food additives, the systemrequires further refinement with the emergence of new and composite food additives [1].

3. Functional mechanism of food additives (based on applied chemistry)

The functions of food additives are realized through specific chemical reactions and physicochemical interactions. Analyzing their mechanisms helps us understand the action principles and achieve accurate dosage control.

3.1. Preservative mechanism

Preservatives exert effects mainly by destroying the enzyme systems and cell structures of microorganisms [2]. For instance, potassium sorbate can penetrate microbial cell membranes, inhibit dehydrogenase activity, and block the metabolism and reproduction of bacteria and molds. Sodium benzoate shows high efficiency in acidic environments and can inhibit the growth of most harmful microorganisms. The mechanisms of preservatives are selective and dose-dependent, and they do not damage human cells at regulated dosages [3]. The chemical structure of preservatives determines their antimicrobial spectrum, for example, organic acid preservatives are more effective against bacteria, while ester preservatives have a broader inhibitory effect on both bacteria and fungi. The synergistic effect between different preservatives can enhance the antimicrobial effect and reduce the dosage of single additives, which is an important research direction in the practical application of food additives.

3.2. Antioxidant mechanism

Antioxidants function by blocking oxidation chain reactions and scavenging free radicals [3]. Lipid oxidation is a typical free-radical reaction that leads to rancidity and off-flavors. Antioxidants such as TBHQ can donate hydrogen atoms to combine with free radicals, terminate the chain reaction, and protect the nutritional components and sensory properties of food. Natural antioxidants such as vitamin C possess both antioxidant and nutritional functions, and their application has become increasingly popular [2]. The antioxidant capacity of additives is closely related to their chemical structure; for instance, antioxidants with phenolic hydroxyl groups have stronger free radical scavenging ability than those without. The combination of natural and synthetic antioxidants can not only improve the antioxidant effect but also reduce the potential risks of single synthetic antioxidants, meeting the demand for healthy food production. Environmental factors such as pH and temperature can affect the chemical stability of antioxidants, thereby influencing their actual antioxidant efficiency in food systems.

3.3. Stabilization, thickening and emulsification mechanism

Thickeners and emulsifiers belong to colloid chemical additives [6]. Most thickeners are hydrophilic polymers that can increase the viscosity of the food system and prevent precipitation and

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stratification. Emulsifiers contain both hydrophilic and lipophilic groups, which reduce the interfacial tension between oil and water phases and form stable emulsions, resulting in a more uniform and delicate texture in beverages, ice cream and baked goods. The thickening effect of thickeners is achieved by forming a three-dimensional network structure in the food system, which traps water molecules and improves the system's stability. The emulsification effect of emulsifiers depends on the balance of their hydrophilic and lipophilic groups; adjusting the ratio of these groups can adapt to different oil-water system requirements. The application of composite thickeners and emulsifiers can solve the problem of single additives' insufficient stability, which is widely used in the production of high-quality processed foods.

3.4. Sensory regulation mechanism

Colorants and sweeteners improve the sensory quality of food through physical and chemical effects [1]. Colorants present specific colors by absorbing certain light waves, while sweeteners produce a sweet taste by binding to taste receptors on the tongue. Flavor enhancers such as monosodium glutamate can enhance the umami taste and improve the overall flavor of food.

All functional mechanisms are based on the principles of applied chemistry, and their effects are closely related to chemical structure, environmental pH, temperature and other conditions [6]. The color stability of colorants is affected by factors such as light, temperature and pH, and their chemical structure will change under adverse conditions, leading to color fading or discoloration. The sweetness intensity of sweeteners is determined by their chemical structure and binding ability with taste receptors, and non-nutritive sweeteners usually have a higher sweetness coefficient than nutritive ones. The sensory regulation effect of food additives is a comprehensive result of physical and chemical interactions, which needs to be adjusted according to the characteristics of different food raw materials.

4. Safety analysis of food additives

Safety is the primary principle for the application of food additives. All approved additives have passed strict safety evaluations, and their scope of application and dosage are clearly restricted by national and international standards [4,5].

4.1. Safety evaluation system

The internationally mainstream safety evaluation procedures include toxicological tests, acceptable daily intake (ADI) formulation and dietary exposure assessment [7]. The European Food Safety Authority (EFSA) and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) have developed complete evaluation guidelines [5,8]. Only additives that are proven to be free of acute, subchronic and chronic toxicity, as well as carcinogenicity, mutagenicity and reproductive toxicity are eligible for approval [3].

4.2. Actual safety risks

Legitimate food additives are not expected to harm human health when used in accordance with standard dosages [2]. The actual risks mainly derive from three sources: first, overuse and misuse of additives by producers; second, the use of illegal non-food additives (e.g., melamine, Sudan Red); third, individual sensitivity and adverse reactions in special populations. Natural additives are not absolutely safe, and their safety also requires systematic evaluation [1].

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4.3. Supervision and standardization

China's GB 2760-2014 strictly regulates the varieties, application scope and dosage of food additives [4]. Strengthening production supervision, market sampling inspection and public science popularization can effectively reduce safety risks. The public should distinguish between "food additives" and "illegal additives" to avoid cognitive bias and unnecessary panic [7].

5. Conclusion

Based on the perspective of applied chemistry, this paper systematically studies the classification, functional mechanisms and safety of food additives through the literature analysis method. The functional classification system established in accordance with GB 2760 and international standards is clear and practical, and it can effectively guide industrial production and application. The functional mechanisms of food additives have a definite chemical basis, including inhibiting microbial growth, scavenging free radicals, improving colloidal stability and regulating sensory properties. Legally approved food additives are safe and reliable when used in accordance with standards, and risks are mainly caused by misuse, overuse and illegal additives. Food additives are necessary for the modern food industry, and their rational application can effectively improve food quality and supply safety.

This study has certain limitations. Specifically, the classification presented in this paper only covers common types of food additives, with limited discussion on emerging and composite additives. Meanwhile, its safety analysis is grounded in existing literature and standards, lacking support from specific experimental data. In future research, scholars can carry out more refined classification of food additives, explore the interaction between composite additives combined with modern analytical techniques, and establish a more accurate risk assessment model, so as to promote the safer and healthier development of the food additive industry.

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