Chapter 5

Antioxidants as Food Additives

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Abstract

Antioxidants are essential chemicals that help sustain health and prevent disease. They function by neutralising free radicals, which are unstable chemicals created by the body's normal metabolic processes or by external influences such as pollution, radiation, and cigarette smoke. When free radicals build up, they can create oxidative stress, which harms cells and contributes to ageing and the development of chronic diseases such as heart disease, cancer, and neurological disorders. Antioxidants help to mitigate this damage by stabilising free radicals and keeping them from hurting the body's cells. They are naturally found in a wide range of foods, including fruits, vegetables, nuts, and whole grains. Common antioxidants include vitamins C and E, beta-carotene, selenium, and a spectrum of phytochemicals such as flavonoids.

1. Introduction

Antioxidants are a wide range of substances that serve an important function in preventing oxidation, which can cause cellular damage and other chronic diseases. Antioxidants, in their broadest sense, are chemicals that, when present in low concentrations relative to oxidisable substrates, considerably delay or block oxidation processes. They work by scavenging reactive oxygen species (ROS), reducing oxidative stress, which has been linked to a variety of health issues such as cancer, cardiovascular disease, and neurological disorders (Uzombah, 2022; Oliverio et al., 2022).

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Antioxidants are categorised into distinct categories based on their source and their mechanism of action. They can be endogenous (made by the body) or exogenous (obtained through dietary sources). Exogenous antioxidants include dietary components such vitamins C and E, polyphenols, and flavonoids (Sardarodiyan & Sani, 2016). The molecular profile of antioxidants in food can differ from those in dietary supplements; for example, foods may include numerous forms of vitamin E, but supplements frequently contain only one variety (Shebis et al., 2013).

In the food industry, antioxidants are used as additives to extend shelf life and retain sensory properties such as flavour, colour, and nutritional value. Commonly used food antioxidants include both synthetic substances such as butylated hydroxytoluene (BHT) and natural components derived from plants, such as green tea extracts and other fruits (Shahidi & Ambigaipalan, 2015; Souza et al., 2011). These antioxidants act by inhibiting the oxidative destruction of lipids and other sensitive components in food, hence reducing rancidity and the generation of hazardous oxidative products (Souza et al., 2011).

Natural antioxidants are replacing synthetic ones in food systems as a result of growing consumer awareness of health and wellness. In addition to their apparent health advantages, natural antioxidants are favoured because they meet consumer standards for food safety and quality (Uzombah, 2022). Although the use of food additives, such as antioxidants, is governed by regulations, natural sources are frequently subject to less scrutiny than synthetic ones (Franco et al., 2019; Chan, 2014). Customers' demands for products devoid of artificial chemicals are reflected in the food industry's broader movement towards "clean labelling" (Sardarodiyan & Sani, 2016).

1.1. Oxidation Reactions of Food Components

Oxidation is a process that involves the loss of electrons, frequently including oxygen, and results in the destruction of important components such as lipids, proteins, and vitamins (Zhou et al., 2022). This process can cause off-flavors, odours, colour changes, and hazardous chemicals, making it a major problem in food science (Duque-Estrada et al., 2019; Shahidi & Zhong, 2010).

Oxidation of food is a chemical process that occurs when food components, mainly fats, oils, and some vitamins, react with airborne oxygen. This reaction can cause changes in the flavour, colour, texture, and nutritional quality of the food. One of the most visible and prevalent results of oxidation is rancidity in fats and oils, which gives food an unpleasant taste and odour.

Lipid oxidation, which is mostly caused unsaturated fatty acids present in oils and fats, is one of the important components of food oxidation. Rancidity and unwanted flavours can result from production of hydroperoxides, which break down into a variety of volatile chemicals (Zhou et al., 2022). Temperature, oxygen exposure, and light can all accelerate the rate of lipid oxidation, which happens regularly during food processing, storage, and cooking (Gümüş & Decker, 2021; Osawa et al., 2008). For example, lipid-rich foods that undergo oxidative deterioration may produce toxic compounds called advanced lipid oxidation end products (ALEs), which have been associated with negative health effects when ingested (Kanner, 2007; Shahidi & Zhong, 2010).

Protein oxidation is another important topic in the research of food oxidation. Heat, light, and metal ions may all cause this process, which results in structural alterations in proteins. These alterations can cause the development of protein carbonyls and reactive species, such as dityrosine, affecting the sensory qualities and nutritional quality of food (Li et al., 2022; Lund et al., 2010). Protein oxidation not only reduces solubility and functioning, but it can also produce toxic chemicals that endanger human health, such as those that disrupt thyroid function and contribute to degenerative disorders (Li et al., 2022; Hellwig, 2019).

Furthermore, oxidation can influence the Maillard reaction, which happens during processing when amino acids and reducing sugars react together. Although this reaction can produce attractive flavours and colours in cooked foods, excessive oxidation can produce undesirable and potentially dangerous compounds (Poojary and Lund, 2022). Maintaining a balance between good and undesirable oxidative changes during food production is critical.

Antioxidants have a well-established role in reducing these oxidation processes, according to both scientific literature and food industry standards. By scavenging free radicals, natural antioxidants such polyphenols, vitamins, and carotenoids can slow down oxidation reactions and increase the shelf life of food (Santoro et al., 2022). By lowering oxidative stress linked to a number of illnesses, the prudent use of these antioxidants not only preserves food but may also help consumers' health (Franco et al., 2016).

1.2. Classification of Antioxidants

Antioxidants are categorised into different types depending on their origin, solubility, method of action, and chemical composition. Understanding these classifications assists in determining their significance in food preservation, health advantages, and use in the food industry.

Origin:

Natural antioxidants: They come from plant and animal sources. Common examples include vitamins (such as vitamin C and E), flavonoids, polyphenols, and carotenoids, all of which have been linked to improved health. These antioxidants are frequently perceived as safer and healthier than synthetic alternatives (Uzombah, 2022).

Synthetic Antioxidants: These are substances that are made artificially with the intention of preventing oxidation. Tert-butylhydroquinone (TBHQ), butylated hydroxytoluene (BHT), and butylated hydroxyanisole (BHA) are examples of common synthetic antioxidants. Despite their effectiveness in food preservation, there are growing worries about the possible health consequences of consuming them (Ashwar et al., 2014; Kebede & Admassu, 2019).

Mechanism of Action:

Free Radical Scavengers: These antioxidants work by directly scavenging free radicals, which are oxidatively damaging chemicals. Vitamins C and E are two examples (Peng et al., 2014).

Breaking chains Antioxidants: These substances efficiently stop the oxidation chain reaction by interfering with it. In this category, phenolic chemicals are prevalent (Shahidi & Ambigaipalan, 2015).

Reducing Agents: This class of antioxidant maintains the integrity of biomolecules by returning oxidised species to their initial condition. One significant endogenous antioxidant in this class is glutathione (Peng et al., 2014).

Solubility:

Hydrophilic Antioxidants: These antioxidants are water-soluble and are found largely in the watery environs of cells. Examples include vitamin C and a wide variety of polyphenolic chemicals (Carlsen et al., 2010).

Lipophilic antioxidants: These fat-soluble antioxidants can suppress lipid oxidation in cell membranes and lipid-rich foods. Carotenoids and vitamin E are two important examples (Madhab et al., 2023; Chen et al., 2012).

Chemical Composition:

Phenolic Compounds: This category includes a wide range of compounds, including flavonoids, tannins, and simple phenols, which have been recognised for their strong antioxidant properties and ability to scavenge free radicals (Shahidi and Ambigaipalan, 2015).

Vitamins: Vitamin C (ascorbic acid) and vitamin E (tocopherols and tocotrienols) are important antioxidants that protect cellular components from oxidative stress (Madhab et al., 2023; Peng et al., 2014).

Minerals: Some minerals, such as selenium and zinc, are required for the formation of antioxidant enzymes such as superoxide dismutase and glutathione peroxidase, which contribute to the body's natural antioxidative defence systems (Kebede & Admassu, 2019; Peng et al., 2014).

Application-Based Classification:

Antioxidants are routinely added to food goods to extend shelf life and prevent spoiling caused by oxidation. Synthetic chemicals like BHA and BHT are widely used, while natural antioxidants found in spices and herbs can also improve food quality (Poljšak et al., 2021; Bolchini et al., 2025).

Active Packaging: Recent advances in food technology have resulted in the introduction of packaging materials containing antioxidants. These active packaging technologies can increase shelf life by slowly releasing antioxidants into the food environment (Fasihnia et al., 2020).

1.3. Mechanism of antioxidants on oxidation reaction

Antioxidants serve a critical role in limiting oxidative damage by interfering in diverse oxidative processes via distinct methods. These processes include free radical scavenging, metal chelation, and other specialised antioxidant reactions, all of which contribute to their effectiveness in stabilising or deactivating reactive species.

Free Radical Scavenging: Scavenging free radicals is one of the primary mechanisms by which antioxidants exert their beneficial effects. Free radicals, including alkylperoxyl radicals and superoxide, are extremely reactive species that can cause oxidative damage in biomolecules (Arora et al., 2000). Antioxidants provide electrons to these radical entities, neutralising and converting them into more stable, less reactive states. For example, genistein has been shown to react with peroxyl radicals primarily at its B-ring, suggesting that certain antioxidant structural characteristics enhance their radical-scavenging activity (Arora et al., 2000). Green tea catechins predominantly exhibit antioxidant action by enhancing radical scavenging capacities (Janeiro & Oliveira-Brett, 2004).

Metal Chelation: Antioxidants also limit oxidation by chelating metal ions like iron and copper, which can catalyse the creation of reactive oxygen species. This technique significantly reduces metal availability for oxidation processes. Flavonoids, for example, have high metal-chelating characteristics because their complex molecular structures bind to metal ions and prevent them from participating in oxidative processes (Sontakke et al., 2020). Caffeic acid, for example, has been shown to form stable complexes with ferric ions, lowering oxidative stress by sequestering pro-oxidant metal ions that would otherwise promote free radical generation (Masuda et al., 2008).

Oxygen Quenching in Singlets

Another powerful oxidiser that can harm lipids, proteins, and nucleic acids is singlet oxygen, a high-energy form of oxygen (Gülçın et al., 2005). In order to prevent the damaging effects of singlet oxygen, antioxidants efficiently quench it, frequently by means of energy transfer processes that return dangerous singlet oxygen to its triplet state (Cheng, 2016). Because of their structured polyene backbone, which offers multiple sites for interaction, carotenoids, for instance, have shown notable effectiveness in singlet oxygen quenching (Cheng, 2016). As a vital lipid-soluble antioxidant in protective cellular membranes, vitamin E is also known for its capacity to scavenge singlet oxygen (Nazıroğlu & Butterworth, 2005).

1.4. Applications of antioxidants in Food Products

Antioxidants serve critical functions in food preservation by enhancing shelf life, improving nutritional value, and retaining sensory qualities. They are employed across various food categories, including oils, meat products, dairy, baked goods, beverages, and packaged foods.

Oils

Antioxidants extend shelf life and preserve quality in the field of edible oils by preventing oxidative degradation. For example, it has been demonstrated that adding oregano essential oil to extra-virgin olive oil improves its oxidative stability while being stored, thereby shielding it from lipid peroxidation (Asensio et al., 2011). Furthermore, studies show that toasting sesame seeds raises their phenolic content, which enhances sesame oil's antioxidant potential (Shi et al., 2017). Many studies have looked into the effectiveness of natural antioxidants including butylated hydroxytoluene (BHT) and rosemary extract in stabilising different types of cooking oils (Okhli et al., 2020; Soydan & Erdoğan, 2019).

Grape pomace extracts used in grapeseed oil are examples of environmentally friendly extracts that improve oxidative stability, demonstrating potential advantages in food processing and also promoting agricultural sustainability (Cisneros-Yupanqui et al., 2024). Superior antioxidant qualities of high-phenolic olive oil help to lessen the negative effects of oxidative stress on human health (Liu et al., 2019).

Meat products

Antioxidants are especially important in meat preservation because they prevent lipid oxidation and off-flavor formation. Incorporating rosemary diterpenes in lamb diets improves antioxidant status and reduces oxidation rates (Ortuño et al., 2016). Furthermore, the use of natural antioxidant extracts obtained from plant sources is being researched as a means of replacing synthetic chemicals in meat production (Lee et al., 2020). Natural extracts, for example, have shown promise in improving the stability and quality of processed meats (Lee et al. 2020). According to Vulić et al. (2024), ascorbic and citric acids are effective antioxidants that can enhance the colour and shelf life of beef products. Antioxidants preserve fatty acid profiles from oxidation, ensuring meat remains tasty and healthy over time.

Dairy products

Antioxidants in dairy products function similarly to those in fats and oils, reducing rancidity and preserving flavour integrity. Studies have shown that adding natural antioxidants can successfully stabilise dairy emulsions (Abreu et al., 2011). Incorporating effective antioxidants into processed cheese, for example, can help preserve quality during storage, prolonging both shelf life and sensory qualities (Abreu et al., 2011).

Baked Products

The usage of antioxidants in baked goods is crucial for enhancing dough stability and reducing oxidative deterioration of lipids found in formulations. Antioxidants like alpha-tocopherol and ascorbic acid are often employed to improve the oxidative stability of the fats and oils used in bread products, which has a substantial impact on the staling process and overall product quality (Dwyer et al., 2012). Furthermore, using antioxidant-rich plant extracts into baked goods can improve both shelf life and nutritional value.

Beverages

Antioxidants are used in the beverage industry, namely in juices and teas, to prevent colour degradation and flavour loss during processing and storage. For example, green tea extracts high in catechins have been shown to stabilise lipid profiles in omega-3 oils when included into emulsified products (Dwyer et al., 2012). They can also be added to fruit-based drinks to boost antioxidant levels, resulting in health benefits when consumed (Song et al., 2010).

Packaged Foods

Active packaging techniques that include antioxidants are gaining popularity in the food industry. These systems progressively release antioxidants to fight oxidative processes in food products during their shelf life. Research has shown that packaging materials impregnated with natural antioxidants can maintain freshness in ready-to-eat foods while reducing rancidity (Chacha et al., 2022; Marcos et al., 2014). Biodegradable films with antioxidants, including α-tocopherol, provide both preservation and environmental benefits (Marcos et al., 2014).

1.5. Legal regulations and limit values about antioxidant using in food industry

The legal regulations and limit values for the use of antioxidants in the food industry varied extensively among global countries. Regulatory authorities such as the FDA in the United States, the EFSA in Europe, and international frameworks like the Codex Alimentarius provide critical recommendations for food safety, efficacy, and labelling of food additives, including antioxidants.

Under the Federal Food, Drug, and Cosmetic Act, the FDA oversees the regulation of food additives in the US, including antioxidants. Antioxidants can be designated as "generally recognised as safe" (GRAS) or require safety testing before being approved as food additives. Limit values have been set for synthetic antioxidants such as Butylated Hydroxy Toluene (BHT), Butylated Hydroxyanisole (BHA), and Propyl Gallate. For example, BHA is permitted in food products at doses of up to 0.02% (Frazzoli et al., 2023). To avoid deceiving consumers, health claims for antioxidants must follow FDA standards and be validated by scientific evidence (Hegazı et al., 2023).

The EFSA in Europe assesses the effectiveness and safety of food additives, such as antioxidants. Food additives Regulation (EC) No. 1333/2008 establishes the regulatory framework. A list of approved food additives is provided by this rule, along with particular limit values for certain antioxidants. For instance, depending on how they are used, the maximum permitted amounts of specific antioxidants in food categories might be established at varying levels. For instance, some antioxidants in processed foods may have a maximum of 0.01% (El-Batal et al., 2023).

According to Silva et al. (2013), the EFSA also mandates thorough research to evaluate the impact of antioxidants on human health, connecting their use to exposure-based safety evaluations.

The FAO and WHO created the Codex Alimentarius, which sets food standards worldwide, including antioxidant guidelines. To ensure that food additives, including antioxidants, do not present health concerns, the Codex Committee on Food Additives (CCFA) sets permissible limits. Member nations are expected to incorporate these requirements into their domestic laws. In order to facilitate trade and improve consumer safety in food products, Codex offers a methodical approach to the evaluation of food additives with a focus on international harmonisation (Mrdovć et al., 2023).

In Asia, regulatory regimes can vary greatly. For example, in China, the National Health Commission establishes particular restrictions for the use of antioxidants in food, which are frequently consistent with Codex recommendations while also addressing local health issues. The General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ) provides guidelines for permissible antioxidant levels in several food categories (Talari et al., 2017). Similarly, countries like India have particular standards that set limitations for certain antioxidants based on their classification as permitted food additives (Belesky, 2019).

In Africa, food additive laws, including antioxidants, are not universal and vary by nation. Some African countries' regulatory systems are focused on guaranteeing the safety and efficacy of food products, with Codex criteria being used to define permitted antioxidant levels, particularly in traditional and processed foods (Judakı et al., 2017). The African Organisation for Standardisation (ARSO) also helps to set standards across the continent (Xiao et al., 2020).

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