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EXPLORING NATURAL SOURCES OF ANTIOXIDANTS AND THEIR POTENTIAL USES IN HEALTH AND INDUSTRY

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ABSTRACT: Antioxidants play a crucial role in maintaining cellular health by mitigating damage caused by reactive oxygen species (ROS). These compounds, sourced from fruits, vegetables, meats, poultry and fish, help counteract oxidative stress, which can lead to cellular deterioration and various diseases. This review explores the classification and characteristics of antioxidants, including ascorbic acid, carotenoids, terpenes and polyphenols. This study explores the sources of plants as a natural antioxidant, part of plant and its major constituent which show antioxidant activity, along with its mechanism of action. Oxidative stress is triggered by environmental and metabolic factors which disrupts biological functions by damaging proteins, lipids, and DNA. While both natural and synthetic antioxidants are used to prevent such damage, synthetic variants like BHA and BHT have raised health concerns, prompting a shift toward natural or plant-derived alternatives. This study highlights the sources and classification of antioxidants, pharmacological benefits, therapeutic potential, and body's mechanism of action of antioxidants, emphasizing their importance in disease prevention and overall well-being.

INTRODUCTION: An antioxidant is a substance that, even in low concentrations, helps to slow down the oxidation of proteins, carbohydrates, lipids, and DNA. These compounds are categorized into three main types:

Primary Defense Antioxidants: This group includes enzymes such as superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GR), along with essential minerals like selenium, copper, and zinc.

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Secondary Defense Antioxidants: This category comprises flavonoids, carotenoids, albumin, vitamin E, vitamin C, and glutathione (GSH), which help neutralize oxidative damage.

Tertiary Defense Antioxidants: These include enzymes responsible for repairing oxidative damage to proteins, lipids, and DNA, such as methionine sulphoxide reductase, proteases, lipases, transferases, and DNA-repairing enzymes [12].

Antioxidants play a crucial role in neutralizing free radicals unstable molecules that can damage cells. By stabilizing these radicals, antioxidants help prevent potential harm, including cancer. Common antioxidants include beta-carotene, lycopene, and

vitamins A, C and E [7]. An imbalance between antioxidants and reactive oxygen species (ROS) results in oxidative stress, which can disrupt cellular functions and contribute to various diseases such as AIDS, autoimmune disorders, arthritis, asthma, cancer, and neurodegenerative disorders [6].

Sources and Origin of Antioxidants: Antioxidants are widely present in fruits, vegetables, nuts, grains, and certain animal-based products such as meat, poultry, and fish. Various foods serve as rich sources of common antioxidants. Beta-carotene, for example, is abundant in orange-colored foods such as sweet potatoes, carrots, cantaloupe, squash, apricots, pumpkins, and mangoes. Additionally, dark leafy greens like collard greens, spinach, and kale are also excellent sources of beta-carotene [2].

Lutein, which is particularly beneficial for eye health, is primarily found in green leafy vegetables, including spinach, kale, and collard greens. Lycopene, a powerful antioxidant, is present in foods such as tomatoes, watermelon, guava, papaya, apricots, pink grapefruit, and blood oranges. Vitamin A exists in several forms, including retinol (Vitamin A1), 3,4-didehydroretinol (Vitamin A2), and 3-hydroxyretinol (Vitamin A3). Foods high in vitamin A include liver, sweet potatoes, carrots, milk, egg yolks, and mozzarella cheese. Vitamin C, also known as ascorbic acid, is found in high concentrations in numerous fruits and vegetables, as well as in cereals, beef, poultry, and fish. Vitamin E, an essential fat-soluble antioxidant, is present in almonds, various oils such as wheat germ, safflower, corn, and soybean oils, as well as in mangoes, nuts, and broccoli [8].

Classification of Antioxidants:

1. Based on Origin:

A. Natural Antioxidants

B. Synthetic Antioxidants

2. Based on Function:

A. Primary Antioxidants

B. Secondary Antioxidants

C. Tertiary Antioxidants

3. Based on Solubility:

A. Water soluble Antioxidants

B. Lipid soluble Antioxidants

4. Based on Mode of Action:

A. Enzymatic

B. Non-enzymatic

Natural Antioxidants: Antioxidants function as chain-breaking agents by interacting with lipid radicals and converting them into more stable forms. They can be categorized into different groups based on their composition and function [10].

Minerals: Essential for antioxidant enzyme activity, minerals play a crucial role in metabolic processes, including carbohydrate metabolism. Key examples include selenium, copper, iron, zinc, and manganese.

Vitamins: These micronutrients are vital for various metabolic functions within the body. Important antioxidant vitamins include vitamin C, vitamin E, and B vitamins.

Phytochemicals: These are non-vitamin, non-mineral plant-based compounds with significant antioxidant properties. They are further classified into:

Carotenoids: This group includes β-Carotene, β-Cryptoxanthin, Lutein, α-Carotene, and Lycopene. Common dietary sources include carrots, tangerines, spinach, apricots, papayas, sweet potatoes, pumpkins, and squash [19].

Terpenes: Major components include Strigol, Cinerin I, Calotropin, Caulerpenyne, and Geraniol. They are found in tea, cannabis, thyme, Spanish herbs, and citrus fruits.

Polyphenols: This diverse category consists of flavanones, anthocyanidins, isoflavones, stilbenes, chalcones, lignans, phenols, secoiridoids, proanthocyanidins, carnosic acid, and rosmanol. Sources of polyphenols include cereals, legumes, oilseeds (such as canola, rapeseed, olive seeds, and flaxseed), vegetables, fruits, and beverages like fruit juices, tea, coffee, cocoa, beer, and wine [20].

The Body's Mechanisms for Combating Oxidative Stress: Prevention focuses on minimizing the production of reactive oxygen species (ROS). Organisms achieve this by limiting oxidative stress exposure, utilizing specialized enzymes like cytochrome oxidase, and employing metal-binding proteins such as ferritin and transferrin to inhibit radical formation.

Interception works by neutralizing ROS before they inflict damage. Non-enzymatic antioxidants like vitamin E (α-tocopherol), vitamin C (ascorbate), and carotenoids help capture free radicals and halt chain reactions. Enzymatic antioxidants, including superoxide dismutases, catalases, and glutathione peroxidases, further regulate oxidative stress.

Repair mechanisms restore biomolecules affected by oxidation. Enzymatic repair systems mend damaged DNA, eliminate oxidized proteins, and degrade harmful lipid peroxidation byproducts. Since antioxidants cannot completely prevent oxidative stress, continuous repair processes are essential for maintaining cellular stability [22].

Applications of Antioxidants:

Antioxidants in Food: Antioxidants have found wide application in the food industry, especially in preserving fats and oils that are prone to spoilage. By slowing down the oxidation process, they help maintain the quality, flavor, and nutritional value of food products. Natural antioxidants present in common herbs and spices such as rosemary, turmeric, oregano, and cloves play a key role in extending the shelf life of foods high in unsaturated fatty acids. These plant-derived compounds help prevent rancidity and oxidative degradation, reducing the need for synthetic preservatives. As consumer demand for cleaner, more natural food ingredients grows, the use of natural antioxidants continues to gain momentum, offering both safety and functional benefits in food preservation [9].

Importance in Premature Infants: Supporting newborns with appropriate levels of enzymatic and non-enzymatic antioxidants may offer protective benefits by reducing cellular damage caused by excessive reactive oxygen species (ROS). This approach is especially valuable in managing conditions commonly seen in premature or critically ill infants, such as retinopathy of prematurity (ROP), bronchopulmonary dysplasia (BPD), necrotizing enterocolitis (NEC), and periventricular leukomalacia (PVL). These conditions are often linked to oxidative stress due to the immature antioxidant defense systems in neonates. By enhancing antioxidant capacity either through nutritional support, supplementation, or therapeutic strategies it may be possible to reduce inflammation, preserve tissue integrity, and improve developmental outcomes in these vulnerable populations. Ongoing research continues to explore optimal dosing, delivery methods, and long-term benefits of antioxidant therapy in neonatal care [17].

Role in Food: Preservation Antioxidants play a crucial role in maintaining the quality and stability of food products by slowing down oxidative degradation. This process helps preserve the flavor, color, texture, and overall nutritional value of food during storage and processing. One of their key functions is to inhibit lipid peroxidation and protein oxidation, which are major causes of spoilage and reduced shelf life, particularly in products containing unsaturated fats and oils. In response to growing consumer demand for cleaner and safer food labels, there has been a significant shift toward using natural antioxidants. Compounds such as vitamin C (ascorbic acid), vitamin E (tocopherols), and plant-derived extracts from herbs like rosemary, sage, green tea, and oregano have gained popularity as effective natural alternatives to synthetic antioxidants like BHA and BHT. These natural compounds not only serve as preservatives but also contribute additional health benefits, such as anti-inflammatory and antimicrobial properties. Their dual functionality makes them highly valuable in modern food systems, both from a technological and a nutritional standpoint [23].

Medical Applications of Antioxidants:

Anti-Cancer Properties: Flavonoids, plant-derived polyphenols, are widely found in fruits and vegetables and are believed to possess anticancer, anti-inflammatory, antiviral, and anti-allergic properties. Around 28 flavonoids, both natural and synthetic, have been investigated for their potential in leukemia treatment [13].

Liver Protection: Studies indicate that antioxidants such as vitamins C and E play a crucial role in managing liver diseases, including hepatocellular carcinoma. Clinical trials support their effectiveness in improving liver health [24].

Effects on the Nervous System: The cerebellum, essential for motor function, is particularly susceptible to ROS-induced damage. Antioxidants are essential for protecting brain development and preventing oxidative damage. However, only a few antioxidants have been identified as potential treatments for acute central nervous system (CNS) injuries [11].

TABLE 1:

Sr. no.	Plant name	Plant part used	Major constituents	Mechanism of action	Ref.
1	Okra *(Abelmoschus esculentus)*	Fruit	Polyphenolic compounds. Quercetin 3-O-glucosyl (1→6) glucoside (QDG) and quercetin 3-O-glucoside (QG)	Extract exhibits a strong DPPH radical scavenging activity and reducing power. Excellent reducing power and free radical scavenging capabilities, including DPPH, superoxide anions, and hydroxyl radicals.	[5]
2	*Achillea millefolium*	*Flower*	Caffeoylquinic acid derivatives	*A. millefolium* water extract exhibited the highest antioxidant activity in TEAC	[26]
3	*Althaea officinalis*	Roots	Chlorogenic acid, caffeic acid, Quercetin	The aqueous extracts of Althea can reduce DNA1 damage in human skin and lung fibroblasts, which is caused by UVA2	[15]
4	Papaya *(Carica papaya)*	Fruit, leaf	Flavonoids -kaempferol, myricetin, quercetin Phenolic acids- caffeic acid and ferulic acid	Ethanol extract showed potent suppressing action towards UVB-induced ROS production	[16]
5	*Euphorbia hirta*	Whole plant	Kaempferol, myricitrin, quercetin, Gallic acid	Ethanolic extract of *E. hirta* flowers were tested to know these extracts'. Free radical scavenging potential. Leaves decoction displayed the highest DPPH. Scavenging potential	[28]
6	*Ficus carica*	Leaves Fruit	40, 50 -Dihydropsoralen, umbelliferone, marmesin, bergapten. Cyanidin-3-O-glucoside, cyanidin-3- O-rhamnoglucoside	Sunscreen agent, cytotoxic, photosensitizer. Antioxidant and radical scavenging actions	[1]
7	*Houttuynia cordata*	leaves	Hyperoside Quercitrin	quercitrin, and hyperoside have the capacity to protect human keratinocytes from UVB-induced apoptosis and inflammation. These effects have been associated with oxidative stress inhibition by decreasing ROS production and the regeneration of endogenous antioxidant defences	[3]
8	*Imperata cylindrica*	Root	Chromone caffeic acid ferulic acid	aqueous extract of *I. cylindrica* can enhance the activity of superoxide dismutase (SOD) in liver and brain tissue of mice with alcoholism, inhibiting the activity of hydroxyl radicals, reducing the level of malondialdehyde, improving the body's antioxidant capacity	[14]
9	*Lonicera japonica*	Flowers, Stems	Caffeic acid Isorhamnetin 3-O-β-d-glucopyranoside Protocate chuic acid Luteolin	Showed marked antioxidant and scavenging activities. Effectively inhibited the lipopolysaccharide (LPS)-induced tumor necrosis factor-α, interleukin-6 and inducible nitric oxide production *in-vitro*	[21]
10	Pear (*Pyrus communis*)	Fruit	3- caffeoylquinic acid Quercetin-3-rutinoside 5-coumaroylquinic acid	Antioxidants inhibit the enzymes involved in the production of free radicals, thus reducing their generation	[29]
11	Broccoli	Fruit	Lutein	Scavenges free radicals by quenching singlet	[27]

				oxygen	
12	Tomato (*Solanum lycopersicum*)	Fruit	Lycopene	Lycopene neutralizes lipid radicals, decreases lipid peroxidation, and helps prevent UV-induced erythema on the skin. It may help lessen the harmful impact of UV radiation and enhance the skins defines against both immediate effects like sunburn and long-term consequences such as skin cancer.	[25]
12	Lemon (*Citrus limon)*	Fruits and seed	Ascorbic acid (Vitamin C) Vitamin E	Vitamins C and E are effective in protecting the skin against damage caused by UVB radiation.	[4]
14	Orange *(Citrus sinensis*)	Fruits and seed	Ascorbic acid (Vitamin C), Vitamin E	Vitamins C and E are effective in protecting the skin against damage caused by UVB radiation.	[4]
15	Cucumber (*Cucumis sativus*)	Fruits	ascorbic acid (vitamin C) and caffeic acid,	It also helps remove dead skin cells and tightens skin. Cucumbers soothe skin irritations, prevent water retention and are rich in water, fibre and beneficial minerals.	[18]

CONCLUSION: Antioxidants are an integral part of the body's defense system, helping to protect cells from the damaging effects of oxidative stress caused by reactive oxygen species. This review has discussed various types of antioxidants, their natural sources especially those found in plants and the mechanisms by which they act to preserve cellular integrity. While synthetic antioxidants are still in use, concerns over their long-term safety have led to a growing preference for plant-based alternatives.

The evidence suggests that natural antioxidants not only support overall health but also offer significant therapeutic potential in preventing and managing various diseases. Ongoing research in this field continues to highlight their importance, reinforcing the need to incorporate antioxidant-rich sources into daily life for better health outcomes.

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