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A REVIEW ON ANTIOXIDANTS AND ITS MECHANISMS, SOURCES AND HEALTH BENEFIT

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ABSTRACT

Antioxidants play a crucial role in mitigating oxidative stress, which is implicated in numerous chronic diseases due to the imbalance between reactive oxygen species (ROS) and the body's ability to neutralize them. This review explores the various mechanisms by which antioxidants protect cells, including scavenging free radicals, chelating metal ions, regenerating other antioxidants, inhibiting oxidative enzymes, repairing oxidative damage and modulating gene expression. Key natural sources of antioxidants include fruits, vegetables, nuts, seeds, whole grains, herbs, spices, tea, coffee and certain animal-based products. The health benefits of antioxidants are substantiated by research highlighting their role in reducing the risk of cardiovascular diseases, cancer, neurodegenerative diseases, eye health issues, diabetes, and supporting immune function. The bioavailability and absorption of different antioxidants vary, influenced by factors such as dietary fat presence and food matrix. Future research directions emphasize understanding synergistic effects, personalized nutrition, the safety and efficacy of supplementation, and novel antioxidant discovery. The review concludes that a balanced diet rich in natural antioxidants is preferable over high-dose supplements for optimal health benefits.

KEYWORDS

Free Radicals, Chelating Metal Ions, Antioxidants and Reactive Oxygen Species (ROS).

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INTRODUCTION

The definition of an antioxidant is "any substance that significantly delays or inhibits the oxidation of that substrate when present in low concentrations compared to that of an oxidisable substrate"[1]. Numerous chronic diseases have been linked to oxidative stress, which is brought on by an imbalance between reactive oxygen species (ROS) and the body's capacity to neutralize them. Endogenous and exogenous antioxidants are essential for preventing oxidative damage. In

addition to summarizing the most recent research on antioxidants' positive health effects and possible therapeutic uses, this review seeks to clarify the processes by which they work[2].

Mechanisms of Action

Antioxidants protect cells from oxidative stress by preventing cellular damage caused by reactive oxygen species (ROS) and free radicals. The following are the main ways that antioxidants function:

Scavenging Free Radicals

By contributing an electron to neutralize free radicals, antioxidants stabilize the radical and stop it from doing more harm.

Ascorbic acid or vitamin C: This water-soluble antioxidant efficiently scavenges free radicals in aqueous settings[3].

By neutralizing lipid radicals, vitamin E (tocopherol) is a lipid-soluble antioxidant that shields cell membranes against lipid peroxidation[4].

Chelating Metal Ions

Certain antioxidants bind to metal ions like iron and copper, preventing them from catalyzing the formation of free radicals.

Flavonoids: Polyphenolic compounds with strong metal-chelating properties[5].

Phytic Acid: Found in grains and legumes, it chelates iron and other metals, reducing their ability to catalyze free radical formation[6].

Regenerating Other Antioxidants

Certain antioxidants ensure the ongoing function of other antioxidants in the cellular environment by regenerating them.

Vitamin C: Preserves the antioxidant properties of vitamin E by renewing oxidized vitamin E[8].

Glutathione: A tripeptide that functions as a direct scavenger of free radicals and regenerates additional antioxidants such as vitamins C and E[9].

Inhibiting Oxidative Enzymes

By suppressing the enzymes that produce free radicals, antioxidants can lessen oxidative stress.

Polyphenols: Inhibit enzymes linked to inflammation and the generation of free radicals, such as lipoxygenase and cyclooxygenase[10].

Glutathione Peroxidase: An enzyme that stops the production of free radicals by reducing lipid peroxides and hydrogen peroxides to water and lipid alcohols[11].

Repairing Oxidative Damage

Certain antioxidants aid in the restoration of cellular function by repairing damage brought on by oxidative stress.

Enzymes for DNA Repair: Enzymes such as endonucleases and DNA glycosylases extract and fix oxidatively damaged DNA bases[12].

Protein Repair Enzymes: Certain enzymes, such as methionine sulfoxidereductase, can restore the functionality of oxidatively damaged proteins[13].

Modulating Gene Expression

Transcription factors that promote the expression of genes involved in stress response and antioxidant defense can be activated by antioxidants.

Nrf2 Pathway: This pathway is activated by Nrf2, which moves to the nucleus and promotes the production of genes related to detoxification and antioxidant defense[14].

Heme Oxygenase-1 (HO-1): An enzyme with cytoprotective and anti-inflammatory properties, whose expression is stimulated by antioxidants[15].

Sources of Antioxidants

Antioxidants have a critical role in reducing oxidative stress and neutralizing reactive oxygen species (ROS). They can be obtained in synthetic forms or through a variety of dietary sources, such as fruits, vegetables, whole grains, nuts, seeds, herbs, and drinks.

Natural Antioxidants

Fruits and Vegetables

Fruits

Berries: Rich in flavonoids and vitamin C. Blueberries, strawberries and raspberries are particularly noted for their high antioxidant content

Citrus Fruits: Oranges, lemons, and grapefruits are high in vitamin C, a potent antioxidant.

Apples: Contain quercetin and other polyphenols with antioxidant properties[15,16].

Vegetables

Leafy Greens: Spinach, kale, and Swiss chard are rich in vitamins A, C and E.

Cruciferous Vegetables: Broccoli, Brussels sprouts, and cauliflower contain antioxidants like sulforaphane.

Tomatoes: High in lycopene, a potent antioxidant[17].

Nuts and Seeds

Nuts: Almonds, walnuts, and hazelnuts are high in vitamin E and other antioxidants

Seeds: Flaxseeds and chia seeds provide omega-3 fatty acids and antioxidants like lignans[18,19].

Whole Grains

Examples: Oats, barley, and brown rice are good sources of antioxidants, including phenolic acids and vitamin E.

Brown Rice: Contains gamma-oryzanol and phenolic compounds[20].

Oats: High in avenanthramides, which have strong antioxidant properties[21].

Herbs and Spices

Examples: Turmeric (curcumin), ginger, garlic, and cinnamon contain various antioxidants.

Tea and Coffee

Tea: Green tea is rich in catechins and polyphenols.

Coffee: Contains antioxidants, including chlorogenic acids[22].

Synthetic Antioxidants

Food Additives

Butylated Hydroxyanisole (BHA) and Butylated Hydroxytoluene (BHT)

Used in food preservation to prevent oxidation[23].

Supplements

Vitamins: Synthetic forms of vitamins C and E are commonly included in dietary supplements.

Minerals: Selenium and zinc supplements provide antioxidant benefits.

Phytochemicals: Compounds like resveratrol and coenzyme Q10 are available as supplements[24].

Endogenous Antioxidants

Glutathione

Mechanism: A critical intracellular antioxidant that helps neutralize free radicals and regenerate other antioxidants[25].

Sources: Produced naturally within the body, but also found in foods like spinach and avocados.

Enzymes

Examples: Superoxide dismutase (SOD), catalase, and glutathione peroxidase are enzymes that neutralize ROS

Support: Essential nutrients like selenium and manganese support these enzymes' activity .

Animal-Based Sources

Meat and Fish

Examples: Fish such as salmon and mackerel are rich in selenium and omega-3 fatty acids with antioxidant properties.

Meat: While not as high in antioxidants as plant sources, meats provide some vitamins and minerals with antioxidant roles.

Health Benefits and Disease Prevention

Antioxidants are essential for lowering oxidative stress and shielding cells from reactive oxygen species (ROS) damage. This section examines the health advantages of antioxidants and their capacity to prevent disease, as substantiated by scientific research.

Cardiovascular Health

Reducing Risk of Heart Disease

Mechanism: Antioxidants lessen the oxidation of LDL cholesterol, shield endothelial cells from oxidative damage, and enhance vascular function in general.

Evidence

Vitamin E: Although findings from earlier trials have been conflicting, a research conducted in 2005 by Miller *et al*. discovered that taking a vitamin E supplement was linked to a lower risk of heart disease[26].

Flavonoids: Research has demonstrated that flavonoids from fruits and vegetables enhance endothelial function and lower blood pressure[27].

Cancer Prevention

Protection against Carcinogenesis

Mechanism: Oxidative damage, which can hasten the onset of cancer, is prevented from damaging cellular DNA by antioxidants.

Vitamins C and E: Although results are not always favorable, research indicates these vitamins may offer some protection against specific cancer forms[28].

Curcumin: Occurring in turmeric, curcumin has been demonstrated to possess anti-cancer qualities by impeding the growth and metastasis of tumors[29].

Neurodegenerative Diseases

Alzheimer's and Parkinson's disease

Mechanism: Oxidative stress, which is linked to th e development of neurodegenerative disorders, is le ssened by antioxidants.

Coenzyme Q10: Potential advantages in Parkinson's disease and neuroprotective properties have been dem onstrated[30].

Vitamin E: According to certain research, vitamin E s upplements may halt the advancement of Alzheimer 's disease[31].

Eye Health

Prevention of Age-Related Macular Degeneration (AMD)

Mechanism: Antioxidants protect the retina from oxidative damage that contributes to AMD.

Evidence:Lutein and Zeaxanthin-These carotenoids are associated with a reduced risk of AMD and improved visual function.

Diabetes Management

Improvement of Insulin Sensitivity

Mechanism: Antioxidants may reduce oxidative stress and inflammation, which are involved in insulin resistance.

Evidence:Alpha-Lipoic Acid-Shown to improve insulin sensitivity and reduce symptoms of diabetic neuropathy[32].

Immune System Support

Enhancing Immune Function

Mechanism: Antioxidants help in maintaining the integrity and function of the immune system by reducing oxidative stress.

Evidence: Vitamin C- Known to enhance various immune functions, including the production of white blood cells and the function of phagocytes.

Bioavailability and Absorption

Antioxidants' ability to effectively promote health is dependent on their bioavailability and absorption. The body's ability to absorb and use antioxidants is just as important to their effectiveness as their presence in the diet. This overview discusses the bioavailability and absorption of various antioxidants and the factors influencing these processes.

Vitamin C

Absorption Mechanism:

Mechanism: Vitamin C (ascorbic acid) is absorbed primarily in the small intestine through active transport mechanisms involving sodium-dependent vitamin C transporters (SVCTs)[33].

Factors Affecting Bioavailability: Absorption efficiency decreases as intake increases. The maximum absorption typically occurs at doses of 200mg or less[34].

Vitamin E

Absorption Mechanism

Mechanism: Vitamin E (tocopherols and tocotrienols) is absorbed with dietary fats in the small intestine and then transported via chylomicrons to the lymphatic system[35].

Factors Affecting Bioavailability: The presence of dietary fat enhances absorption. Variations in tocopherol forms (alpha-tocopherol is more bioavailable than others) also affect bioavailability[36].

Polyphenols

Absorption Mechanism

Mechanism: Polyphenols are absorbed mainly in the small intestine, but their bioavailability is influenced by the food matrix, digestion, and microbial metabolism[37].

Factors Affecting Bioavailability: Polyphenols are often poorly absorbed and rapidly metabolized. The presence of dietary fiber and the form of polyphenol (e.g., glycosides vs. aglycones) impact absorption[38].

Carotenoids

Absorption Mechanism

Mechanism: Carotenoids, including beta-carotene, are absorbed with dietary fats in the small intestine and then transported via chylomicrons[39].

Factors Affecting Bioavailability: Absorption is enhanced by the presence of dietary fat and cooking, which can break down cell walls and increase carotenoid bioavailability[40].

Selenium

Absorption Mechanism

Mechanism: Selenium is absorbed in the small intestine primarily in the form of selenomethionine and selenocysteine, and then incorporated into selenoproteins[41].

Factors Affecting Bioavailability: Selenium's bioavailability is influenced by the selenium content in soil and food sources, as well as interactions with other minerals[42].

Alpha-Lipoic Acid

Absorption Mechanism

Mechanism: Alpha-lipoic acid is absorbed in the gastrointestinal tract and distributed throughout the body where it acts as a cofactor for mitochondrial enzymes[43].

Factors Affecting Bioavailability: Bioavailability can be affected by the form of alpha-lipoic acid used (e.g., R-lipoic acid vs. S-lipoic acid) and the presence of food[44].

Future Directions

Future research in the field of antioxidants should focus on several key areas:

Understanding Synergistic Effects

Whole foods contain a complex matrix of nutrients that may work synergistically to provide health benefits. Future studies should investigate the synergistic effects of various antioxidants within whole foods to better understand their combined impact on health.

Personalized Nutrition

Advancements in genomics and metabolomics may allow for personalized dietary recommendations based on individual genetic makeup and metabolic profiles. Personalized nutrition can optimize antioxidant intake tailored to individual needs and health conditions.

Antioxidant Supplementation

Further research is needed to determine the safety and efficacy of antioxidant supplements, including appropriate dosages and long-term effects. This includes studying the impact of supplements in various populations and health conditions.

Novel Antioxidants

Identifying and studying new natural antioxidants from underexplored sources, such as certain plants, algae, and microorganisms, can expand the range of available antioxidants and their potential applications in health and disease prevention.

Mechanistic Insights

More in-depth studies are required to understand the precise mechanisms by which antioxidants exert their effects at the molecular and cellular levels. This includes exploring how antioxidants influence signaling pathways, gene expression, and cellular homeostasis.

Clinical Trials

Well-designed clinical trials are essential to validate the health benefits of antioxidants observed in epidemiological and laboratory studies. These trials should aim to establish clear links between antioxidant intake and the prevention or management of specific diseases.

CONCLUSION

Free radical neutralization, metal ion chelation, antioxidant regeneration, oxidative enzyme inhibition, oxidative damage repair, and gene expression modulation are all important ways that antioxidants help shield the organism from oxidative stress. Many health benefits, including a lower risk of chronic diseases like cancer, heart disease and neurological problems, can be obtained from a varied diet high in antioxidant-rich foods and beverages, fruits, vegetables, nuts, seeds, whole grains, herbs, spices, legumes, beans and seafood.

Although the advantages of antioxidant-rich diets are widely established, there is ongoing debate on the function of antioxidant supplements. According to some research, high supplement doses may not have the same health advantages as antioxidants found in whole foods and may even be harmful because of redox imbalances. For optimum health, a balanced strategy that emphasizes natural antioxidant sources is advised.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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