

Basics of Antioxidants and Their Importance

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Abstract

Fast living leads to an overabundance of free radicals in the body, which ultimately leads to mortality and a reduction in life expectancy by damaging cells, tissues, and organs. Consuming antioxidants aids in scavenging free radicals to ward off both acute and persistent illnesses. Antioxidants are essential that reducing the reactive mechanisms and the negative consequences of reactive oxygen species (ROS) throughout the chain supply and individual physiology. ROS are crucial for neuronal signaling, differentiation, tissue homeostasis, and longevity. In this overview, we go over the many forms of ROS, how they affect the function of cells, and whether they promote or inhibit cancer development. ROSs' detrimental impacts and their significance in the initiation of pathology are explored. A crucial part of these defense strategies is played by antioxidants. It is generally recognized that the inclusion of phenolic chemicals, particularly phenolic acids and flavonoids, is associated with antioxidative and pharmacologic effects. Antioxidants are now a crucial component of sophisticated health care. Antioxidants, whether they be organic or artificial, can help combat many diseases early on and works best when they are present in high concentrations. They affect how adequately the therapy responds. In addition to its usage in nutritious dietary supplements, emphasis is being placed on utilizing them as natural substitutes for synthetic versions to improve food durability and prevent degradation by oxidation throughout manufacturing and preservation. In purpose to support technological improvement in this domain, this overview summarizes relevant and widely recognized findings on the efficient significance of organic and synthesized antioxidants with associated therapeutic value.

Keywords: Antioxidants, ROS, free radicals, pathology, importance, applications

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Abbreviations

RON	reactive oxygen and nitrogen species
ET	electron transfer
HTD	hydrogen atom donation
EDTA	ethylenediaminetetraacetic acid
CA	citric acid
Vit C	Vitamin C
Vit B	Vitamin B
Vit A	Vitamin A
MDA	malondialdehyde
8-OHdG	8-hydroxy-2'-deoxyguanosine levels

1.1 Introduction

Imagine your body as a bustling city, with millions of residents busily going about their daily activities. In this city, just like in any vibrant community, there is a natural process of wear and tear. As time passes, structures deteriorate, and waste accumulates. However, to maintain the city's vitality and ensure its residents' well-being, there are diligent workers known as "antioxidants." Antioxidants, pivotal in cellular protection, counteract the harm induced by unstable molecules termed free radicals. These radicals, through oxidative reactions, instigate cellular damage, potentially culminating in conditions like cancer. Antioxidants engage with free radicals, stabilizing them and thwarting potential harm. Key antioxidants encompass beta carotene, carotenoid, vit A, B, C, as well as various polyphenols [1]. An antioxidant has the ability to slow down or prevent different compounds from oxidizing, which is the chemical process by which ions move from one material to an oxidation agent. This decay procedure births a chain reaction, setting off detrimental chain reaction within cells [2, 3]. Antioxidants step in, oxidizing themselves and removing the free radical intermediates that cause these chain reactions to stop. Interestingly, several antioxidants—such as polyphenols, thiols, and ascorbic acid—also function as reducing agents [4]. While oxidation reactions are vital for life, their immoderation can prove deleterious. Consequently, organisms, both flora and fauna, maintain intricate antioxidant defense systems. These include a range of enzymes, including catalase, superoxide dismutase, and several oxidoreductases, as well as antioxidants, including glutathione, vitamin C, and vitamin E [5]. Free radical damage can be brought on by low antioxidant levels or malfunctioning antioxidant enzymes, which may cause damage or even death to cells [6]. Given the potential implication of free radical damage in numerous human ailments, extensive research explores the utility of antioxidants in pharmacology, particularly in treating stroke and neurodegenerative disorder [7]. Nonetheless, whether oxidative stress acts as the cause or consequence of diseases remains unclear. Antioxidants are extensively utilized in dietary supplements, aiming to sustain health and avert conditions like cancer and coronary heart disease. While early studies suggested potential health benefits of antioxidant supplements, subsequent large clinical trials failed to validate such advantages and instead hinted at potential harm with

excessive supplementation. Additionally, antioxidants find broad industrial applications, functioning as chemicals in food and Corrective and inhibiting condensation in latex and petrol [8, 9]. Chemists have long acknowledged the ability of antioxidants to mitigate oxidation caused by free radicals, essential for maintaining stability in various substances, including lubrication oils and plastics. Human biological processes, encompassing respiration, metabolism, digestion, and energy conversion, generate reactive oxygen and nitrogen species (RONs), which can manifest as free radicals or readily generate them [10]. RONs, at moderate concentrations, play pivotal roles in biological pathways but can cause considerable damage at elevated levels, leading to disruptions in cellular signaling and Free radical damage [11]. This imbalance can lead to irreversible alterations in cell compounds, affecting cellular health and contributing to major chronic ailments such as cancer, cardiovascular, liver, and neurological disorders. Antioxidant defense mechanisms encompass a spectrum of approaches, including inhibiting free radical production, scavenging free radicals, converting free radicals into less dangerous substances, postponing the emergence of more hazardous species and halting the spread of chains reactions, bolstering the endogenous antioxidant defense system through synergistic action, and chelation. These multifaceted mechanisms collectively contribute to cellular resilience against Free radical damage and its detrimental moment [12].

1.2 Generalization of Antioxidant

Antioxidants is compounds that protect cells from oxidative damage caused by free radicals and reactive oxygen species (ROS). Oxidative stress resulting from an inequality between the production of these harmful molecules and the body's ability to neutralize them has been linked to various chronic diseases, including cardiovascular diseases, cancer, neurodegenerative disorders, and aging [13]. The main types of antioxidants are those that use a single electron transfer (ET) mechanism or hydrogen atom donation (HAT) to eliminate free radicals. Antioxidant catalysts that are prooxidant are neutralized by secondary antioxidants [14]. These include compounds that deactivate reactive species like singlet oxygen (beta-carotene) or chelate prooxidant metal ions (such iron and copper), such as (EDTA) and citric acid (CA) [10]. Mechanism of antioxidants -Scavenging Free Radicals: Antioxidants, through various enzymes and molecules, can neutralize free radicals by donating electrons [15]. This process mitigates the harmful chain reactions initiated by free radicals.

Enzymatic Scavengers: as reverse fibrosis, catalase, and GPx1, act as the first line of defense against free radical damage, reverse fibrosis. For example, catalyzes the dismutation of superoxide radicals into less harmful species.

Non-enzymatic Antioxidants:

- Non-enzymatic antioxidants encompass a wide range of molecules, including vit (e.g., vitamin E,C), lignans (e.g., flavonoids and resveratrol), and trace elements (e.g., selenium and zinc). These antioxidants exert their effects by quenching ROS directly or indirectly [16].

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Chelation of Metal Ions:

- Some antioxidants, like metal-binding proteins and chelators, combat oxidative stress by binding to metal ions (e.g., iron and copper) that catalyze the formation of highly reactive radicals. This prevents metal-mediated ROS generation [17].

Regulation of Transcription Factors:

- Some antioxidants activate transcription variables, like the nuclear factor erythroid 2-associated factor 2 (Nrf2), to modify how cells react to oxidative stress. Nrf2 controls the expression of numerous antioxidant genes, enhancing the body's overall antioxidant capacity [18].

Mitochondrial Protection:

Mitochondria are major sources of ROS production. Antioxidants, particularly those targeted to the mitochondria, reduce mitochondrial ROS generation and maintain mitochondrial function [19].

The mechanisms of action of natural antioxidants and oxidative processes. When polyunsaturated lipids are exposed to light, heat, ionizing radiation, metal ions, or metalloprotein catalysts, a free radical chain reaction is set off, which causes the autoxidation of the lipids in food. Oxidation can also be initiated by the enzyme lipoxygenase. Photooxidation can occur when exposed to light, and high-temperature thermal oxidation—which occurs when food is cooked, grilled, or fried—produces polar and polymeric compounds. The oxidation that happens to food most frequently is called autoxidation. The initiation (creation of lipid free radicals), propagation, and termination (generation of nonradical products) reactions are part of the traditional route of autoxidation, as shown in Figure 1.1 [20].

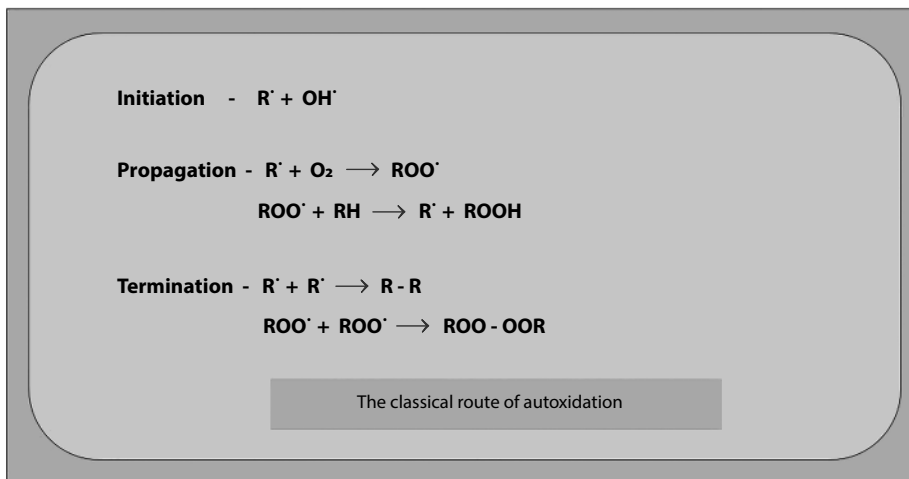


Figure 1.1 Autoxidation process [20].

1.3 Reactive Oxygen Species (ROS) and Free Radicals

Reactive oxygen species (ROS) and free radicals are fundamental components of cellular physiology, denoting chemically reactive molecular entities that harbor unpaired electrons in their outer orbits [21, 22]. Reactive Oxygen Species surround a contrast array of oxygen-derived species, including superoxide anion ($O_2^{\bullet-}$), hydroxyl radical ($\bullet OH$), hydrogen peroxide (H_2O_2), and singlet oxygen (1O_2), among others. On the other hand, free radicals, a subset of ROS, exhibit exceptional reactivity due to their unpaired electron, which drives them to readily engage in oxidative reactions [23].

These molecules are generated within the cell during various physiological processes, including aerobic respiration, immune responses, and cellular signaling [24, 25]. However, when their production exceeds the capacity of endogenous antioxidant defenses, it can lead to free radical damage.

The causes of ROS and free radical formation are multifaceted, encompassing both endogenous and exogenous sources [26]. Endogenously, ROS are produced during mitochondrial respiration, where electrons escape from the ETC [27]. Additionally, cellular enzyme such as nicotinamide adenine dinucleotide hydrogen phosphate oxidases and xanthine oxidoreductase contribute to ROS production as part of normal cellular functions [28]. Exogenously, exposure to outside influences like ionizing rays, pollutants, and heavy metals can increase ROS generation. The consequences of elevated ROS and free radicals are profound and multifarious. Oxidative stress, characterized by an inequality between ROS production and the body's ability to detoxify these species, is a common result [29]. This imbalance can lead to oxidative damage to biological molecules found in cells, such as proteins, fats, and DNA and RNA ultimately contributing to the pathogenesis of various diseases, such as cancer, neurodegenerative disorders, cardiovascular diseases, and inflammation-related conditions.

In response to the challenge posed by ROS and free radicals, the body has evolved a sophisticated defense system, employing endogenous antioxidants like superoxide dismutase, catalase, and glutathione peroxidase [30]. However, exogenous antioxidants from the diet, including vit E,C as well as polyphenols, play a pivotal role in bolstering the cellular defense against oxidative stress. Antioxidants function by donating electrons to free radicals without becoming destabilized themselves, thereby neutralizing these potentially harmful species. By counteracting the detrimental effects of reactive oxidative stress and free radicals, antioxidants serve as an essential safeguard against the progression of diseases rooted in oxidative stress. Understanding the intricate interplay between ROS, free radicals, and antioxidants is central to elucidating the molecular underpinnings of health and disease and may offer novel avenues for therapeutic intervention [31].

Pathology related to antioxidants: Pathology related to antioxidants is fundamentally centered on the intricate interplay between the protective role of antioxidants and the detrimental consequences of free radical damage [32]. Free radical damage, marked by an imbalance between the generation of reactive oxygen species and the body's power to detoxify or repair the resultant damage, underpins numerous pathological conditions spanning various organ systems [33–37]. Oxidative stress stands as a linchpin in a plethora of ailments, ranging from cardiovascular diseases, neurodegenerative disorders, and cancer to diabetes, inflammatory conditions, and the process of aging itself [38]. At its core, oxidative stress is

perpetuated by free radicals, which include highly reactive molecules such as superoxide anion (O_2^-), hydroxyl radicals ($OH\cdot$), and hydrogen peroxide (H_2O_2) [39]. These agents wreak havoc on cellular components, inflicting harm upon DNA, proteins, and lipids [40]. In this intricate biological battle, antioxidants emerge as the valiant defenders of cellular integrity. These compounds come in two categories [41]: enzymatic antioxidants like superoxide dismutase, catalase, and glutathione peroxidase, and non-enzymatic antioxidants including vit C and E, glutathione, and flavonoids [42]. Acting in unison, these antioxidants mount a concerted effort to eliminate radicals and maintain the delicate balance of cellular redox equilibrium [43]. The pathological implications of oxidative stress are far-reaching and multi-faceted [44]. Cardiovascular diseases, encompassing conditions like atherosclerosis, hypertension, ischemia-reperfusion injury, and heart failure, bear the heavy burden of oxidative stress-induced damage [45]. Emerging evidence suggests that diets rich in antioxidants and antioxidant supplementation hold promise in mitigating cardiovascular pathology by alleviating oxidative damage [46]. Neurodegenerative disorders, such as Alzheimer's disease, Parkinson's disease, ALS, and multiple sclerosis, have their origins intertwined with oxidative stress-induced damage, contributing to their onset and progression [47]. Antioxidant therapy offers hope in delaying neurodegeneration and enhancing cognitive function. Cancer development, a multifaceted process governed by cellular and molecular alterations driven by a variety of endogenous and exogenous factors, is marked by oxidative DNA damage [48]. This damage serves as a key hallmark of carcinogenesis, instigating the initiation and promotion of cancer through chromosomal defects and the activation of oncogenes by free radicals. Diabetes and metabolic disease, characterized by free radical damage as a defining feature, underscore the potential of antioxidants in preventing diabetic complications, such as mononeuropathy, and retinopathy, by counteracting oxidative stress-induced damage. Furthermore, inflammatory disorders, particularly those of a chronic nature, are often perpetuated by oxidative stress [49]. Antioxidants, equipped with their anti-inflammatory properties, present a potential avenue for attenuating conditions like rheumatoid arthritis and inflammatory bowel disease [50]. The repercussions of antioxidant deficiency are dire, as insufficient intake or impaired antioxidant defense mechanisms significantly heighten the susceptibility to oxidative damage [51]. This exacerbates the pathology associated with various diseases, reinforcing the paramount importance of maintaining an adequate antioxidant defense system. In summary, the intricate web of oxidative stress, antioxidants, and their pathological implications underscores the critical role of these molecules in maintaining cellular health and the prevention of numerous diseases across various systems in the body [52]. Understanding this delicate balance is pivotal in the ongoing pursuit of novel therapeutic interventions and lifestyle modifications aimed at mitigating the burden of oxidative stress-related diseases [53–58].

Natural origin of Antioxidant: Reactive Oxygen Species (ROS) and free radicals are dynamic entities known for their potential to cause cellular damage, contributing to a range of diseases, including cancer and cardiovascular conditions [59]. In response to this challenge, antioxidants found in various foods play a crucial role in maintaining health. These antioxidants are abundant in fruits, vegetables, nuts, seeds, and select beverages, offering a multifaceted defense against oxidative stress. Fruits and vegetables, for instance, are rich sources of antioxidants, including vitamin C, E [60], elements such as selenium, and phytochemicals, such as flavonoids and carotenoids [61] as shown in Figure 1.2.

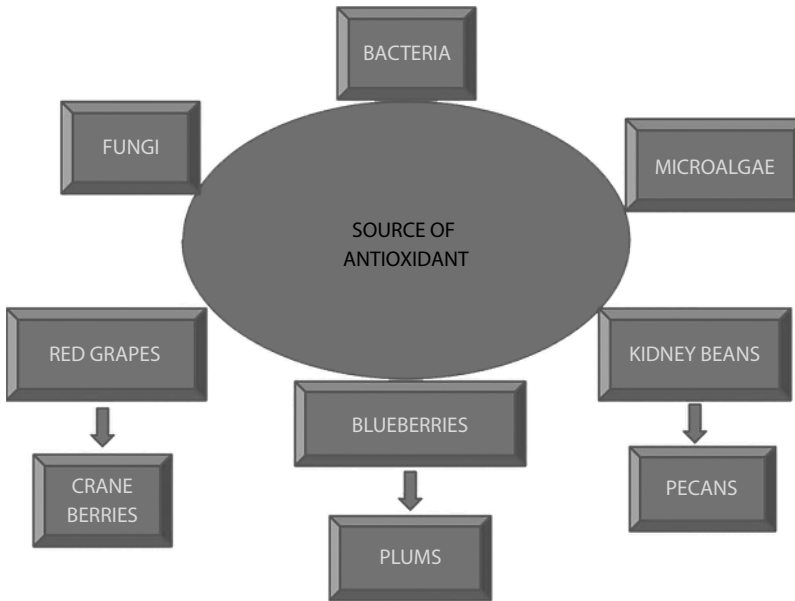


Figure 1.2 Sources of antioxidants.

These compounds are synthesized by plants as a defense mechanism against environmental stressors and as a means to attract pollinators [62]. In the realm of cereals and legumes, polyphenols, particularly phenolic acids, feature prominently. Ferulic acid, mono-hydroxybenzoic acid and (E)-3-(4-Hydroxyphenyl)-2-propenoic acid [63] are vital components, while buckwheat stands out with its abundant rutin content [64]. These polyphenolic compounds exist in both ester [65] and glycoside forms [66], with their chemical structure and concentration directly influencing their antioxidant activity [67, 68]. Additionally, catechins are found in cereal grains, with buckwheat, oats, and rye containing noteworthy amounts. Beverages [69] and spices also contribute significantly to antioxidant intake [70]. Coffee, tea, cocoa, red wine, and herbs and spices are rich sources of antioxidants [71]. In tea, catechins are prominent, particularly in green tea, which boasts over 2-times higher antioxidant activity compared to black or red tea. Roasted coffee, on the other hand, features chlorogenic acid as the dominant polyphenolic compound [73]. Flavonoids [72], a diverse group of naturally occurring compounds, offer strong antioxidant properties and can be found in various plant-based foods. Citrus fruits, berries, and dark chocolate are rich sources of specific flavonoids like hesperidin, naringin, anthocyanins, and epicatechin. Flavonoids combat oxidative stress through mechanisms such as free radical scavenging, metal chelation, and the enhancement of antioxidant enzymes [74]. Furthermore, marine environments are emerging as novel sources of antioxidants, with microalgae [75] and seaweed offering valuable contributions. Fucoxanthin from *Sargassum siliquastrum* [76], for example, has been found to protect human fibroblasts from UV-B-induced oxidative stress, thereby reducing intracellular [77] ROS, enhancing cell survival, and minimizing DNA damage. Additionally, compounds like fragilamide from *Martensia fragilis* exhibit moderate antioxidant activity, further expanding the scope of potential natural sources for antioxidants. Mechanism of action of various antioxidants is shown in Figure 1.3.

Antioxidant category	Mechanism of action
Carotenoids Lycopene β-Carotene	Lycopene traps O ₂ [•] ; β-Carotene β-carotene scavenges O ₂ [•] – anions and peroxy radicals
Isothiocyanates Sulforaphane	Phase II enzyme enhancer.
Phenolic compounds BHA, t-BHQ, curcumin	Enhancers of phase II enzyme such as reductases (e.g. quinone reductase) and conjugating enzymes (e.g. glutathione S-transferase).
Micronutrients Selenium	Selenium is an essential component of several antioxidant enzymes, including glutathione peroxidase (GPx), thioredoxin reductase, phospholipid hydroperoxide glutathione peroxidase, and selenoprotein P. Its presence within these enzymes is crucial for its role in preventing lipid peroxidation, which is the process of oxidative damage to lipids or fats.
Antioxidant enzymes SOD Catalase	SOD dismutates O ₂ [•] → H ₂ O ₂ Catalase converts H ₂ O ₂ → H ₂ O

Figure 1.3 Mechanism of action of antioxidants.

Research has explored the connection between the color spectrum of fruits and vegetables and their antioxidant capacity, categorizing them into three groups based on Total Antioxidant Capacity (TAC). The first group includes high-TAC fruits like black grapes and strawberries. The second group comprises medium-TAC fruits such as blueberries and green apples. The third group consists of fruits with low-medium TAC, including mangoes and bananas, revealing the diversity of antioxidants in nature and emphasizing the health benefits of dietary variety. This classification is derived from computer vision-based image analysis of color hues related to TAC.

1.4 Importance of Antioxidant in Medicine

Antioxidants, the molecular heroes that combat the destructive forces of oxidative stress, play a pivotal role in the field of medicine. As the human body relentlessly generates reactive oxygen species (ROS) and free radicals through metabolic processes, it faces a constant battle against cellular damage, inflammation and causes the rise of various diseases. The importance of antioxidants in medicine lies in their remarkable ability to neutralize these harmful molecules and safeguard cellular health. Antioxidants have become a formidable asset in the field of medical science, presenting a potent means for not only preventing chronic ailments such as cancer, cardiovascular diseases, and neurodegenerative disorders but also for fortifying the body's immune defenses. Their emergence marks a promising pathway for interventions that encompass both preventive measures and therapeutic strategies. This introduction sets the stage to explore the multifaceted impact of antioxidants in medicine, underscoring their significance in the quest for better health and well-being. Here we are going to discuss on uses of antioxidant in various conditions and diseases [78, 79].

In Pregnancy -Pregnancy imposes heightened nutritional demands on mothers to support fetal development, with several micronutrients serving as essential cofactors or

antioxidants. Normal placental development generates oxidative stress, which intensifies in the absence of sufficient antioxidant micronutrients, adversely affecting both the placenta and maternal circulation. Selenium, a crucial component of selenoproteins, including antioxidant enzymes like glutathione peroxidase, experiences reduced concentrations and activity during pregnancy (1st trimester: 65 µg/L; 3rd trimester: 50 µg/L). In pregnant women prone to postpartum thyroid dysfunction (PPTD), supplementation with 200 µg/d selenomethionine significantly lowers PPTD and permanent hypothyroidism incidence, attributed to enhanced selenoprotein activities mitigating postpartum immunological rebound [80].

Shifting to heart health, carotenoids, responsible for the vibrant hues of fruits and vegetables, showcase potent antioxidant properties. Beyond adding color, they contribute to lowering heart disease and cancer risks, boosting the immune system, and safeguarding against age-related macular degeneration – a leading cause of irreversible blindness in adults [81].

Neurological effect -A study has demonstrated Vit A neuroprotective effects against cytotoxicity associated with amyloid fibrillation. Given its capacity to interact with the Aβ-42 peptide, vitamin A emerges as a potential candidate for the therapy of Alzheimer's and Parkinson's diseases, countering systemic amyloidosis [82]. Various studies have established a correlation between vitamin C deficiencies and neurodegenerative disorders, including Parkinson's, Alzheimer's, Huntington's diseases, and amyotrophic sclerosis. Notably, a clinical study indicated that the administration of vitamin C and/or E supplements resulted in a reduced risk of cognitive decline in individuals aged ≥65 years. Furthermore, proanthocyanidins, a class of natural flavonoids, demonstrated efficacy in alleviating rotenone-induced oxidative stress in human neuroblastoma SH-SY5Y dopaminergic cells, serving as a model for Parkinson's disease [83, 84]. Co-administration of astaxanthin and fucoxanthin exhibited neuroprotective effects on pheochromocytoma neuronal cells, presenting a potential treatment approach for Alzheimer's disease.

In cancer, oleuropein has been identified as a compound that not only hampers cell proliferation but also triggers apoptosis in breast cancer cells. Its antiproliferative impact extends to human hepatocellular carcinoma cells, breast cancer cells, various human tumor cells, and human colon carcinoma cells [85]. Additionally, pectin, extracted from Citrus peels, serves as a widely employed gelling agent in diverse food industrial processes prevent cancer. In MTT assays, the exposure to 6-OHDA resulted in a concentration-dependent reduction in cell viability in PC12 cells, corroborated by apoptosis confirmation Particularly, concentrations ranging from 50 µM to 400 µM revealed the enhanced protective potential of EGCG, leading to a substantial reduction in apoptotic cells and the prevention of apoptosis-related nuclear changes. Mechanism of action of different natural antioxidants are shown in Figure 1.4.

Toxicity of antioxidant: Antioxidants are substances that help protect the body from the damaging effects of free radicals, which are unstable molecules that can damage cells and contribute to the aging process and various diseases, including cancer and cardiovascular diseases [96]. While antioxidants are generally beneficial for health, like many compounds, they can have potential toxic effects if consumed in excessive amounts. Here are some aspects to consider regarding the potential toxicity of antioxidants:

- 1) Excessive Supplementation: Consuming high doses of antioxidant supplements, such as vit A, C, E, and beta-carotene, beyond the recommended daily allowances (RDAs), can lead to toxicity. Excessive intake of these supplements

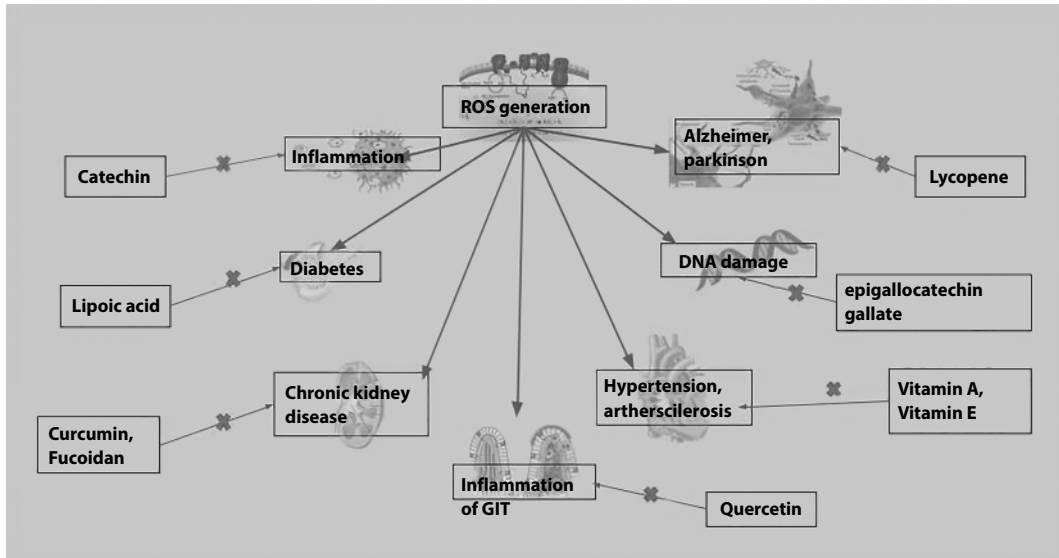
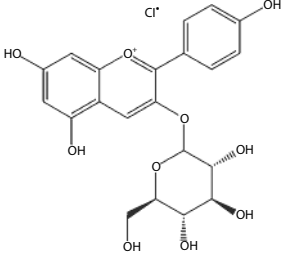
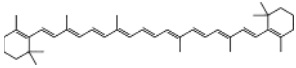
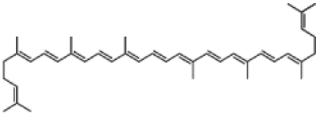
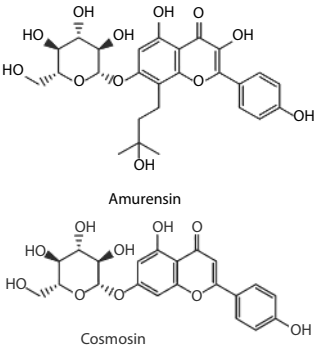
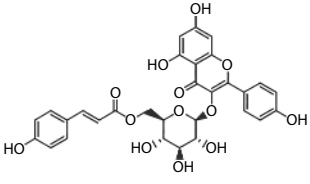


Figure 1.4 Mechanism of action of different natural antioxidants [89, 90].

may cause nausea, diarrhea, stomach cramps, and in severe cases, can lead to organ damage [97–99].

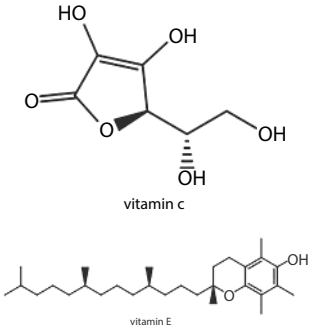
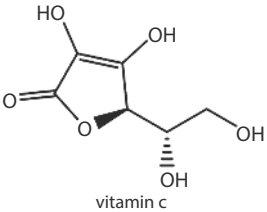
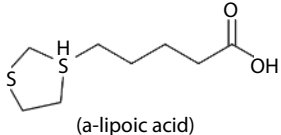
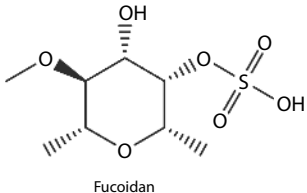
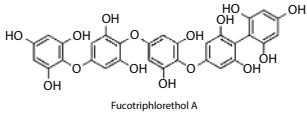
- 2) **Vitamin A (Retinol) Toxicity:** Vitamin A is an essential nutrient, but excessive intake, especially in the form of supplements, can lead to vitamin A toxicity [100]. This can cause dizziness, nausea, headaches, blurred vision, bone pain, and in severe cases, it can affect the liver and even be life-threatening.
- 3) **Selenium Toxicity:** Selenium is an essential trace element and antioxidant. However, excessive intake can lead to selenosis, causing symptoms like hair loss, nausea, diarrhea, skin rashes, and in severe cases, it can result in nerve damage and liver and kidney problems.
- 4) **Iron and Copper Overload:** Iron and copper are essential minerals with antioxidant properties. However, excessive levels of these minerals in the body can lead to toxicity [101]. Iron overload (hemochromatosis) can cause fatigue, joint pain, and eventually, damage to the liver, heart, and pancreas. Copper toxicity can lead to gastrointestinal symptoms and neurological issues.
- 5) **Interference with Chemotherapy:** High doses of antioxidants during cancer treatment, especially chemotherapy, may interfere with the treatment's effectiveness [102–104]. Some studies suggest that antioxidants can protect cancer cells from the damaging effects of chemotherapy.
- 6) **Interaction with Medications:** Antioxidants can interact with certain medications, affecting their efficacy or potentially causing harmful effects. For example, vitamin E can interact with blood thinners, and high doses of vitamin C may interfere with certain cancer treatments.
- 7) **Potential Pro-Oxidant Effects:** In certain conditions and at high concentrations, antioxidants can switch from being protective to potentially harmful by acting as pro-oxidants [105]. This paradoxical effect can lead to cellular damage rather than protection.

S. no.	Antioxidant	Impact on health	References
1	<p data-bbox="260 291 400 320">Anthocyanin</p>  <p data-bbox="400 610 475 629">Anthocyanin</p>	<p data-bbox="639 291 1026 542">Dietary antioxidants have the potential to offer health benefits by aiding in the prevention of various diseases, including neuronal disorders, cardiovascular conditions, cancer, diabetes, inflammation, and more.</p>	[86]
2	<p data-bbox="260 658 391 687">Carotenoids</p>  <p data-bbox="353 768 417 784">Beta carotene</p>	<p data-bbox="639 658 1005 813">Carotenoid intake may lower the risk of cancer, cardiovascular diseases, and other chronic conditions, and some also serve as provitamin A.</p>	[87]
3	<p data-bbox="260 838 364 867">Lycopene</p>  <p data-bbox="391 996 448 1012">Lycopene</p>	<p data-bbox="639 838 1013 1025">Lycopene administration improved cognition, reduced oxidative stress markers, increased MDA and 8-OHdG and prevented neuroinflammation and apoptosis.</p>	[88]
4	<p data-bbox="260 1051 542 1079">Amurensin and cosmosiin</p>  <p data-bbox="381 1286 458 1302">Amurensin</p> <p data-bbox="354 1421 422 1437">Cosmosiin</p>	<p data-bbox="639 1051 1016 1302">Research findings indicate that amurensin and cosmosin, both flavonoids extracted from <i>Trigonella foenum</i>, display promising potential in hindering neurodegeneration induced by NaNO₂ in the hippocampus and cortex regions of mice brains.</p>	[89]
5	<p data-bbox="260 1476 364 1505">Tiliroside</p>  <p data-bbox="422 1702 489 1717">Tiliroside</p>	<p data-bbox="639 1476 1026 1692">Research has demonstrated the anti-neuroinflammatory potential of tiliroside, a glycosidic flavonoid, in increasing Nrf2, HO-1, and NQO1 protein levels, suggesting Nrf2 protective pathway activation in microglia.</p>	[90]

(Continued)

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(Continued)

S. no.	Antioxidant	Impact on health	References
6	vit E, α-lipoic acid and Vit. C  <p>The image shows two chemical structures. The top structure is Vitamin C (ascorbic acid), a five-membered lactone ring with two hydroxyl groups on the double bond and a dihydroxyethyl side chain. The bottom structure is Vitamin E (α-tocopherol), a long hydrocarbon chain with a chromanol ring at the end containing a hydroxyl group.</p>	In a study these three antioxidant combination preserved arachidonic acid levels and positively impacted the D-6 desaturase system and unsaturated fatty acid levels in both diabetic and non-diabetic rats.	[91]
7	vitamin c  <p>The image shows the chemical structure of Vitamin C (ascorbic acid), a five-membered lactone ring with two hydroxyl groups on the double bond and a dihydroxyethyl side chain.</p>	Vitamin C supplementation effectively reduces the accumulation of (sugar alcohol) sorbitol RBC's of diabetic patient, normalizes sorbitol levels in T1DM within 30 days, reduces capillary fragility, and improves glucose and lipid metabolism as well as glycemic control.	[92]
8	lipoic acid  <p>The image shows the chemical structure of α-lipoic acid, consisting of a five-membered 1,2-dithiolane ring attached to a six-carbon aliphatic chain ending in a carboxylic acid group.</p>	Lipoic acid enhances glucose transport in muscle cells, safeguards the insulin receptor in adipocytes, and increases insulin-mediated glucose uptake in patients with T2DM, potentially improving insulin sensitivity.	[93]
9	Fucoidan  <p>The image shows the chemical structure of Fucoidan, a fucose sugar unit with a methoxy group at C2, a hydroxyl group at C3, and a sulfated group at C4.</p>	Fucoidan inhibited H ₂ O ₂ -triggered PC12 cell apoptosis by scavenging ROS and enhancing SOD and GSH-Px activity.	[94]
10	Fucotriphlorethol A  <p>The image shows the chemical structure of Fucotriphlorethol A, a complex polyphenolic compound consisting of three phloracetophenone units linked together.</p>	Fucotriphlorethol A, derived from the consumable brown alga <i>Fucus vesiculosus</i> L., demonstrates inhibition of cytochrome P450 1A, exhibiting IC ₅₀ values within the range of 17 to 33.5 µg/ml.	[95]

S. no.	Antioxidant	Side effect	References
1	Vit E	The study found that in some cases, high-dose antioxidant supplementation, particularly vitamin E, was associated with an increased risk of mortality. It suggested that excessive antioxidant intake might not always be beneficial and could potentially have adverse effects.	[106]
2	Vitamin C	The research found that excessive vitamin C intake was linked to an increased risk of developing kidney stones, highlighting the importance of moderation in antioxidant supplementation.	[107]
3	selenium	Furthermore, increased seminal plasma levels of selenium (≥ 80 ng/ml) were reported to be associated with decreased motility, asthenozoospermia and elevated abortion rates, whereas selenium levels between 40 and 70 ng/ml were reported to be optimal for re-productive performance.	[108]
4	Resveratrol	This study show that Gastrointestinal issues, interactions with medications.	[109]
5	Beta-Carotene	In individuals who smoked and were administered a daily supplementation of 20 mg β -carotene (Alpha-Tocopherol, Beta Carotene Cancer Prevention Study Group, 1994), or 30 mg β -carotene along with 25,000 IU retinyl palmitate, a noteworthy elevation in the likelihood of developing lung cancer was observed during an efficacy trial involving 29,133 and 18,314 subjects, respectively, in comparison to a placebo.	[110]

1.5 Conclusion

Antioxidants, the stalwart defenders against the ravages of oxidative stress, have cemented their significance in the realm of medicine. In the bustling city of our body's biological processes, where metabolic activities produce reactive oxygen species (ROS) and free radicals, antioxidants act as vigilant protectors. They neutralize these harmful molecules, thus safeguarding cellular health and contributing to the prevention of a multitude of diseases. Their importance extends across the medical spectrum, from thwarting the progression of chronic conditions like cancer, cardiovascular diseases, and neurodegenerative disorders to enhancing the body's natural defense mechanisms.

In the realm of cancer, antioxidants play an important role, with their ability to inhibit cell proliferation and induce apoptosis, potentially transforming the landscape of cancer

treatment. However, the delicate balance between their benefits and potential toxicity must be maintained. Excessive supplementation can lead to adverse effects, including nausea, organ damage, and even life-threatening conditions. Vitamin A, selenium, iron, and copper are all susceptible to toxicity when consumed in excess. Furthermore, the interaction of antioxidants with chemotherapy and medications can influence their efficacy, and their pro-oxidant effects, especially at high concentrations, can paradoxically lead to cellular damage. Therefore, moderation in antioxidant consumption is key to reaping their benefits while mitigating potential risks. In a world where oxidative stress and the resulting diseases pose a significant threat to human health, antioxidants stand as formidable allies, offering protection, prevention, and the potential to revolutionize the landscape of modern medicine. Their significance in maintaining health and well-being underscores the need for continued research and responsible consumption, paving the way for a healthier, more resilient future.

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