Antioxidants and Their Impact on Human Health

Dr.Sunanda Nandikol*[1], Shalini V[2], Shrinidhi[2], Saniya[2]

[1]Assistant Professor, Dept of Pharmacy practice BLDEA's SSM College of Pharmacy & Research Centre, Vijayapura

[2]Pharm-D Intern Dept of Pharmacy Practice ,BLDEA's SSM College of Pharmacy & Research Centre,Vijayapura

Corresponding author: **Sunanda Nandikol**
Email: sunanda.nandikol@gmail.com
Doi: **10.5281/zenodo.16093584**
Received: 05 June 2025
Accepted: 18 June 2025

ABSTRACT:

Antioxidants are vital compounds that inhibit oxidative damage caused by reactive oxygen species (ROS), thereby protecting cellular structures and maintaining physiological balance. Found both endogenously and in dietary sources—particularly fruits, vegetables, and microalgae—antioxidants function through mechanisms such as p0electron donation, radical scavenging, and repair of oxidized molecules. Their roles extend to disease prevention, with growing evidence linking oxidative stress to chronic conditions like cancer, cardiovascular disease, diabetes, and neurodegenerative disorders. Natural antioxidants, including vitamins C and E, phenolics, and carotenoids, are increasingly favored over synthetic counterparts due to concerns about toxicity and lower efficacy. Modern food technology employs antioxidants for preservation and nutritional enhancement, with encapsulation technologies advancing their stability and bioavailability. Despite their therapeutic potential, challenges such as poor solubility, degradation, and low bioavailability hinder clinical application. Ongoing research aims to overcome these limitations and clarify the complex relationship between antioxidant intake and health outcomes. Current recommendations emphasize a diet rich in antioxidant- containing foods and lifestyle modifications to minimize oxidative stress exposure. As scientific understanding of redox biology evolves, antioxidants are positioned as key agents in promoting health, managing disease, and advancing functional food development. Interdisciplinary efforts are essential for translating research into practical interventions that optimize antioxidant efficacy and safety in human health. In Conclusion, antioxidants play a pivotal role in protecting against oxidative damage and maintaining cellular health. While a diet rich in natural

antioxidants is beneficial, further research is necessary to fully understand the therapeutic potential and limitations of antioxidant supplementation in disease management.

KEYWORDS: Antioxidant, oxidative stress, free radicals, reactive oxygen species, human health.

INTRODUCTION:

Antioxidants are the compounds that inhibit or prevent oxidative damage to target molecules in living organisms. They function as secondary metabolites both in the human body and in fruits and vegetables. To protect vulnerable substrates from oxidation, plants synthesize a wide variety of antioxidants, including alkaloids, phenolics, and vitamins C and E. Since the human body cannot produce enough antioxidants to counter the constant threat posed by reactive oxygen species (ROS), plant-derived dietary antioxidants are considered vital for maintaining human health. Each antioxidant molecule can neutralize one ROS at a time by donating electrons, thereby halting the chain reaction that damages cellular components. Additionally, antioxidants serve as scavengers, protecting cells and tissues from harm. Cellular defense

against excessive free radicals also involves preventative mechanisms, repair systems, and both physical and antioxidant-based defences.[1]

Antioxidants, either natural or synthetic, are classified by bioactivity (enzymatic/non-enzymatic), solubility (water/fat-soluble), and size (small/large molecules). Enzymatic antioxidants neutralize free radicals through conversion reactions, while non-enzymatic ones directly inhibit them. Endogenous antioxidants are produced by the body, while exogenous ones come from the diet— both work synergistically to maintain redox balance. Primary antioxidants stabilize free radicals, and secondary antioxidants decompose harmful peroxides. Regular antioxidant intake helps prevent non-communicable diseases like cancer, diabetes, and heart disease, and also protects the skin from UV damage. Their therapeutic value is increasingly recognized in disease management and overall wellness.[1]

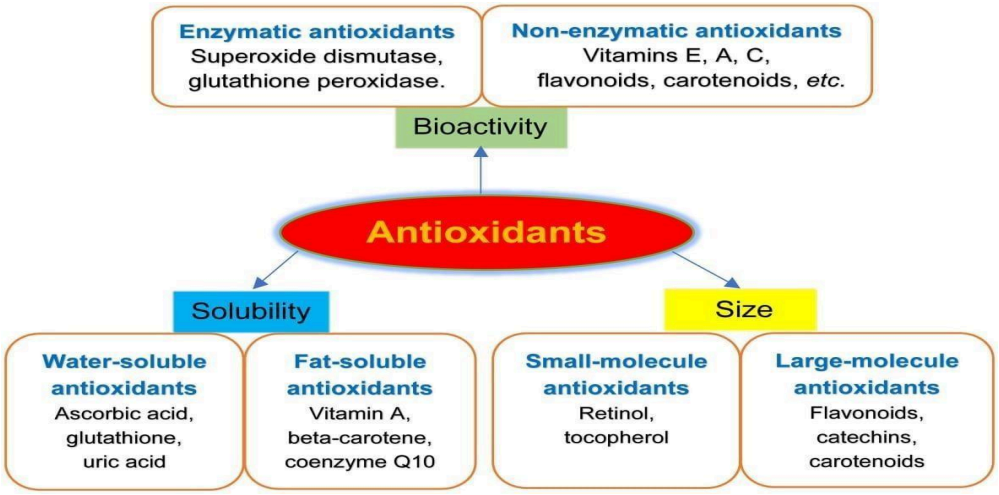

Figure 1: Different classes of antioxidants

Concerns over the safety and effectiveness of synthetic antioxidants have driven a growing interest in natural alternatives. Plant-based antioxidants, known for their health benefits and minimal side effects, are gaining attention—particularly microalgae. These microscopic, single- celled organisms thrive in aquatic environments and convert sunlight into biomass through photosynthesis. Recent research highlights their rich diversity of bioactive compounds, many with strong antioxidant properties, making microalgae a promising yet underexplored resource.[2]

Because antioxidants can neutralize free radicals, they are believed to reduce the risk of certain diseases associated with oxidative stress. However, the relationship between antioxidant intake— particularly through supplements—and disease prevention remains complex and not fully conclusive. While some studies suggest potential benefits, others indicate limited or inconsistent effects, highlighting the need for further research to clarify their role in health and disease management.Nevertheless, a diet rich in fruits and vegetables offers numerous health benefits beyond antioxidant content. Foods naturally high in antioxidants are typically also rich in dietary fiber, low in saturated fat and cholesterol, and packed with essential vitamins and minerals. This

nutrient-dense profile supports overall health and contributes to the prevention of various chronic conditions.[7]

Current trends in antioxidant and their impact on human health

Antioxidants have garnered significant scientific interest due to their wide-ranging health benefits, including anti-aging and anti-inflammatory properties. Today, they continue to be utilized across multiple fields, particularly in food technology, where they are incorporated into various food products to enhance nutritional value and address quality-related issues. As a

result, research aimed at identifying and quantifying the antioxidant activity of natural foods and their bioactive components is progressing rapidly. Additionally, antioxidants are increasingly being incorporated into encapsulation technologies, which are employed to preserve and stabilize sensitive food constituents, further expanding their practical applications in the food industry.Encapsulation has emerged as a cutting-edge approach in food science, playing a vital role in the preservation, stabilization, and controlled release of bioactive food components. Modern applications of encapsulation focus on extending shelf life, enhancing nutritional profiles, improving digestibility, and accelerating ripening processes. Recently, the technology has gained traction for its ability to support the development of diverse food products while maintaining their natural characteristics. These advancements reflect a growing trend toward functional foods that offer both health benefits and consumer appeal, positioning encapsulation as a key innovation in the evolving food industry.

Antioxidant preservatives, widely used in the food and pharmaceutical industries, include both natural and synthetic compounds. Natural antioxidants such as ascorbic acid (vitamin C) and tocopherols (vitamin E) are commonly used, alongside synthetic antioxidants like propyl gallate (PG), tertiary butylhydroquinone (TBHQ), butylatedhydroxyanisole (BHA), and butylatedhydroxytoluene (BHT).Concerns regarding the safety of synthetic antioxidants emerged in the 1980s and 1990s, with several in vivo studies reporting potential health risks.A 1993 study found that BHA and BHT could cause toxic effects when consumed in high doses over extended periods. However, other research indicated that regular, low-dose intake of these compounds was not linked to the development of gastric cancer. To address the ongoing debate, the European Food Safety Authority conducted a comprehensive review of available data and based on current evidence, established acceptable daily intake (ADI) limits: 0.25 mg/kg/day for BHA and 1.0 mg/kg/day for BHT. These limits were deemed safe for both adults and children. Despite these safety assessments, the debate continues. Recent studies have pointed out that synthetic antioxidants may still pose toxicity risks, are often more expensive and may offer lower efficacy compared to their natural counterparts. Consequently, especially in developed countries, there has been a notable increase in the preference for natural antioxidants. Their cost-effectiveness, superior antioxidant properties, and potential benefits for health and longevity have significantly driven consumer interest and industry focus toward more natural preservative options.[6]

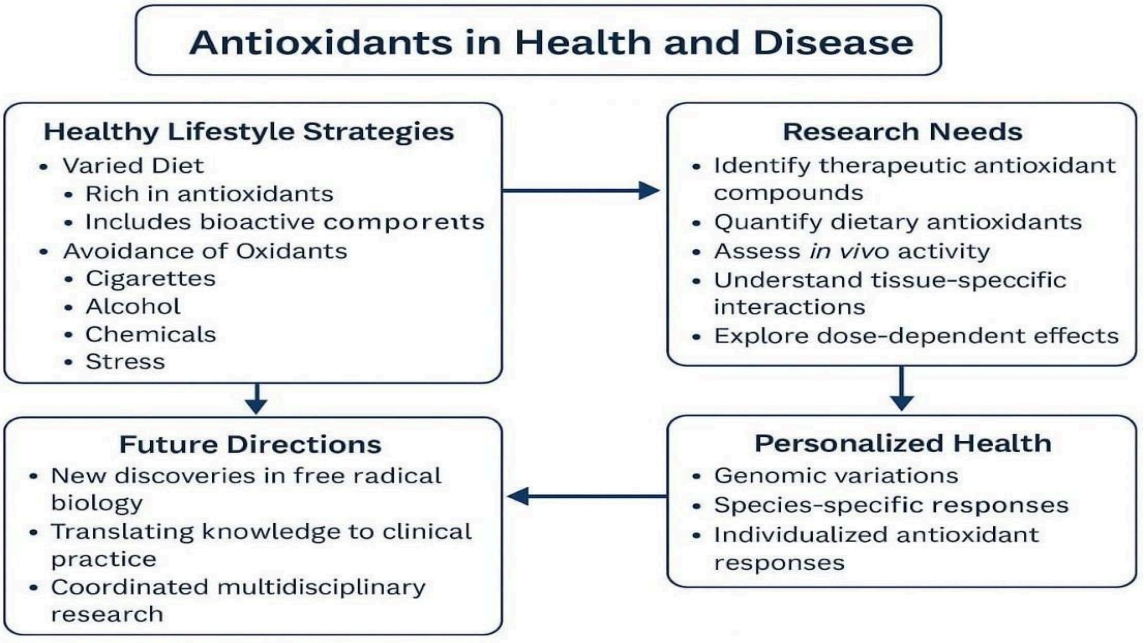

Figure 2. Framework for understanding the role of antioxidants in human health and disease

Mechanism of action of antioxidants:

Antioxidant defense mechanisms are a universal feature across species, although their composition and efficiency may vary. These systems play a critical role in sustaining life by regulating oxidation processes essential for cellular metabolism, immune function, and the maintenance of complex biological structures. However, while oxidation is necessary for life, unchecked oxidative reactions can become harmful, leading to cellular damage and the development of numerous diseases. Oxidation is a chemical reaction that produces reactive oxygen species (ROS), which, when generated in excess, initiate destructive chain reactions. These highly reactive molecules can damage essential cellular components, including lipids, proteins, and DNA. Various exogenous factors—such as pollution, ultraviolet radiation, cigarette smoke, and certain chemicals—can further increase ROS levels, exacerbating oxidative stress and contributing to tissue injury and disease pathogenesis. Antioxidants serve as the body's natural defense against the harmful effects of ROS. These compounds can neutralize free radicals, thus protecting cells from oxidative stress-related disorders. They play a vital role in maintaining cellular homeostasis and optimal physiological function by preventing the formation of new radicals, scavenging existing radicals to interrupt chain reactions, and repairing biomolecular damage caused by oxidative stress.

Antioxidant defense systems operate at several levels, including prevention, radical scavenging, repair, and adaptation. Preventive antioxidants block the initial formation of ROS, while radical scavengers neutralize existing reactive species. Repair antioxidants, particularly those found in the cytosol and mitochondria of mammalian cells, detect and degrade oxidatively damaged proteins, thereby preventing the accumulation of dysfunctional molecules and maintaining protein quality control. In response to oxidative stress, adaptive antioxidants are synthesized and targeted to affected cellular compartments, guided by signaling pathways activated by free radical presence.

Together, these mechanisms reflect the complexity and importance of antioxidant systems in protecting the body from oxidative damage. As research continues to uncover the intricate roles of antioxidants, they are increasingly recognized not only as protective agents but also as potential therapeutic tools in the prevention and management of various oxidative stress- associated diseases.[1]

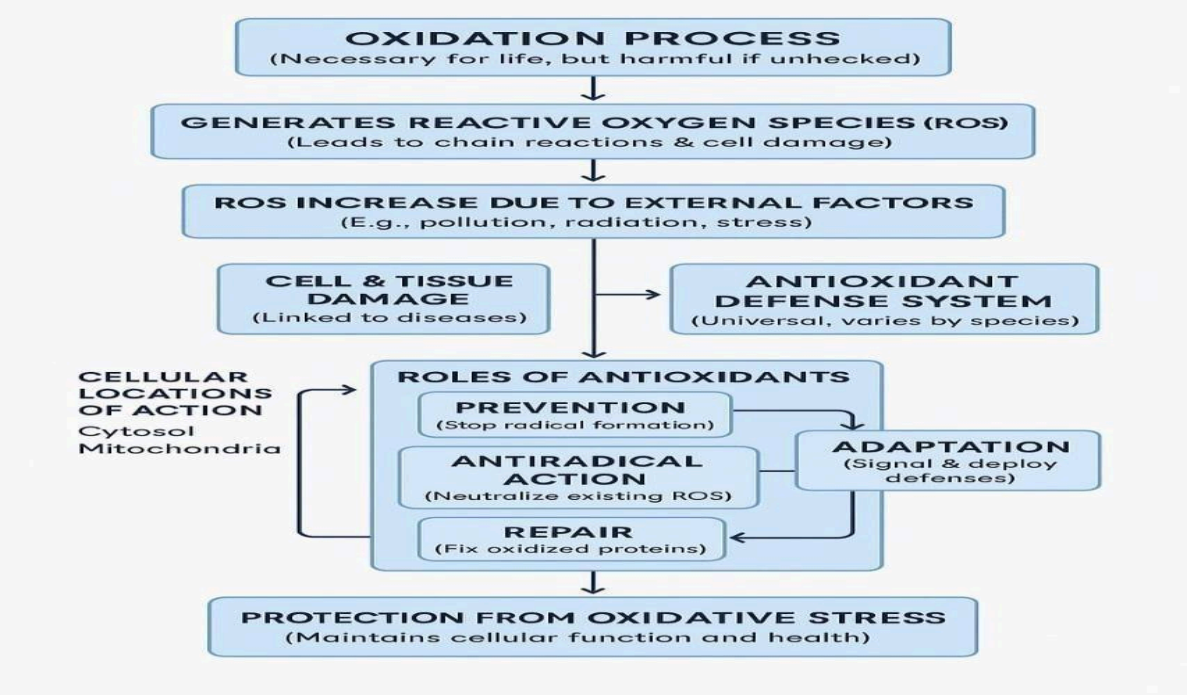

Figure 3.Mechanism of antioxidants.

Antioxidant Based Therapies

Antioxidants help prevent or slow cellular damage caused by free radicals unstable molecules generated by the body in response to environmental stress and other internal factors.The human body naturally produces certain antioxidants, known as endogenous antioxidants, which help defend against oxidative damage. In addition to these, the body also relies on exogenous antioxidants—those obtained from external sources such as food and supplements. Free radicals are unstable molecules that are generated as natural by-products of cellular processes, particularly during the metabolism of food and the body's response to environmental exposures such as pollution and radiation. While the body has mechanisms to manage and neutralize free radicals, an imbalance—where the production of free radicals exceeds the body's ability to eliminate them—can lead to a condition known as oxidative stress. Oxidative stress has been associated with cellular damage and is believed to contribute to the aging process and the development of various chronic diseases. Antioxidants play a crucial role in neutralizing free radicals, thereby supporting overall cellular health and reducing the risk of oxidative damage. [3] Antioxidants are believed to help neutralize free radicals in the body, which may contribute to improve the overall health. antioxidants plays a crucial role in protecting the body from oxidative stress, which is the cellular damage caused by free radicals. Various factors and activities can contribute to oxidative stress, including mitochondrial activity, excessive physical exercise, tissue trauma from inflammation or injury, and ischemia followed by reperfusion damage. Dietary choices also play a role, especially the consumption of refined or processed foods, trans fats, artificial sweeteners, and products containing certain dyes and additives. Additionally, smoking environmental pollution, radiation exposure, and contact with harmful chemicals such as pesticides, industrial solvents, and certain medications including oxidative stress. By neutralizing free radicals, antioxidants help minimize this damage and support overall health. Exposure to such activities and environmental factors can lead to cellular damage, which may trigger a series of harmful biological responses. These include the excessive release of free iron or copper ions, activation of phagocytes (a type of white blood cell involved in immune response), an increase in enzymes that generate free radicals and disruption of the electron transport chain within cells. Together, these effects contribute to oxidative stress. Oxidative stress has been associated with the development of several series health condition including cancer, atherosclesrosis and vision loss. It is belived that free radicals cause cellular changes that may contribute to the onset and progression of these and potentially other diseases. Increase in the intake of other antioxidant is thought to help contract oxidative stress and may reduce the risk of related health issues.Plant-based foods, particularly fruits and vegetables are among the best natural sources of antioxidants. These nutrient-rich foods are often labeled as "superfoods" or "functional foods" due to their potential health-promoting properties. To ensure an adequate intake of specific antioxidants, it's important to include a variety of these foods in your daily diet. Vitamin A can be obtained from dairy products, eggs, and liver, while vitamin C is abundant in fruits and vegetables such as berries, oranges, and bell peppers. Vitamin E is found in nuts, seeds, sunflower oil, other vegetable oils, and leafy green vegetables. Beta-carotene is present in brightly colored produce like carrots, peas, spinach, and mangoes, and lycopene is found in red and pink fruits such as tomatoes and watermelon. Lutein can be sourced from green leafy vegetables, corn, papaya, and oranges. Selenium is available in whole grains like rice, corn, and wheat, as well as in nuts, eggs, cheese, and legumes. Other antioxidant-rich foods include eggplants, legumes such as black or kidney beans, green and black teas, red grapes, dark chocolate, pomegranates, and goji berries. Incorporating a wide variety of these foods into your meals can help support overall health by supplying the body with a broad spectrum of protective antioxidants.[3]

The intricate relationship between free radicals, antioxidants, and the functioning of various organs and systems in the human body has been the focus of extensive scientific inquiry in recent decades. A significant milestone in understanding this relationship has been the discovery of redox signaling, which has provided critical insights into the molecular mechanisms that govern cellular responses to oxidative stress. Antioxidants have garnered considerable attention in recent

years due to their potential roles as both prophylactic and therapeutic agents across a wide range of diseases. Free radicals —particularly reactive oxygen species (ROS) and reactive nitrogen species (RNS)—have been implicated in the pathogenesis of numerous health conditions, including cardiovascular diseases, cancer, diabetes, autoimmune disorders, neurodegenerative diseases, gastrointestinal ailments, ocular disorders, and even the natural aging process. By neutralizing ROS and RNS, antioxidants serve as essential agents that help prevent cellular and molecular damage, thereby supporting the maintenance of physiological balance and promoting overall health. The growing recognition of the role of oxidative stress in disease development has initiated what many consider a medical revolution, reshaping our understanding of disease prevention and treatment. This paradigm shift has opened promising new avenues in healthcare, emphasizing the importance of redox biology in clinical practice and therapeutic innovation. Antioxidants have emerged as promising immune modulators with the potential to be employed both prophylactically and therapeutically alongside conventional medical treatments. Exogenous antioxidant supplements can function in several ways: directly neutralizing free radicals and halting free radical-mediated reactions, preventing lipid peroxidation, and enhancing the body's endogenous antioxidant defense systems. These mechanisms collectively contribute to their therapeutic and preventive benefits.

In recent years, research has uncovered numerous innovative strategies and significant findings regarding the application of antioxidants in health and disease. Natural sources such as foods, spices, and medicinal plants are particularly rich in antioxidant compounds and present a valuable resource for therapeutic development. Several bioactive antioxidants—including epigallocatechin-3-O-gallate, lycopene, ellagic acid, coenzyme Q10, indole-3-carbinol, genistein, quercetin, as well as vitamins C and E—have demonstrated pharmacological efficacy in both the prevention and treatment of various disorders. These compounds target oxidative stress, either by mitigating its damaging effects or by enhancing the body's intrinsic antioxidant capacity.As oxidative stress is a key factor in the pathophysiology of numerous diseases, strategies aimed at managing it through antioxidant supplementation are likely to offer significant clinical benefits. Thus, integrating antioxidant-based approaches into current treatment paradigms holds promise for improving outcomes in a wide range of health conditions. [4]

Challenges in antioxidants and their impact on human health

Despite the presence of endogenous defense mechanisms against reactive oxygen species (ROS), increasing evidence suggests that modern lifestyle changes, dietary habits, environmental pollution, and psychological stress have heightened human susceptibility to ROS-induced oxidative stress. To date, over a hundred disorders have been linked to ROS-mediated pathophysiology. The role of ROS in the aging process is particularly well established. Recent advances in biomedical research have begun to elucidate the molecular underpinnings of free- radical biology and the intricate biological interactions involved in disease progression. Notably, both clinical and experimental studies indicate that the depletion of endogenous antioxidant enzymes under pathological conditions may be counteracted by the administration of exogenous antioxidants, offering promising therapeutic potential.Inspite of sustained interest in the therapeutic potential of antioxidants, several challenges continue to hinder their effective utilization in the prevention and management of human diseases. While dietary antioxidants have been associated with a reduced risk of chronic conditions and an overall promotion of health, translating these benefits into successful clinical outcomes remains complex. The identification and development of both natural and synthetic antioxidants, along with their optimal formulation, pose significant scientific and technological hurdles. Key limitations—such as poor solubility, low permeability, instability during storage, degradation in the gastrointestinal tract, and extensive first-pass metabolism—complicate their bioavailability and therapeutic efficacy. Furthermore, modifications in dosage forms, physicochemical characteristics, biopharmaceutical profiles, and pharmacokinetic behaviours are critical considerations in antioxidant drug development. Although advancements in both the therapeutic and nutritional applications of antioxidants have shown promise, the field has also faced notable setbacks, highlighting the pressing need for more effective strategies in formulation and clinical translation.[5]

Currently, promoting a diverse and balanced diet rich in antioxidant-containing foods remains one of the most effective strategies for harnessing the health benefits of antioxidants and other bioactive food components. Equally important is the avoidance of oxidative stress-inducing factors such as cigarette smoke, excessive alcohol consumption, exposure to environmental pollutants, and psychological stress. Ongoing research is essential to identify and quantify the therapeutically relevant dietary constituents with antioxidant properties, evaluate their in vivo activity, and understand their interactions with biological tissues. Furthermore, elucidating the relationship between antioxidant intake and their dose-dependent physiological effects is crucial to optimizing their role in disease prevention and health promotion. With advances in clinical research and a growing understanding of genetic and interspecies variability, the specific effects and mechanisms of antioxidants are expected to become increasingly clear. The future promises significant progress in the field of free radical biology and antioxidant science, with the potential to translate foundational knowledge into practical, health-enhancing interventions. Achieving this will require coordinated, interdisciplinary research efforts involving biomedical scientists, phytochemists, nutritionists, and clinicians to comprehensively evaluate the role of antioxidants in human health and disease management in the decades to come.[5]

CONCLUSION:

While antioxidants are recognized for their potential health benefits, current scientific evidence does not conclusively establish their effectiveness in improving human health outcomes when considered in isolation. Emerging research indicates that lifestyle factors-such as diet, physical activity, environmental exposures, and individual health conditions-play a significant role in modulating the impact of antioxidants on health. Therefore, a comprehensive understanding of how antioxidants influence health necessitates considering these multifaceted factors collectively. This holistic approach is essential for accurately assessing the potential effects of antioxidants on health conditions and overall survival.[8]

Numerous underutilized fruits and vegetables, such as moringa, tamarind, and jackfruit, are rich in antioxidants and hold significant potential in preventing and managing non-communicable diseases (NCDs) like cancer, diabetes, and cardiovascular ailments. Despite their health benefits, these crops remain largely neglected. Incorporating such antioxidant-rich foods into regular diets can enhance the body's defense against oxidative stress, thereby supporting overall health and reducing the risk of chronic diseases.[1]

REFERENCES

1. TheclaOkeahunwa Ayoka1,* , Benjamin O. Ezema1, ChijiokeNwoye Eze2 and Charles Okeke Nnadi32022;7(3):179-189Antioxidants for the Prevention and Treatment of Non- communicable DiseasesNsukka 410001,EnuguState, Nigeriahttps://www.xiahepublishing.com/2572-5505/JERP-2022-00028
2. Leonel Pereira 1,2* , JoãoCotas 1,2 , Ana Valado 3,4 May 31, 2024Antioxidants from microalgae and their potential impact on human well-being University of Bologna, Italyhttps://www.explorationpub.com/Journals/eds/Article/100848
3. Megan Ware, RDN, L.D. November 8, 2023How can antioxidants benefit our health https://www.medicalnewstoday.com/articles/301506
4. AtliArnarson July 12, 2023Antioxidants Explained in Simple Termshttps://www.healthline.com/nutrition/antioxidants-explained
5. SaikatSen*Raja ChakrabortyNovember 17, 2011y,The Role of Antioxidants in Human Health Kurnool, AndhraPradesh -518 218, Indiahttps://pubs.acs.org/doi/10.1021/bk-2011- 1083.ch001
6. CumaZehiroglu 1, SevimBeyzaOzturkSarikaya 2019 July29The importance of antioxidants and place in today's scientific and technological studiesGumushane University, GumushaneTurkeyhttps://pmc.ncbi.nlm.nih.gov/articles/PMC6828919/

7. Dean Shaban June 26, 2023Health Benefits of Antioxidantshttps://www.webmd.com/diet/health-benefits-antioxidants
8. SimaGoodarzi; MSc1, SimaRafiei; PhD2, Maryam Javadi; PhD*1,3, HosseinKhademHaghighian; PhD1 &SoheilaNoroozi; MSc 14 Feb 2018 A Review on Antioxidants and Their Health Effects Qazvin,Iranhttps://applications.emro.who.int/imemrf/J_Nutr_Food_Secur/J_Nutr_Food_Secur_2018_3_2_106_112.pdf