Functional Foods in Aging and Longevity: Insights from Ethnobotany

CHAPTER 19

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SUMMARY

Plant-based functional foods are increasingly recognized for their potential to enhance health and longevity, particularly in the context of aging populations. These foods, enriched with bioactive compounds such as antioxidants and anti-inflammatory agents, play a crucial role in mitigating age-related diseases by combating oxidative stress and supporting cellular repair. Traditional medicine systems like Ayurveda and Traditional Chinese Medicine have utilized these bioactive substances for centuries, yet the integration of this knowledge into modern dietary practices remains limited. The mechanisms of action and therapeutic qualities of different plant-based foods are essential for regulating biological processes and encouraging healthy aging. To improve health outcomes and address the socioeconomic challenges brought on by an aging population, this chapter promotes the preservation of medicinal plants and the sustainable development of functional foods that capitalize on these natural advantages.

INTRODUCTION

Growing older is a complex procedure characterized by the degradation of cells and molecules that affects tissue function over time, increasing an organism's susceptibility to illness and death (Carmona & Michan, 2016). Diet and lifestyle are essential factors in this endeavor, with nutrition significantly influencing various cellular aging processes. superior plant-based diets that are abundant in bioactive phytonutrients and vital nutrients, can positively affect multiple mechanisms of aging, including inflammation, metabolism, and cellular repair (Jacquier et al., 2024). Longevity, often defined as the length of an individual's life, is affected by environmental and genetic factors, including diet. Populations with the highest life expectancy, such as those from the "Blue Zones" (areas with a high proportion of centenarians), exhibit dietary patterns rich in plant-based foods, suggesting the importance of nutrition in extending lifespan (Buettner, 2005).

Foods that have functional properties are defined as those that offer health advantages that go beyond just nourishment. They include whole foods as well as fortified, enriched, or enhanced options that may positively affect health when frequently ingested and in effective amounts in the context of a diverse diet (Hasler, 2000). The foods are frequently high in vital nutrients, bioactive chemicals, and antioxidants, all of which are linked to a host of health advantages, including as better immunity, better digestion, and a lower risk of developing chronic illnesses like diabetes and heart disease (Sireesha, 2024). Plant-based diets rich in bioactive phytonutrients can help counteract aging markers and lower the risk of chronic diseases. Researchers today promote a positive aging model that emphasizes maintaining functional abilities rather than merely focusing on the lack of illness (Jacquier et al., 2024).

Slowing the aging process remains a critical concern in public health. Prioritizing interventions that promote health throughout the lifespan is essential for improving quality of life. Over the past century, industrialized countries have seen significant increases in life expectancy, which has contributed to a substantial rise in the aging population. By 2030, it is projected that around 20% of the population will be 65 years of age or older. The global increase in the aging population is placing a substantial burden on the economy and society. It is essential to conduct further investigation into the biological processes of aging to support the development of interventions that can mitigate the negative health effects of aging-related health issues, including neurodegenerative disorders, cancer, diabetes, and cardiovascular diseases (Phu et al., 2020).

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The use of plants in medicine to treat, diagnose, prevent disease, and promote health has long been a vital aspect of traditional medicine. Traditional remedies have often served as inspiration for modern medicine, leading to the (re)discovery of effective treatments, as seen with the success of the antimalarial drug artemisinin and the Nobel Prize awarded to Prof. Tu Youyou for her groundbreaking work. This individual recognition underscores the broader significance of traditional medicines. It's important to remember that this is not a unique instance, a lot of plants have played key roles in traditional medical systems such as Chinese, Indian, Japanese, Thai, Korean, African, American, and European medicine (Okoro et al., 2021). Despite antioxidants are not pharmaceuticals, they can significantly contribute to alleviating age-related illnesses and promoting healthy longevity. When consumed in combination with a balanced daily diet, antioxidants provide a broad range of phytochemicals that offer a potential strategy for promoting endurance and treating aging-related conditions such as cardiovascular and neurodegenerative disorders, as well as diabetes. However, despite considerable advancements, some pathological mechanisms are yet unknown, and further investigation into the potential adverse effects of medicinal plants is required. For instance, the impact of plant-based antioxidants on certain enzymes, like XOR, may have unintended interactions with other drugs broken down by the same enzyme. Nevertheless, it is widely acknowledged that bioactive substances derived from plants hold significant therapeutic potential in both disease prevention and treatment. Therefore, additional research is essential to explore under-investigated macro- and micro-molecular aspects. Furthermore, pharmacokinetic and pharmacodynamic studies are needed to expand the development of nutraceuticals, functional foods, and innovative bioactive compounds for future drug formulations (Hano & Tungmunnithum, 2020).

SCIENCE OF AGING AND ITS DIETARY INFLUENCE

Biological Mechanisms of Aging

In humans, aging is inevitable. The slow deterioration of physiological processes and the diminished ability to cope with environmental stresses result in greater susceptibility and vulnerability to disease (Troen, 2003). Aging is driven by both internal and external stressors within cells, which diminish the natural ability of cells to recover. Changes also influence protein homeostasis, chromosomal shape, and genetic information. Key factors such as Telomere shortening, epigenetic modifications, genomic damage, and compromised protein regulation increase as cells, tissues, and organisms age, with accumulated damage further accelerating the aging process. Cellular senescence, marked by a cell cycle arrest that cannot be reversed, is another hallmark of aging cells. Reactive oxygen species (ROS) have complicated, two-phase impacts in aging phenotypes: at optimal levels, they can be advantageous, but an excess of ROS leads to harmful consequences (López-Otín et al., 2023). Cellular senescence offers certain physiological advantages, such as suppressing tumor formation; however, the excessive accumulation of senescent cells amplifies the detrimental consequences of aging [Fig. 1 (Longo et al., 2015)]. The intricate interplay between aging phenotypes and processes has made it challenging to develop effective anti-aging strategies. However, recent findings from phytochemical research suggest a promising approach to reducing the aging process in humans, potentially lowering the likelihood of age-related diseases and enhancing both life expectancy and health span (Pyo et al., 2020).

Nutritional Influence on Aging

Proper nutrition across the entire lifespan plays a critical role in preserving both mental and physical health. It is believed that nutrition during the early and middle stages of life significantly influences the aging process. As a result, studying the connection between diet and aging, especially as it relates to longevity, must take into account dietary factors in early and middle adulthood (Chen, 1986). Both physiological processes and environmental influences cause organisms to spontaneously create reactive species and free radicals (Bhattacharya, 2015). Free radicals are typically produced during ATP (adenosine triphosphate) synthesis in the mitochondria when cells utilize oxygen, a vital component of energy production. A disparity between the excessive production or accumulation of free radicals and the body's ability to detoxify these reactive molecules leads to oxidative stress. Numerous degenerative and age-related chronic diseases are mostly caused by this oxidative stress (Dhalaria et al., 2020). An abundance of proof suggests that one of the main causes of aging is oxidative stress produced in the mitochondria as a consequence of cellular respiration (Martel et al., 2019). Delaying or preventing the progression of such diseases through the use of plants is an appealing strategy for promoting healthy aging (Si & Liu, 2014). A well-balanced nutritional diet is acknowledged as an effective means of combating these diseases, as it significantly impacts aging and health without causing any side effects (Dhalaria et al., 2020). Similarly, polyphenols present in fruits, vegetables, and tea possess anti-inflammatory qualities that help to reduce chronic inflammation and support healthy aging (Scalbert et al., 2005).

ETHNOBOTANICAL APPROACHES TO AGING: CASE STUDIES

Traditional Chinese Medicine (TCM)

Over 10,000 herbal medicines are included in Traditional Chinese Medicine (TCM), some of which were imported from other nations and areas (Shi et al., 2022). Traditional Chinese

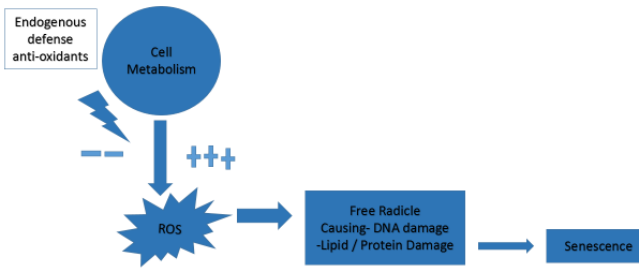

Fig 1. Diagrammatic representation of oxidative stress theory

Medicine (TCM) has a lengthy history of using herbal remedies to promote longevity and treat age-related diseases. One of the most well-known herbs in TCM is Panax ginseng, which is often referred to as the "root of immortality." Studies have demonstrated that Panax ginseng contains ginsenosides, which exhibit antioxidant, anti-inflammatory, and immune-modulatory properties, making it a valuable tool for promoting healthy aging (Ratan et al., 2021). Initial findings from preclinical research have demonstrated the anti-aging properties of Traditional Chinese Medicine (TCM). Chinese herbal remedies slow down intestinal aging by three mechanisms: reducing inflammation, enhancing intestinal metabolites, and modulating gut microbiota. These effects may be linked to the reduction of telomerase mRNA levels in old mice (Shenghua et al., 2020). Extracts from herbs increased levels of movement and better heart health during aging, while simultaneously prolonging the elderly flies' healthy lifespan (Teseo et al., 2021). One polyphenolic substance is curcumin derived from Curcuma longa, has been demonstrated to extend the average lifespan of certain model organisms for aging. According to some theories, curcumin has anti-inflammatory and antioxidant qualities, improves immune cell chemotaxis, and suppresses NF-κB activation (Zia et al., 2021). This implies that during the aging process, Traditional Chinese Medicine (TCM) may positively regulate immunological function. Furthermore, it has been discovered that mulberry leaves help Caenorhabditis elegans live longer. Together, these studies demonstrate TCM's anti-aging properties and hold out hope for creating more robust anti-aging therapy plans (Ding et al., 2024).

Ayurveda

Ayurvedic medicine, originating from India and the Indian subcontinent, is a personalized system of traditional medicine. It emphasizes a comprehensive approach to health, with the intention of maintaining balance and harmony in all aspects of life, including the body, mind, and spirit (Farooqui et al., 2018). For instance, it has been demonstrated that a number of Ayurvedic herbs and formulations, commonly known as Rasayana, greatly improve health, strengthen immunity, increase vitality, and encourage longevity in addition to providing stress protection. These remedies are believed to support healthy aging, slow down degenerative changes, and rejuvenate cells and tissues at various levels (Sharma & Martins, 2020). Ashwagandha is one of the most well-known single-herb Rasayanas. Frequently referred to as Indian ginseng due to its rejuvenating and tonic effects, numerous studies have highlighted its adaptogenic qualities, which aid in stress management. In some investigations, ashwagandha even outperformed ginseng. One study showed that it improved physical endurance, prevented stress-related depletion of vitamin C and cortisol, and reduced gastrointestinal ulcers caused by stress. Its name, meaning “the sweat or smell of a horse” in Sanskrit, symbolizes its ability to impart strength and stamina. It is now widely recognized for enhancing energy and endurance. Ashwagandha’s adaptogenic properties enable the body to manage stress-related conditions by addressing the underlying causes, rather than merely alleviating symptoms with sedative effects.

African and Indigenous Medicines

African native plant species have a rich ethnomedical history and are used for a variety of purposes. They have long been utilized for traditional applications across various African countries. Africa is home to around 400 plant species that are utilized as vegetables, with over 90% of these species being indigenous to the continent. The high micronutrient content and potential therapeutic effects of three native African plants—Adansonia digitata (baobab), Moringa oleifera (moringa), and Hibiscus sabdariffa (hibiscus)—have drawn attention as valuable nutritional elements (Debelo et al., 2023). Worldwide, people have long utilized the fruit of Adansonia digitata, sometimes known as baobab, for its therapeutic qualities. In African nations, several components of the plant have been used to treat diarrhea and dysentery, reduce fever, hydrate people, and act as antiparasitic, antitussive, and sudorific agents. Additionally, research has shown that baobab possesses antioxidant, anti-inflammatory, analgesic, and antimicrobial properties, expanding its known therapeutic applications (Silva et al., 2023). Moringa oleifera's (MO) functional bioactive chemicals are responsible for a variety of biological actions, including antiproliferative, hepatoprotective, anti-inflammatory, antinociceptive, antiatherosclerotic, oxidative DNA damage protection, antiperoxidative, and cardioprotective properties. Phenolic acids, flavonoids, alkaloids, phytosterols, natural sugars, vitamins, minerals, and organic acids are some of these substances that support its many health advantages and traditional therapeutic applications (Saini et al., 2016).

BIOACTIVE COMPOUNDS IN FUNCTIONAL FOODS

Bioactive compounds from food have been studied for their biological effects on the human body, leading to the rise of functional foods as potential options for disease prevention and treatment. Stress and unhealthy lifestyles have been shown to have a detrimental effect on the immune system, raising the risk of infections, cancer, and cardiovascular and cerebrovascular disorders. Therefore, the demand for functional foods and nutraceuticals has significantly increased as a result of greater awareness of the link between nutrition and health (Mondal et al., 2021).

Polyphenols

The health advantages of numerous natural products and nutraceuticals made from foods, plants, and other organisms have been investigated. In recent decades, research on nutrition has placed a great deal of emphasis on polyphenols, which are abundant organic substances found in plants. According to mounting data, polyphenols are essential for controlling weight, metabolism, and chronic illnesses while lowering the risk of age-related degenerative disorders. According to studies, their anti-inflammatory and antioxidant qualities may help prevent or treat non-communicable diseases like obesity, cancer, neurodegeneration, and cardiovascular problems. (Meccariello & D’Angelo, 2021).

Many polyphenolic molecules function as potent antioxidants both in vivo and in vitro, helping to prevent oxidative stress damage. By modulating various signaling

pathways, these compounds support anti-aging activities and have been shown to extend lifespan. Polyphenols have demonstrated positive effects on numerous age-related diseases, impacting overall life expectancy (TeLe). Additionally, the relationship between polyphenolic molecules and apoptosis has been identified as a key mechanism for promoting longevity (Maleki et al., 2020). Plant compounds such as resveratrol, curcumin, quercetin, and catechins, found abundantly in fruits and vegetables like apples, pears, cherries, berries, peppers, and carrots, as well as tea, coffee, olive oil, garlic, and onions, act as potent antioxidants. These compounds enhance the stability of telomerase, supporting longer telomeres and overall longevity. While aging causes telomeres to shorten, these antioxidant-rich foods can help slow down the process, serving as a natural elixir for a longer and healthier life (D'Angelo, 2023).

Vitamins and Minerals

Foods rich in antioxidants are often classified as functional foods. Antioxidants like vitamins A, C, E, and selenium help eliminate harmful particles in the blood that have been linked to heart disease, stroke, and other complications. Examples of antioxidant-rich foods include tea (containing catechins), grape juice (rich in resveratrol), berries (with flavonoids like quercetin), and citrus fruits (containing flavonoids and limonoids). These foods contribute to reducing oxidative stress and supporting overall health (Al-Saqqa, 2021). In modern society, there is a growing focus on optimizing longevity by reducing physical and mental decline and lowering the risk of disease. Nutritional factors, particularly micronutrients like vitamins (A, B, C, D, E, folate) and minerals (copper, iron, magnesium, selenium, zinc), play a key role in this process (Table 1). Though needed in small amounts, micronutrients function as antioxidants, coenzymes, and cofactors in metabolism and genetic regulation. They help maintain immune, nervous, and endocrine system health, protect against oxidative stress, and contribute to successful aging and longevity (Ćurko-Cofek, 2021).

How Functional Foods Promote Longevity

Aging is closely linked to a persistent rise in reactive oxygen species (ROS), the buildup of a low-grade pro-inflammatory state, and a decline in age-related autophagy, indicating that these factors may significantly contribute to the aging process. In fact, reducing ROS and low-grade inflammation, along with enhancing autophagy through calorie restriction or other dietary interventions, has been shown to extend lifespan across a range of model organisms. Notably, recent research suggests that certain small molecules derived from food, known as phytochemicals, can also prolong lifespan in various animal species (Si & Liu, 2014). Calorie restriction (CR) is the only non-genetic intervention shown to extend the lifespan of various model organisms, ranging from yeast to mammals. It helps preserve biological functions by delaying or lowering the risk of many age-related diseases (Fig. 2).

The beneficial effects of CR are linked to several biological mechanisms, such as altering energy metabolism, decreasing oxidative stress, enhancing insulin sensitivity, reducing chronic inflammation, promoting autophagy, supporting neuroendocrine function, and triggering hormesis. The molecular signaling pathways involved in CR's anti-aging effects include sirtuins, PGC-1α, activated AMP-activated protein kinase, insulin/IGF-1, and the mTOR pathway, which together form a complex, interconnected network (Yessenkyzy et al., 2020). However, since most individuals would struggle to adhere to a strict CR diet regimen, it is clear that seeking natural or pharmacological compounds that can mimic the effects of CR without the need to reduce food intake, particularly in middle to older age, is highly advisable. These substances are referred to as calorie restriction mimetics (CRMs). Current potential candidates, such as resveratrol and other polyphenols, rapamycin, 2-deoxy-D-glucose, and other glycolytic inhibitors, target the same signaling pathways as CR. These include the insulin pathway, AMP-activated protein kinase activators, autophagy stimulants, alpha-lipoic acid, and various antioxidants (Chung et al., 2013). Resveratrol, a

Table 1. Examples of positive health effects linked to phytochemicals, vitamins, and trace elements

Substances	Sources	Outcomes	Comments
Beta-carotene	Foods and dietary Supplements*	Negative outcomes on cardioprotective, neuroprotective, anticancer, decreased mortality increased risk of lung cancer especially in smokers	*Positive outcomes could be found only in animal studies on anticancer issues
Vitamin C	Foods and Dietary Supplements	Cancer prevention	
Vitamin E	Foods and Dietary Supplements	Cancer Prevention decreased mortality	
Selenium	Foods and Dietary Supplements	Cancer Prevention +/-	
Polyphenols EGCG catechins	Black and green tea	Cancer Prevention	
Lycopene	Tomato	Antioxidant and Cancer Prevention	
Flavonoid Anthocyanin	Food (dark black color vegetables and fruits esp. berries)	**Antiinflammation, Improves Lipid Profiles, Cancer Prevention	**Positive outcomes can be found in animal studies
Curcumin	Turmeric	Cancer prevention	
Genistein	Soybeans	Cancer prevention	
Ginko biloba	Plant leaves supplements 120-160gm	Improves cognitive function	Caution: May cause herb-drug interaction

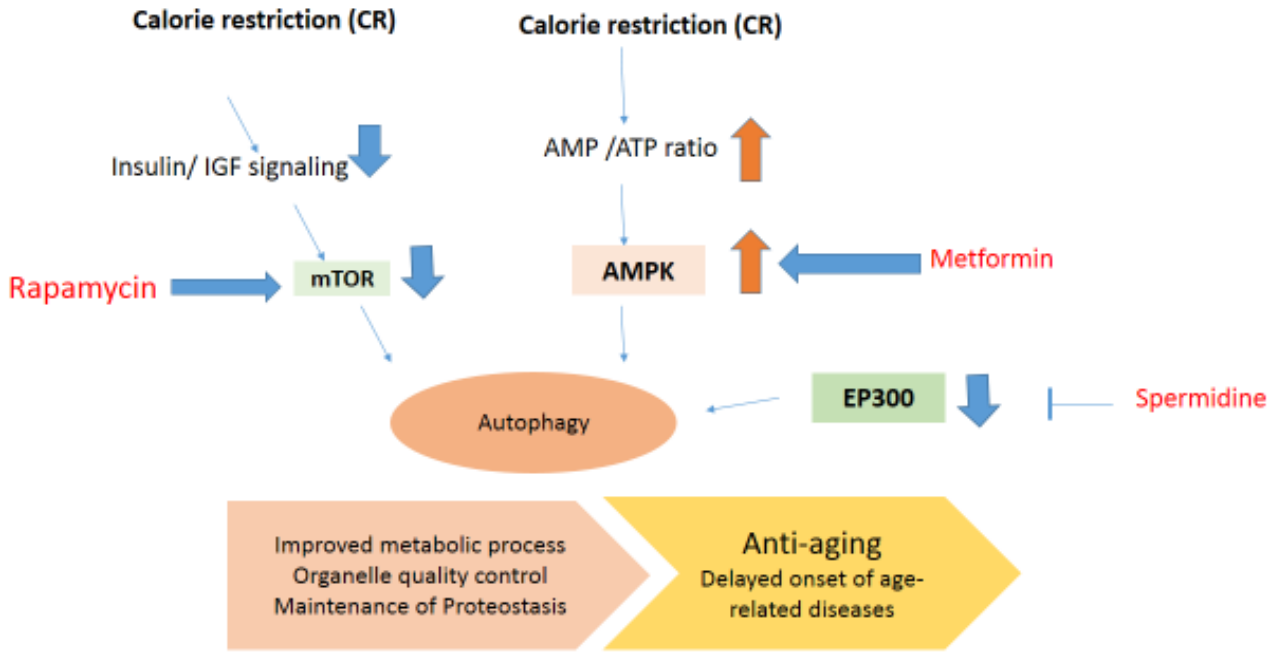

Fig 2. Calorie restriction (CR) and its mimetics regulate autophagy by decreasing mTOR signaling and activating AMPK. CR reduces insulin and IGF levels, increasing the AMP/ATP ratio, which triggers autophagy. Mimetics like rapamycin inhibit mTOR, metformin activates AMPK, and spermidine enhances autophagy by inhibiting EP300)

compound found in red wine and grapes, mimics the effects of calorie restriction by activating sirtuins, a group of proteins that play a key role in cellular stress resistance and longevity (Baur & Sinclair, 2006). Studies have shown that resveratrol supplementation can extend lifespan and improve metabolic health in animal models, making it a promising CRM for humans (Baur et al., 2006).

EMERGING FUNCTIONAL FOODS

The global food concept is shifting from a past focus on hunger relief, preventing nutrient deficiency diseases, and survival, to a growing emphasis on foods that serve as functional ingredients, promoting improved health and overall well-being (Janabi et al., 2020). The earliest references to goji berries are linked to their use in traditional Chinese medicine, where they were utilized as mild Yin tonics, as well as in tinctures and powders (Yao et al., 2021). Additionally, since ancient times, goji berries have been highly prized and consumed in various forms, including raw, dried, or processed into tea, juice, wine, or liqueur (Amagase & Farnsworth, 2011). Recent advancements in instrumental techniques have enabled detailed analysis of the complex composition of goji berries. Studies have revealed that goji berries are rich in nutrients like lipids, proteins, fiber, vitamin C, and minerals, along with non-nutritive bioactive compounds such as phenolic compounds, polysaccharides, and carotenoids. Additionally, in vitro antioxidant tests, in vivo studies, and clinical trials have helped to uncover some of the health benefits of goji berries. This research has led to the development of a new dietary concept, promoting goji berries as a functional food or as ingredients in innovative food products (Vidović et al., 2022). Oxidative stress plays a key role in causing damage to the brain and neurons (Ferreira et al., 2018). In traditional medicine, plant parts such as leaves, stems, roots, flowers, fruits, and seeds have been used as alternatives or complements to pharmaceuticals and synthetic drugs for treating neurodegenerative disorders. Most plant matrices contain antioxidants, which are bioactive compounds that help neutralize reactive oxygen species (ROS) (Santana & Macedo, 2019).

CHALLENGES AND FUTURE DIRECTIONS IN ETHNOBOTANICAL RESEARCH

With the rising popularity of functional foods, concerns about the sustainability and preservation of medicinal plants have also surfaced. Many plants used in traditional medicine are wild-harvested, and over-harvesting can endanger their survival. For instance, Panax ginseng is classified as a vulnerable species due to excessive exploitation for its medicinal benefits. Implementing sustainable harvesting methods and cultivating medicinal plants in controlled environments can safeguard these valuable resources. Furthermore, raising awareness about the importance of biodiversity conservation is essential for ensuring the continued availability of functional foods sourced from ethnobotanical plants. Future research should focus on combining ethnobotanical knowledge with modern scientific methods to thoroughly explore the health benefits of traditional remedies. While ethnobotanical studies offer important insights into the potential therapeutic uses of plants, rigorous clinical trials are needed to confirm these benefits in contemporary settings. Integrating traditional wisdom with advancements in biotechnology and pharmacology could lead to the discovery of new bioactive compounds and the development of innovative functional foods (Fabricant & Farnsworth, 2001).

CONCLUSION

Functional foods play a significant role in promoting aging and longevity, particularly those derived from ethnobotanical sources. In an aging global population, where plant-based bioactive compounds such as antioxidants and anti-inflammatories are seen as promising tools to mitigate age-related diseases. By combining traditional knowledge with modern scientific research, functional foods have the potential to positively influence aging by supporting cellular repair, reducing oxidative stress, and enhancing metabolic processes. The integration of ethnobotanical knowledge and scientific advancements highlights the importance of preserving medicinal plants and studying their bioactive compounds for developing innovative health interventions. It is essential to continue investigating these bioactive substances and to develop sustainable practices for harvesting and preserving medicinal plants. Only through these actions can society fully harness the benefits of functional foods to combat the challenges associated with an aging population and improve health outcomes.

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