Vegetables as Source of Functional Foods and Nutraceutical: Their Role in Disease Prevention

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Abstract
The increased prevalence of non-communicable diseases, such as cardiovascular disease, diabetes, obesity, and cancer worldwide has attracted considerable attention towards diet as a strategy for disease prevention. Vegetables are examined as functional foods, and source of nutraceuticals in the prevention and health promotion against chronic diseases. Vegetables are found to be rich in macronutrients, micronutrients, and fiber content, along with numerous bioactive compounds such as polyphenols, flavonoids, carotenoids, glucosinolates, organosulfur compounds and phytosterols. Clinical, epidemiological, and experimental studies show that these compounds show both anti-oxidative, anti-inflammatory, cardioprotective, anti-carcinogenic, and metabolic regulatory effects on the body through several biological mechanisms. The consumption of vegetables has been inversely associated with incidence of ischemic heart disease, stroke, hypertension, type 2 diabetes, and cancer. This article also covers the trends of developments in the vegetable-based nutraceuticals: nutrigenomics, nanotechnology mediated delivery of nutrients, use of microgreens and agricultural by-products as source of high value bioactives. Even with these exciting trends, we are faced with issues such as bioavailability, phytochemical variability and human clinical trial paucity and regulatory concerns. It is concluded that vegetables form an essential part of preventative nutrition. Increasing the access of vegetables in our diet and vegetables derived nutraceuticals would make a significant impact in alleviating the problem of global NCDs, both health-wise and economic-wise.

Keywords: *Functional foods; Nutraceuticals; Vegetables; Bioactive compounds; Disease prevention; Non-communicable.*

Introduction

Today, the global health panorama is characterized by an increase in non-communicable diseases (NCDs) that account for roughly 70%-73% of world deaths (Upadhyay, 2022; Coates et al., 2020). Cardiovascular diseases, cancer, chronic lung diseases and diabetes are significant in contributing to the worldwide burden of disease; they are associated with risk factors that can be modified, such as unbalanced intake in diet composition as well as in quantity and quality of nutrients (Upadhyay, 2022). Therefore, there has been an increasing interest in functional foods and nutraceuticals from the scientists since these products possess an additional nutritive value in addition to their ordinary nutrients and hence, they can be an important tools in the prevention of diseases at the primary level (Di Cesare, 2019; Upadhyay, 2022). Vegetables are some of the

best-known functional foods and an adequate consumption of many kinds of vegetables is helpful in the prevention of cardiovascular problems, high blood pressure and metabolic diseases (Upadhyay, 2022). The interest on nutritionally driven interventions represents a global shift of paradigm concerning the development of diseases and mortality on human beings.

The increasing prevalence of chronic diseases at the moment, can be perceived as an epidemiological transition that occurred during the industrial revolution (Jakovljevic & Milovanovic, 2015). In the past, human morbidities could be represented as acute bacterial diseases and infectious diseases, that could be resolved within few weeks but with high rate of mortality to the newborns and mothers (Jakovljevic & Milovanovic, 2015). However, it was in the 19th century that the invention of vaccines and antibiotics along with increasing health standards and sanitation created a dramatically longer human life span (Jakovljevic & Milovanovic, 2015; Hambleton et al., 2023).

As human beings began to live much longer than before, the prosperity diseases that previously were only confined to rich people became lifelong diseases that effect the world populations (Jakovljevic & Milovanovic, 2015). With such shift, health systems have begun to focus more on prevention, instead of cure of reactive acute conditions, through a long-term strategy aimed at the prevention and management of chronic diseases (Jakovljevic & Milovanovic, 2015), hence stressing on dietary factors that contribute significantly towards healthy promotion today.

Dietary risks represent one of the major globally health losses, currently ranking highest among traditional health risks, including alcohol consumption, air pollution and others (Coates et al., 2020), the Mediterranean type diet, rich in fruits and vegetables, alongside physical activity appears to be beneficial against the rising incidence of non-communicable diseases (Upadhyay, 2022). Practically, diets low in vegetables (less than 340g and more than 500g/day) is already proved to be leading causes of global deaths and disability (Di Cesare, 2019; GBD 2015 Risk Factors Collaborators, 2016). In reality, vegetables function by helping out to combat against hypertension and diabetes, as functional components like fibres, micronutrients and etc will manage and control blood sugar and lipids levels effectively (Upadhyay, 2022).

As such, health promotion interventions have become focused more on the identification and intervention of such risks factors in order to decrease death of premature disease conditions and also reduce macro-economic burden caused by diseases (Upadhyay, 2022), which led the author to focus on the objectives of the current write-up.With increasing global burdens of NCDs and the relationship between diet and long term health that is already demonstrated, this review aims to provide a comprehensive outlook of vegetables' role as functional foods against the prevalence of diseases and NCDs. This study is expected to synthesize information regarding the impacts of vegetable-rich diets on the incidence of NCDs, particularly diabetes and cardiovascular diseases (Upadhyay, 2022), also examining disparities within global variations of dietary risks factors as nutritional transitions of lower- and middle-income countries affect and influence developing health problems. Furthermore, future prospects of using legislation and legal provisions, along with technology based nutritional monitoring, for improving healthiness of food supply will also be evaluated.

Conceptual and theoretical framework

Foods that contain bioactive ingredients that can affect the human body in a positive manner are known as functional foods. Upadhyay (2022) suggests that food could also be viewed through the role it plays due to the bioactive ingredients such as omega 3 and polyunsaturated fatty acids, used for support of heart health and cardiovascular risks of heart disease. These functional foods

remain in their original food form and are recommended for people with hypertension and blood pressure control. With an increase in life expectancy and the presence of various chronic conditions present today, incorporating these foods into the daily diet has a preventive impact on the metabolic risks related to prosperity diseases (Jakovljevic & Milovanovic, 2015; Upadhyay, 2022). Function foods when incorporated within the existing whole food matrix of daily consumption, is a focused, yet broader application of nutritional intervention, nutraceuticals.

Nutraceuticals refer to those foods or products that can affect health, are taken with medicinal intent or for a broader purpose, which may have health benefits beyond the provision of essential nutrients (Di Cesare, 2019; Upadhyay, 2022). They are commonly taken to treat various illnesses or health conditions and include vitamins, minerals, fatty acids, etc. These nutrients are in their concentrated form and are most effectively delivered in forms that are most commonly known as pharmaceutical dosages or tablets or capsules. Upadhyay (2022) believes that Nutraceuticals play a key role in chronic diseases such as heart diseases with the use of omega 3 polyunsaturated fats for the purpose of managing long term health condition risks such as stroke and myocardial infarction. The difference between these two is that functional food contains, food in its normal composition and form whereas the nutraceutical is the purified bioactive compound found within a food. Understanding the differences between functional foods and nutraceuticals helps provide a focused application of nutritional therapy that goes beyond general dietary guidelines to meet the nutritional needs for clinical intervention (Di Cesare, 2019). To enable further discussion into the application of functional foods and nutraceuticals, we shall first categorise them. The categorisation of functional foods usually occurs in terms of processing, the application in clinical care and for what need. The lowest processed functional foods are also categorised as conventional functional foods. These are food products in their whole state which are also biologically valuable, such as fruits, oily fish and vegetables. These food types have been used to prevent heart disease, whole grains and pulses used for metabolic regulation etc (Upadhyay, 2022). Modified functional foods differ to conventional foods as they are enhanced/fortified and enriched food items for their improved nutritional value. According to Di Cesare (2019) and Upadhyay (2022), these food products are seen to require intervention from the government to improve the supply and nutritional quality. This typically takes form of the fortification of staples to help prevent regional nutrient deficiencies. The final categorisation is that of medical food. Medical foods can be found in the diet and have been developed to meet the requirements of particular dietary management of disease for clinical therapy based on medical prescription or under medical supervision. For instance, low-sugar grains and fibrous food materials are prescribed for the treatment and prevention of diabetes and gestational diabetes for regulation of blood sugar levels (Upadhyay, 2022). Like functional foods that are categorised in relation to their process and nutritional need in clinical therapy, nutraceuticals can also be categorised based on their chemical origin, and method of delivery. Nutraceuticals can be categorised into dietary supplements, herbal products, probiotics/prebiotics and bioactive compounds based on their origin, and biological form which can serve purposes for targeted prevention and therapy (Upadhyay, 2022). The nutritional supplements contain supplements such as multivitamins, multi minerals and fatty acids and are considered beneficial to a person as they can improve lipid profiles and prevent diseases related to the artery walls. Herbal products, on the other hand, refer to plant extracts which are most commonly known for their pain-relieving purposes in medicine for use post-surgery (Updahyay, 2022). Probiotics and Prebiotics which is seen by Upadhyay (2022) as beneficial bacteria and non-digestible fibres supporting beneficial bacteria, have been proved to enhance health. Furthermore, the eating of pulses, whole grains and fibrous foods

supports a prebiotic environment within the digestive system which benefits the microbiome and subsequently contributes to good health (Coates et al., 2020). Bioactive compounds are isolates components of food in isolated chemical form used as health applications and tool kits to address conditions relating to disease as found in the detection and prevention of cardiovascular diseases (Upadhyay, 2022). Understanding the classification and variety of available tools for nutritional enhancement proves the strong link between health and prevention of disease.

Relationship between functional foods and disease prevention

Functional foods are proven to be effective in the prevention of disease through tackling modifiable risk factors that are responsible for the enormous global impact of non-communicable diseases. This is in form of altering food structure that is low in fruits, whole grains and vegetables, these food components have been linked to global mortality and disability (Coates et al., 2020; Upadhyay, 2022). The functional food components address specific pathways in the metabolism. Dietary fibre helps with controlling insulin resistance and glucose levels in diabetes (Upadhyay, 2022) while PUFAs and unsaturated fats replace saturated fats thereby lowering cholesterol and high blood pressure (Upadhyay, 2022). It is important to note the relevance of eating vegetables on a daily basis as the intake of less than 340g- 500g of vegetables per day is associated with increased incidence of ischaemic heart disease, oesophageal cancer and stroke (Coates et al., 2020). Increasing the intake of these functional food components, the life expectancy of disease-free living could be enhanced, and it will reduce the economic and macroeconomic effects of the chronic diseases on the rest of the world (Upadhyay, 2022).

Vegetables as Functional Foods and Sources of Nutraceuticals

The concept of vegetables as functional food is that they have physiological effects in the human body that limit the occurrence of chronical illness and provide more than just the needed nutrition for survival and health benefits. Vegetables are the common part of meals and one of the major sources of nutraceuticals, where biologically active compounds found in food are separated and sold in pharmaceutical form, (e.g powder, capsules) for the beneficial effects on the body (Jalgaonkar et al., 2019; Nicolescu et al., 2023; Singh & Devi, 2015). Based on consumers the trend of consuming these products is increasing for solutions to individual health and also to fight metabolic syndromes like Type 2 diabetes, obesity and cardiovascular diseases according to Awuchi and Okpala (2022) and Saka and Acikgoz (2025). The consumption of vegetables on a daily basis is linked to the reduced risk of the occurrences of stroke and many other types of cancer and also acting as first line of defense against chronic inflammation and oxidative stress (Awuchi& Okpala, 2022). The inherent structure in the nutrition of vegetables including essential and secondary nutrients is responsible for their effects.

Nutritional composition of vegetables

Vegetables are classified as protective food because their nutritional contents (vitamins, mineral, fiber etc) have low caloric density but are highly concentrated (Javed et al., 2019; Panwar et al., 2024; Singh & Devi, 2015). The most available vitamin from vegetables were vitamins K, vitamin C, E, A and the B-complex (Panwar et al., 2024; Singh & Devi, 2015). For instance, carrots are the primary source of beta-carotene, which serves as vitamin A, also broccoli and spinach are rich source of vitamin C and folate (vitamin B9) which is essential in cell division and immunity (Javed et al., 2019; Panwar et al., 2024; Ramya & Patel, 2019). According to Onoruoiza et al., (2024), Ramya & Patel, (2019), and Singh & Devi, (2015) green leafy

vegetables are rich sources of vitamin K, which is a key component in blood clotting and health bone. Javed et al. (2019) and Awuchi& Okpala (2022) have reported that vegetables are a wide source of macro- and micro-minerals which are vital to the metabolism homeostasis. Some examples include iron and calcium present in spinach while sweet potatoes and potatoes are excellent sources of potassium for blood pressure control (Panwar et al., 2024; Singh & Devi, 2015; Javed et al., 2019; Ramya & Patel, 2019). Minerals such as zinc and selenium in vegetables contribute to overall health, they are co-factors of enzymes and act as antioxidant (Javed et al., 2019; Ramya & Patel, 2019). Vegetables are good sources of fiber. Vegetables contain both soluble and insoluble fibers including pectins, cellulose and beta-glucan (Awuchi& Okpala, 2022; Jalgaonkar et al., 2019; Ramya & Patel, 2019). According to Awuchi& Okpala, (2022); Jalgaonkar et al. (2019), Ramya & Patel, (2019), and Wang et al. (2023), the fiber matrix from vegetables is clinically used in diabetes treatment to regulate blood sugar, lower LDL cholesterol thereby reducing the risk of cardiovascular diseases.

Bioactive compounds in vegetables

Bioactive compounds are non-essential compounds that are part of metabolic pathways, which when involved in these pathways may result in desirable health outcomes Martirosyan and Ekblad (2022), Ochoa-Velasco et al. (2017) and Panwar et al. (2024). They are very diverse and are classified by their chemical structure and biological activities (Javed et al., 2019; Panwar et al., 2024). One type of bioactive compound that falls into the large class of over 6,000 different types, are the flavonoids and polyphenols. These compounds include, among others, the anthocyanidins, flavones, and flavonols (Panwar et al., 2024; Fabela-Moron, 2024; Onoruoiza et al., 2024). In particular, flavonoids and polyphenols, possess antioxidative and anti-inflammatory properties that have shown potential for cardiovascular health protection by preventing platelet aggregation Saka &Acikgoz (2025), Singh & Devi (2015), Panwar et al (2024).

Another example of a compound with these properties, are carotenoids which belong to the class of lipid-soluble pigments and their most popular forms are B-carotene, lutein, lycopene and zeaxanthin which give the vegetables their vibrantly colored red, yellow and orange appearance Onoruoiza et al. (2024); Panwar et al., (2024); Ramya & Patel, (2019);Yepshak et al. (2024); Singh & Devi, (2015). These compounds have proven to be excellent singlets of oxygen scavengers thus protecting eyes from eye diseases and different cancers Jalgaonkar et al., (2019); Panwar et al., (2024). Glucosinolates and organosulfur compounds, are another class of compounds found mostly in cruciferous and allium vegetables, sulfur with its various molecules such as sulforaphane and allicin possess potent anti-carcinogenic and anti-microbial properties (Panwar et al., 2024; Awuchi& Okpala, 2022; Jalgaonkar et al., 2019; Singh & Devi, 2015).

Plant sterols, which are also a bioactive compound, are structurally similar to dietary cholesterol and compete for the same receptors for absorption in the small intestine. By this property they effectively lower the risk of cardiovascular diseases by reducing cholesterol levels in the blood (Awuchi& Okpala, 2022; Javed et al., 2019; Sharma et al., 2019). The most effective means to take advantage of this combination of nutrients and compounds, is by consuming specific functional groups of vegetables.

Functional Vegetables and their nutraceutical components

Leafy Green Vegetables

Spinach, lettuce, and Amaranthus species which are nutrient dense with lutein, folate, and Vitamin K (Singh & Devi, 2015; Onoruoiza et al., 2024; Panwar et al., 2024). The mentioned

vegetables have been referred to as superfoods because they have high levels of antioxidants and are capable of protecting against neurodegenerative diseases and anemia as discussed by Panwar et al. (2024). Spinach has also been thought to contain alpha-lipoic acid, a potent antioxidant that aids in detoxification of the liver (Singh & Devi, 2015).

Cruciferous vegetables

These belong to the Brassicaceae family which includes broccoli, cabbage, cauliflower and kale. Brassicaceae vegetables have high quantities of glucosinolates (Favela-Gozalez et al., 2020; Kim & Park, 2009; Sharma et al., 2019). Glucosinolates can be converted to isothiocyanates and sulforaphane by cutting or chewing of the vegetable. These in turn promote the body's phase II detoxification enzymes and inhibit the growth of tumours of the lung, breast and colon (Singh & Devi, 2015; Saka &Acikgoz, 2025). Additionally, Broccoli is a good source of vitamin C and lutein, aiding in the maintenance of the immune system and vision (Javed et al., 2019; Onoruoiza et al., 2024; Jalgaonkar et al., 2019; Singh & Devi, 2015).

Leguminous Vegetables

These are green peas and beans which are unparalleled amongst all the vegetables in having both protein and flavonoid content (isoflavones) (Panwar et al. 2024; Awuchi and Okpala 2022). Genistein and daidzein which act like estrogens and have an effect on menopausal symptoms while inhibiting enzymes that cause growth of tumor (Awuchi and Okpala 2022; Fabela-Moron 2024; Panwar et al. 2024; Singh and Devi 2015) is present in the above vegetables. Additionally, the legumes are an excellent source of soluble fiber, which improves digestion and regulates blood glucose level in diabetics (Ramya and Patel 2019; Jalgaonkar et al. 2019; Awuchi and Okpala 2022; Sharma et al. 2019).

Mechanisms of Disease Prevention by Vegetable-Based Functional Foods

Vegetable-based functional foods exert a variety of actions on the prevention of disease by affecting metabolic, antioxidant, genetic, and cell-signaling processes. These foods contain diverse bioactive compounds known as phytochemicals which are synthesized by plants for defensive mechanisms, but elicit health benefits in humans (Saka &Acikgoz 2025). The main actions include:

1. **Antioxidant Defense and Redox Regulation:** Vegetables are among the first defenses against reactive oxygen species (ROS) and free radicals which induce the damage to cellular systems that leads to inflammatory and degenerative diseases (Javed et al. 2019; Onoruoiza et al., 2024; Panwar et al., 2024). They are divided into two categories:

i Neutralization of Free Radicals: Bioactive phytochemicals (carotenoids, e.g. Lycopene, beta-carotene, and vitamin C, E, selenium) serve as quenchers that stabilize free radicals to the extent that they cannot oxidize cellular components like nucleic acids, proteins, and lipids (Onoruoiza et al., 2024; Jalgaonkar et al., 2019).

ii Inhibition of LDL Oxidation: The primary mechanism in cardiovascular disease is the ability of phenolic compounds (flavonoids and e.g. Lycopene, hydroxytyrosol) to inhibit low-density lipoprotein (LDL) cholesterol oxidation. This prevents the initiation of atherosclerosis and the buildup of arterial plaque (Awuchi& Okpala 2022; Saka &Acikgoz 2025).

iii Activation of Enzymes: Saka and Acikgoz (2025) note the presence of specific phytochemicals such as apigenin in celery activate antioxidant enzymes like superoxide dismutase (SOD) and catalase.

2. **Anti-Inflammatory Signalling Pathways:** Chronic inflammation promotes metabolic syndrome and cancer. Vegetable phytochemicals interfere with signaling pathways in immune response. According to Saka and Acikgoz (2025) anti-inflammatory signals are:

i NF-B Inhibition: Phytochemicals (curcumin, sulforaphane, kaempferol) attenuate inflammation by inhibiting the Nuclear Factor kappa B (NF-B) signaling pathway to downregulate pro-inflammatory cytokines (IL-6, TNF-).

ii Cytokine Regulation: Flavonoids and phenolic compounds abundant in leafy greens and legumes, are able to modulate and regulate cytokines in the production of innate and acquired immunity.

3. **Anticancer and Chemopreventive Mechanisms:** Vegetable-based functional foods protect against various stages of cancer development.

i Phase I and II Enzyme Induction: Isothiocyanates (e.g. Sulforaphane in broccoli) enhance the induction of Phase II detoxification enzymes that facilitate the elimination of harmful compounds and carcinogens from the body (Saka and Acikgoz, 2025).

ii Cell Cycle Arrest and Apoptosis: Sulfur compounds (in Allium vegetables e.g. Garlic, onions) and glucosinolates (in cruciferous vegetables) possess the ability to arrest the cell cycle and promote programmed cell death (apoptosis) of malignant cancer cells to limit the growth of tumors.

iii Pathway Suppression: These phytochemicals produce anticancer activity by modulating various signaling pathways including PI3K/Akt, MAPK, and Wnt/-catenin pathways that are generally overactive in prostate, breast and colon cancers (Saka and Acikgoz, 2025).

4. **Metabolic and Gastrointestinal Regulation:** The rich fibre content and certain phytochemicals in vegetables regulate the metabolism of glucose and lipids.

i Fibre-Matrix Interaction: Dietary fibre can trap fats and sugars in the digestive tract, inhibiting their subsequent uptake in the bloodstream and promoting their elimination.

ii Short-Chain Fatty Acid (SCFA) Production: Fibre in vegetables undergo fermentation by colonic bacteria producing Short Chain Fatty Acids (SCFA, e.g. Butyrate). This provides the colonic epithelial cells with energy and stimulates epithelial regeneration while inhibiting general systemic inflammation.

iii Insulin Sensitivity: Quercetin and kaempferol flavonols in certain vegetables, reduce the cell damage associated with oxidative stress which in turn improves insulin sensitivity and glucose regulation in individuals with diabetes or obesity.

5. **Cardiovascular and Endothelial Protection**: Vegetables affect blood pressure and blood flow via physiological triggers in addition to cholesterol lowering.

i Vasodilation: The compound allicin in garlic is known to function as a vasodilator, and reduce blood pressure through mechanisms similar to ACE inhibitors.

ii Nitric Oxide Production: Flavonoids in dark green leafy vegetables (kale and spinach) are able to increase the levels of nitric oxide (NO) and endothelial function is improved.

iii Anti-thrombotic Effects: Bioactive phytochemicals also inhibit platelet aggregation and may prevent thrombotic stroke or myocardial infarction (Saka and Acikgoz, 2025).

Current Evidence on Vegetables in Disease Prevention

It is well-documented that vegetables act as protective foods, capable of reducing the global epidemic of non-communicable chronic diseases such as CVDs, type 2 diabetes and a wide array of cancers Upadhyay (2022); Favela-Gonzalez et al. (2022); Panwar et al (2024); Yepshak et al. (2025). This protective action is due to their high content of bioactive phytochemicals such as polyphenols, carotenoids, and organosulfur compounds that act as a potent antioxidant and anti-inflammatory agent (Awuchi& Okpala 2022; Saka &Acikgoz, 2025; Yepshak et al. (2024); Singh & Devi, (2015). A diet high in vegetables has been shown to lower the incidence of stroke and ischemic heart disease due to its dense composition of vitamins, minerals and dietary fibers that contribute to maintaining a healthy metabolic balance Javed et al. (2019); Onoruoiza et al. (2024); Ramya and Patel (2019). The role of dietary fiber as a first-line defence against diabetes and obesity, through the modulation of both blood pressure and blood glucose levels Awuchiand Okpala (2022); Javed et al. (2019); Ramya and Patel (2019), has provided convincing evidence for the consumption of these foods. The contribution of components from food from basic nutrition to various biological actions from fighting free radicals to regulation of signal transduction has led to vegetables being identified as an essential functional food, in the prevention of non-communicable chronic diseases Javed et al. (2019); Saka &Acikgoz2025; Sharma et al. (2019), warranting large human studies to evaluate their consumption on health.

Clinical and Epidemiological Evidence

Epidemiological and clinical studies continually indicate a pronounced inverse correlation between higher dietary intake of vegetables and a lower risk of life diseases (Kim & Park 2009; Stanaway et al., 2022; Woodside et al., 2023). A meta-regression analysis estimated that a daily consumption of 306g to 372g is related to a 23.2% reduced risk of stroke and 22.9% reduced risk of IHD (Stanaway et al., 2022). In the Chinese Longitudinal Healthy Longevity Survey, an increasing consumption of vegetables lowered the risk of CVD, especially hypertension among elderly population (Wang et al., 2023).

Compared to different cancer subtypes, Kim and Park (2009) also stated that the association between a higher consumption of cruciferous vegetables and the reduced risk of esophageal and colorectal cancers is "probably". In the metabolic health, a total intake of 5 portions of fruit and vegetable daily (where at least 3 portions were vegetables) resulted in the lowest mortality due to CVD and respiratory illnesses (Woodside et al., 2023). In spite of all the exciting results, the industrial translation from observational studies are accelerating due to the new technical developments in the field of food science.

Emerging Trends in Vegetable-Based Nutraceutical Development

One of the current trends in the production of vegetable-based nutraceuticals is personalized health solutions, by employing areas such as nutrigenomics to customize the intake of nutrients to individuals according to their own genetic makeup (Jalgaonkar et al. 2019; Saka &Acikgoz, 2025). New technologies in production such as 3D printing technology are being investigated in an effort to improve the functional food matrix by accurate delivery of targeted bioactives (Awuchi& Okpala, 2022). Also growing interest lies in microgreens which have been described as concentrated functional bioactives (like sulforaphane) which are capable of delaying the onset of type 2 diabetes. In order to promote better delivery of such unstable molecules, technology such as nanotechnology and gastro-resistant carrier systems are being employed to increase the stability of these phytochemicals during the process of digestion, as well as bio-accessibility

(Onoruoiza et al. 2024; Saka &Acikgoz, 2025). The industry is beginning to look towards waste streams from agricultural waste (like peels and stems of vegetables) as potential resources from which high-value fiber and antioxidants could be extracted (Saka &Acikgoz, 2025). Though the above applications hold significant promise, many challenges remain in their translation to the field and in terms of technical challenges.

Challenges and Limitations

Perhaps one of the biggest difficulties with this field is that currently the majority of evidence suggesting the health properties of phytochemicals is derived from in vitro and animal-based studies and has not yet been rigorously confirmed through clinical trials involving humans (Saka &Acikgoz, 2025; Sharma et al., 2019). Another difficulty with understanding the role that vegetables and their bioactive compounds have on health is that variability in the amount of bioactive compound present within the vegetables themselves varies due to pre-harvest factors such as; the geographical location, genetics of the plant and the climate conditions in addition to storage time and preparation techniques after harvest (Panwar et al., 2024; Woodside et al., 2023). As suggested by Nicolescu et al., (2023) and Saka &Acikgoz, (2025),bio accessibility can also be problematic as due to the complex structure within the matrix of the whole vegetable, sometimes absorption into the body is inefficient. Remaining residual confounding is also often a problem when observational studies are undertaken, since in many cases individuals consuming the most vegetables will also have other healthy lifestyles and so it is often hard to discern if an individual's better health is due to diet alone or due to an exercise routine or not smoking etc (Stanaway et al., 2022). Another significant difficulty with recommending increasing the consumption of conventionally produced vegetables is the presence of pesticide residue, since there is evidence to suggest that this residue can actually reduce the positive effect of the vegetables on cardiovascular disease (Woodside et al., 2023). All these factors coupled with the problems surrounding proving a health claim and obtaining appropriate regulatory measures for nutritional science mean that it is necessary to have a defined strategy for what is required to advance this area further.

Future Perspectives

Future directions of disease prevention via nutrition are expected to involve an integrated, multi-sector approach with vegetable quality and intake at the forefront of national health policies (Geddam, 2016; Wolfenden et al., 2021). Some expected future directions involve the incorporation of microbiota-based nutrition whereby vegetable-derived compounds are utilized to manipulate the intestinal bacteria, within individual dietary prescriptions (Saka &Acikgoz, 2025). The public health dimension should also involve cooking innovation and education to dispel consumer preconceptions of taste and texture of vegetables so that all socio-economic classes increase their daily vegetable consumption (Panwar et al., 2024). There is an opportunity for plant breeding and molecular genetics to create "nutraceutical-enriched" varieties high in certain phenolic acids and vitamins (Woodside et al., 2023; Singh & Devi, 2015). Policy strategies in terms of increased government subsidies for vegetable production and the promotion of community gardens should be developed globally for better access and affordability of vegetables (Panwar et al., 2024; Stanaway et al., 2022). Ultimately, achieving a world "5-a-day" can lead to increased years lived disease-free and alleviate the macroeconomic impact of the NCD pandemic (Woodside et al., 2023).

Conclusion

This review summarizes the functional foods and nutraceutical contributions of vegetables in prevention and treatment of non-communicable diseases. This is evidenced by the fact that vegetables contain nutrients such as vitamins, minerals, and dietary fibers as well as various phytochemicals namely polyphenols, flavonoids, carotenoids, glucosinolates, organosulfur compounds and phytosterols. These components exert disease preventive roles via various mechanisms such as antioxidant protection, anti-inflammatory action, regulation of metabolic processes, gut microbial balance, and cell signaling pathways of carcinogenesis and cardiovascular health. Clinical and epidemiological studies reveal an inverse relationship between dietary consumption of vegetables and the risk of CVDs, type 2 diabetes, stroke and certain cancers. Current advancements in nutrigenomics, nanotechnology and efficient, sustainable extraction of bioactive components from by-products of vegetables opens the door for individualized approach to prevention of disease through dietary intake of functional foods and nutraceuticals from vegetables. Some issues remain, which includes the variation of bioactive compound content of vegetables and bioavailability of some phytochemicals, a lack of human trials for certain phytochemicals and regulatory limitations with health claims. Collectively, increases in vegetable consumption and incorporation of vegetable-derived functional foods and nutraceuticals into public health initiatives may be efficient and low cost strategies to combat chronic disease burden worldwide. Larger scale human trials and better delivery systems for bioactive components and appropriate policies promoting healthy vegetable consumption are needed for the future.

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