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Review Article

Vegetables as Functional Foods: A Review of Their Role in Promoting Human Health and Disease Prevention

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Abstract

India is the world's most populous country and produces nearly 207 million tonnes of vegetables annually, ranking second only to China. It is paradoxical that a country with such high vegetable production potential experiences considerable post-harvest losses, which reduce per capita availability and contribute to poor access to vegetables. Poor access to, and low intake of, vegetables have led to nutritional deficiencies arising from inadequate vitamin and mineral intake, ultimately contributing to many non-communicable diseases (NCDs) prevalent among people, particularly adolescents. This review discusses the status of vegetable production and consumption, the contribution of vegetable groups to food and nutritional security, and the role of bioactive compounds such as polyphenols, carotenoids, lycopene, tocopherols, phytosterols, flavonoids, thiosulphides and glucosinolates. Vegetables, as protective foods containing vitamins and minerals, can help promote immune responses and support the physical and mental well-being of individuals. Consistent inclusion of recommended vegetables in the diet could pave the way for a drug-free system of medicine to cure many non-communicable diseases, besides contributing to vigour. India, with its vast biodiversity of vegetables, particularly tropical vegetables, has considerable scope to provide a balanced diet through the inclusion of recommended vegetables, while also adding variety to the diet. While undernutrition is viewed seriously, overnutrition is also increasing and needs immediate attention, as the country is likely to have nearly one-third of the world's malnourished people in another 30 years. It is paradoxical that India, despite being the second-largest global vegetable producer, might have a larger proportion of people living with nutritional disorders and associated diseases. Hence, it is imperative to address post-production problems contributing to the poor availability of fresh and nutritious vegetables at affordable prices, and to strengthen supply chain management to ensure quality vegetables are available at reasonable prices throughout the year. Considering the importance of vegetables in nutritional security and their inconsistent and insufficient inclusion in daily diets as per National Institute of Nutrition recommendations, this brief review discusses the status of vegetable production and availability, the bioactive components of vegetables and their role in human health, problems associated with poor vegetable intake, and future strategies.

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1. Introduction

Vegetables are an essential part of a balanced diet and add variety to it. Any nutritional imbalance in the diet is considered unhealthy, as it leads to deficiency disorders, including cardiovascular diseases, type 2 diabetes and many types of cancer [1]. The prevalence of overweight and obesity among people is not only the result of excess energy consumption but also the result of inadequate vegetable consumption. Rapid urbanisation has led to changes in the lifestyle and consumption patterns of people, with greater consumption of foods high in energy, fat, sugar and salt, and low consumption of fruits, vegetables and whole grains. The increasing number of people with overweight and obesity is the result of such improper and unhealthy dietary consumption, which harms quality of life and shortens the lifespan. Globally, adult obesity is reported to have doubled since 1990, while obesity among adolescents has quadrupled. Worldwide, more than 390 million people aged between 5 and 19 have been found to be overweight, including 160 million people categorised as overweight [2]. It is observed that nutrition programmes in India primarily address undernutrition, posing challenges in addressing overnutrition [3]. As of 2019, the cost of obesity in India is estimated to be $23.24 billion, with $5.13 billion attributed to direct medical costs. It is estimated to grow 19-fold by 2060 if the current trends continue [3]. This is paradoxical in a country such as India, which is home to one-third of the world's malnourished population, as per the 2018 Global Nutrition Report. The inclusion of vegetables as per dietary requirements in daily meals could reduce the severity of this most common and serious issue, and it is imperative not only to produce more vegetables but also to reduce post-harvest losses and thereby make vegetables available and accessible at a reasonable cost for every individual [4]. Recent studies on the role of vegetables have brought to light their possible effects on cognitive performance and mental health, and regular consumption of vegetables is positively correlated with several aspects of mental health, such as decreased symptoms of anxiety and depression, elevated mood and better cognitive function [5]. Vegetables also provide essential nutrients with fewer calories, making them ideal for maintaining a healthy life and avoiding obesity while ensuring adequate nutrient intake. They contain valuable food ingredients that can be successfully utilised to build up and repair the body. Vegetables are also valuable in maintaining the alkaline reserve of the body [6]. Vegetables are highly regarded for their health-promoting properties and have therefore historically held a place in dietary guidance because of their vitamin, mineral, dietary fibre and, more recently, dietary bioactive content [7, 8]. However, the discussion indicates a continuing gap between high production potential, year-round affordability and accessibility, and the recommended daily inclusion of vegetables, particularly in relation to nutritional security and the prevention of non-communicable diseases. Considering the importance of vegetables in nutritional security and the inconsistent and insufficient supply of vegetables to the common people at affordable rates, this review focuses on the present status of vegetable production and consumption in India and the future strategies to be formulated for shaping a healthy society.

2. Methodology Adopted

The information pertinent to the topic was collected through a comprehensive literature search in Google Scholar and Scopus using the search strings "importance of vegetables in human health" and "medicinal value of vegetables". Articles published after 2020 were mostly cited, with a few earlier references discussing the biochemical constituents of vegetables. Original research papers, excluding abstracts of conferences and seminars, were reviewed. The supporting data relevant to the discussion were extracted from authenticated global and national web sources for reliability and to substantiate the discussion. The data were subjected to thematic evaluation.

3. Vegetables in Food and Nutritional Security

India is the second-largest producer of fruits and vegetables, with a record vegetable production of 207.21 million tonnes from 11.23 million ha [9]. Despite such a high level of production, cereal intake towards meeting the daily calorific requirement appears high, constituting nearly 48.00 and 41.00 percent in rural and urban India, respectively [10]. It is also paradoxical to note that 53 percent of women in the age group of 5 to 49 years are anaemic, and about 9.00 and 10.00 percent of adult women and men are reported to be obese. Undernutrition due to low vegetable intake has led to nearly 35 percent of children being categorised as stunted, 17.30 percent as wasted and 1.60 percent as overweight, all below the age of 5 years.

A diet with an insufficient quantity of one or more nutrients can lead to malnutrition. The World Health Organization defines malnutrition as deficiencies, excesses or imbalances in the consumption of energy, protein and other nutrients, and it includes both undernutrition and overnutrition. Micronutrient deficiencies of iron, zinc and iodine account for 60%, 30% and 15%, respectively [11].

Vegetables, being major sources of vitamins and minerals, can enable the body to produce enzymes, hormones and other substances that are vital for normal metabolism and growth. The high-tech production technologies available for hybrid vegetable production have enhanced total vegetable production considerably in the last few years with a marginal rise in area, ensuring its potential role in alleviating malnutrition and resultant disorders. As with anaemia, another aspect of serious concern is the prevalence of hypertension and diabetes among both genders, not only in urban populations but also in rural populations. The solution to this issue is likely to become more complex, as a demographic shift is expected in the near future, with more of the population in the vulnerable age group of 40 to 74 likely to be added by 2050. The probability of death in India due to NCDs is reported to be around 23.70 percent.

The probability of overcoming nutrition-based issues is further worsened by the burgeoning population, which is likely to touch 9.10 billion by 2050, demanding that global food production be doubled, with average global per capita land availability of just 0.27 ha and 0.12 ha at the national level. Moreover, with the recent announcement of the new guidelines on carbohydrate intake in adults and children, WHO has recommended fruit and vegetable consumption in children and adolescents, specifying a level of 250 g/day for children aged 2–5 years, 350 g for the age group 6–9 years, and 400 g as the recommended level for adults and the age group $\geq$ 10 years [12].

Vegetables, being protective and capable of yielding more per unit area, could prove to be suitable alternatives for food and nutritional security. Vegetables, as a rich source of fibre, could aid better bowel movement and offer protection against colon cancer, besides lowering blood cholesterol. The phytochemicals contained in vegetables help to offer protection against cancer and cardiovascular diseases, besides improving the human immune system through the supply of vitamins and minerals. They also aid in neutralising the acid secreted during protein/fat digestion, making them ideally labelled as "protective foods". As per the dietary recommendation of ICMR-NIN, a regular intake of 350 g of vegetables could contribute 5 percent (100 kcal) of the daily energy requirement, besides providing 4 g of protein, 1 g of fat and 17 g of carbohydrate [2]. Vegetables are also regarded as low-glycaemic-index foods, and thus suited for diabetic regulation.

Bioactive compounds include many essential and non-essential compounds, which are abundantly present in vegetables, such as vitamins and other phytochemicals, and have many beneficial health effects. Among the different bioactive compounds, polyphenols, carotenoids, lycopene, tocopherols and phytosterols are considered the most important in the human diet [13]. Carotenoids and xanthophylls are important pigments supplied by vegetables. Carotenoids offer protection against colorectal cancer, breast and prostate cancer, besides protecting the skin from UV rays. They help in improving the immune system and provide oxidative protection to glutathione phase II detoxification enzymes (GS transferase) in the liver, thus aiding in eliminating pollutants and toxic materials from the body. Xanthophylls comprise compounds with positive biological effects, viz., canthaxanthin (red orange), cryptoxanthin, zeaxanthin (yellow orange) and astaxanthin (red), and provide antioxidative protection to vitamin A, vitamin E and other forms of carotenoids [14]. Vitamins A and C are essential for keeping the immune system strong. The integrity and functionality of epithelial tissues, which have a protective role as a barrier against infections, depend on vitamin A. Further, vitamin A helps in maintaining T and B lymphocyte activity, both of which are considered inevitable for adaptive immunity [5].

Evidence suggests that regular inclusion of vegetables in the diet is associated with a lower risk of several adverse health outcomes, including ischaemic heart disease (IHD), stroke, type 2 diabetes and oesophageal cancer [15]. The 2019 Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) estimated that 429,000 (95% uncertainty interval (UI) = 340,000–718,000) deaths and 13.0 million (8.25–17.5) disability-adjusted life years (DALYs) were attributable to low vegetable consumption globally in 2019.

Flavonoids are another important group of compounds found widely in lettuce, onion, broad bean and other vegetables, including quercetin, kaempferol, myricetin and luteolin. Flavonoids are capable of preventing LDL cytotoxicity in cell lines and thereby reducing atherosclerosis and coronary heart diseases. The richness of vegetables in calcium, phosphorus and iron is important for bone health and the prevention of anaemia, while zinc, copper, manganese and selenium are found to be effective in optimising insulin metabolism and lowering plasma cholesterol levels [13].

Alliin and methiin are the major thiosulphides present in onion, garlic and leek, which are highly unstable and converted to diallyl thiosulphinate and thiosulphinate by the action of alliinase and allinlyase. Thiosulphides are capable of reducing cholesterol and fatty acid synthesis, preventing peroxidation of LDL, enhancing fibrinolysis, improving fluidity of erythrocytes, increasing antioxidant status and inhibiting angiotensin-converting enzymes. Cruciferous vegetables are therefore reported to protect the lungs, while tomatoes and peppers protect against oesophageal and prostate cancer.

Bitter gourd is rich in charantin, which has high hypoglycaemic properties or other actions of potential benefit against diabetes mellitus. Bitter gourd also contains insulin-like peptides and alkaloids capable of preventing glucose absorption from the intestine. It has been reported that the additive and synergistic effects of phytochemicals in vegetables are responsible for their potent antioxidant and anticancer activities, and that the benefit of a diet rich in fruit and vegetables is attributed to the complex mixture of phytochemicals present in whole foods [16].

The enormous diversity available in vegetables can help in catering to every dietary requirement of human beings, as rightly pointed out by Dr M. S. Swaminathan: “There is a horticultural remedy for every nutritional malady.” Thus, it becomes an absolute necessity to improve the availability and affordability of nutrient-dense vegetables.

3.1. Cucurbitaceous Vegetables

Cucurbits act as purgatives, anthelmintics, anti-inflammatory agents and cardioprotective foods. The tetracyclic triterpenoids present in cucurbits are responsible for their bitterness, and the anti-inflammatory property is mainly due to the ability of bitter compounds to inhibit cyclooxygenase enzyme involved in mediating inflammation and pain [14]. Bitter gourd contains charantin, vicine (a glycoalkaloid in the seed) and polypeptide-p (insulin-like protein), all of which contribute to its hypoglycaemic properties[17].

The juice of bottle gourd fruit is a good remedy for heart and urinary problems, as well as for diabetics. The seeds contain lagenin, a novel ribosome-inactivating protein with ribonucleolytic property, offering defence against diseases [18]. The fruits of musk melon are used as a tonic, laxative, diuretic and diaphoretic. It is also used in the treatment of chronic eczema, a non-contagious chronic inflammation leading to dry, red, itchy patches. The fruits are also found to be powerful antioxidants.

Pumpkin fruit gives a cooling effect, increases appetite, cures leprosy and purifies the blood. It has cucurbitane and hexane cucurbitane glycosides and other triterpenoids. An anti-ulcer type of cucurbitane has been isolated from pumpkin seeds. Ash gourd is praised for its ability to manage peptic ulcer, haemorrhage, asthma, cough, diabetes, epilepsy and other nervous disorders [19]. Cucumber aids in relieving constipation and indigestion, acts as a coolant and demulcent. Glycosides containing anti-ulcer properties are also reported to be present in leaves and seeds [19].

3.2. Solanaceous Vegetables

Tomato is the richest source of lycopene and vitamin C. Lycopene plays a vital role in fighting against cancerous cell formation. Its high potassium level helps to support nerve health, and its high iron content helps to maintain blood health. The presence of vitamin K plays a role in blood clotting, while anthocyanins protect against cancer [20].

Brinjal is rich in phenolic compounds, viz., caffeic acid and chlorogenic acid, and flavonoids such as nasunin, which is present as part of the anthocyanin pigment in the peel of eggplant. Anthocyanin is capable of preventing cardiovascular dysfunction and exerts a protective effect on pancreatic cells. Chlorogenic acid has antimutagenic (anticancer), antimicrobial, anti-cholesterol and antiviral properties. Fruits contain flavonoids such as myricetin and kaempferol, which are very effective in controlling blood cholesterol [21].

Capsaicin, a major component of chilli, has antibacterial, anticarcinogenic, antidiabetic and analgesic properties. It is found as the main ingredient in topical analgesic ointments as a pain reliever. It helps in reducing LDL cholesterol in obese individuals. Chillies are also rich in antioxidants such as beta-carotene, lutein, zeaxanthin, cryptoxanthin and vitamin C.

The starch present in potato offers protection against colon cancer, improves glucose tolerance and insulin sensitivity, and lowers plasma cholesterol and glyceride levels. The tuber storage protein ‘patatin’ has antioxidant activity. Kukomines present in potato have blood-pressure-lowering properties. Potato also contributes a small amount of selenium and folate, which are involved in DNA and RBC formation [22].

3.3. Bulbous Vegetables

Sulphur contained in onion protects against stomach and colon cancer. The pigment quercetin has anti-inflammatory properties. The presence of fructo-oligosaccharides in onion stimulates the growth of healthy bacteria and suppresses harmful bacteria in the colon, such as *Salmonella, Bacillus* and *E. coli*. Regular consumption of onion can lower blood pressure and the serum levels of cholesterol and triglycerides. Osteoclasts, the cells that break down and resorb bone tissue in repair activity, are inhibited by Gamma-L-glutamyl-trans-S-1-propenyl-L-cysteine-sulfoxide (GPCS) present in onion. Garlic is capable of stimulating intestinal peristalsis and helps in creating digestive juices. The presence of allicin gives antibacterial and antifungal activity. Quercetin, diallyl disulphide and alliin present in garlic have the ability to block cancer-causing agents such as nitrosamine and aflatoxins linked to liver, lung and gastrointestinal disorders [23].

3.4. Cruciferous Vegetables

Crucifers are rich in isothiocyanate and sulforaphane, the biotransformation products of glucosinolates. These are capable of blocking the enzymes responsible for tumorous growth in the liver, lung and gastrointestinal tract. Broccoli is rich in sulforaphane, which can arrest the cell cycle and cause apoptosis of cancerous cells. The indole-3-carbinol in broccoli and cabbage is also found to be anticancerous [19].

3.5. Yam Vegetables

Steamed corms of *Colocasia* contain around 30 percent starch and 3 percent sugar and are considered a high-energy food. The leaves and petioles are considered good sources of vitamins A and C, and the pressed juice of the petiole is used as a styptic or astringent and may be used to arrest arterial haemorrhage, as well as an antidote to the stings of wasps and other insects. Elephant foot yam is another vegetable used in the treatment of piles, enlargement of the spleen, tumours, asthma, bronchitis, nausea, abdominal pain and elephantiasis as an anti-inflammatory agent [24].

3.6. Moringa

All parts of the plant act as cardiac and circulatory stimulants. Leaves are rich in vitamins A and C and serve as emetics. The roots are used in treating intermittent fever, hysteria, palsy, chronic rheumatism, dropsy, enlargement of the spleen and dyspepsia.

3.7. Root Vegetables

Carrot is known for its richness in vitamin A, besides the presence of B1, B2, C and D. It increases urine excretion and thereby eliminates uric acid. It serves as an appetiser, anti-dysenteric, carminative and cardiotonic. It cures leprosy, piles, burning sensation, thirst, biliousness (nausea) and tumours. It contains bioactive polyacetylenes, including falcarindiol, falcarindiol-3-acetate and falcarinol, which have anti-inflammatory and anticarcinogenic properties.

Beetroot contains phenolic acids such as caffeic acid, ellagic acid, syringic acid, vanillic acid and ferulic acid, besides flavonoids, viz., rutin, myricetin, kaempferol and quercetin. The pigments present in beetroot include betaxanthin, iso-betanin and betanin. The oxalic acid found in this root encourages the development of nephroliths, which is not suited for people with kidney disorders. Antioxidant, antidepressant, antimicrobial, anti-inflammatory, diuretic, aphrodisiac and carminative properties are reported to be present in beetroot. The antioxidant activity of betanin present in the root extract is 10 times higher than that of tocopherol and 3 times higher than that of catechin.

Radish contains glucosinolates and their derivatives, such as isothiocyanates, nitriles and cyano-epithioalkanes, besides essential oils, flavonoids and other polyphenolic compounds. The microgreens of radish contain a significantly greater amount of glucosinolate (3.8-fold) and isothiocyanates (8.2-fold) than mature radish taproots. Radish is recommended as a hepatoprotectant (liver), diuretic, antimicrobial, antioxidant, anti-inflammatory, antithrombotic, antiscorbutic and astringent. It is also considered a natural remedy for stomach bloating, inadequate digestion, gallstone prevention and promotion of bile production and bile function.

Turnip is valued for its anticancer property, which is due to the presence of 2-phenylethyl isothiocyanate, phenylpropionitrile, brassica phenanthrene A, 6-paradol and trans-6-shogaol.

3.8. Tuber Crops

It is informed that about 6 percent of the world's dietary energy is provided by tropical tubers. They can play a pivotal role in overcoming hidden hunger, as they contain carotene, fibre, omega-3 fatty acids and other minerals.

Tapioca contains antioxidant substances, viz., coniferaldehyde, isovanillin, 6-deoxy jacaerubin, scopoletin, syringaldehyde, pinoresinol, p-coumaric acid, ficusol, balanophonin and ethamivan, and is found useful in the treatment of coeliac disease of the small intestine, bone and neurological issues, cardiovascular diseases, and issues associated with the prostate, gastrointestinal tract and blood pressure.

4. Biofortification in Vegetables – A Novel Approach

Biofortification is a combination of two terms, namely 'bio', which originated from a Greek word meaning life, and 'fortification', a Latin word that means strengthening. Biofortification aims to enhance the nutritional content of crops, thereby mitigating the adverse impact of human malnutrition resulting from deficiencies in essential vitamins and minerals [25]. Biofortification is a strategy involving the breeding of nutrient-rich crop varieties, offering a sustainable, cost-effective and long-term solution to overcome hidden hunger. It helps in enhancing levels of micronutrients such as iron, zinc, iodine and vitamin A in vegetable crops, offering a greater role in improving nutritional security, particularly among rural populations in developing and underdeveloped countries [11]. Considering the nutritional importance of vegetables and the wide diversity available among species, efforts are focused on breeding varieties/hybrids enriched with nutrients. Carotene-rich sweet potato (Sree Kanaka, Bhu Sona, Bhu Kanti and Bhu Ja), anthocyanin-rich sweet potato (Bhu Krishna), anthocyanin-rich greater yam (Sree Neelima), carotene-enriched cauliflower (Pusa Beta Kesari 1), anthocyanin-rich radish (Pusa Jamuni) and carotene-rich radish (Pusa

Gulabi) are a few examples. Madhunban Gajar is a high-carotene carrot bred by a farmer with as high as 275 mg/g of carotene. Similarly, anthocyanin- and carotene-rich cauliflower hybrids (Valentena and Carotena) are also available in the market.

Each vegetable group contains a unique combination and amount of phytonutriceuticals, which makes it distinguishable from other groups and vegetables within its own group. Inclusion of vegetables in daily meals is strongly associated with improvement of gastrointestinal health and good vision, besides a reduced risk of heart disease, stroke, chronic diseases such as diabetes, and some forms of cancer. Most phytochemicals contained in vegetables are strong antioxidants and are thought to reduce the risk of chronic diseases by protecting against free-radical damage, modifying metabolic activation and detoxification of carcinogens, or even influencing processes that alter the course of tumour cells. Nutrition is not merely a quantity issue but also a quality issue, and vegetables in all forms ensure an adequate intake of most vitamins and nutrients, dietary fibres and phytochemicals, which can bring a much-needed balance to solve many nutrition-related problems that ultimately result in many non-communicable diseases [26].

Table 1: List of Bio fortified Vegetables from ICAR [4]

Crop	Variety	Special feature
	Pusa Beta Kesari 1	Developed by ICAR-IARI, New Delhi in 2015; country's first biofortified cauliflower; contains high b-carotene (8.0-10.0 ppm) in comparison to negligible b-carotene content in popular varieties; curd yield: 40.0-50.0 t/ha.
Potato	Bhu Sona	Developed by ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala in 2017; high b-carotene (14.0 mg/100 g) content as compared to 2.0-3.0 mg/100 g b-carotene in popular varieties; tuber yield: 19.8 t/ha; dry matter: 27.0-29.0%; starch: 20.0%; total sugar: 2.0-2.4%
Sweet Potato	Bhu Krishna	Developed by ICAR-Central Tuber Crops Research Institute in 2017; high anthocyanin (90.0 mg/100g) content in comparison to popular varieties which have negligible anthocyanin content; tuber yield: 18.0 t/ha; dry matter: 24.0-25.5%; starch: 19.5%; total sugar: 1.9-2.2%; salinity stress tolerant.
Radish	Pusa Jamuni	Developed by ICAR-IARI, New Delhi in 2012; first purple fleshed unique trait nutritionally rich radish variety. Distinct advantage in root size, shape, yield and consumer preference over the existing varieties. Higher anthocyanins and ascorbic acid.
Radish	Pusa Gulabi	Developed by ICAR-IARI, New Delhi in 2012; first entire pink fleshed unique trait nutritional rich radish variety. Medium root size, cylindrical shape, optimal yield and consumer preference over the existing varieties. High total carotenoids, anthocyanins and optimal ascorbic acid.

5. Conclusion

This brief review on the potential of vegetables as protective foods reveals the importance that they could play in alleviating malnutrition and thus help in protecting against many non-communicable diseases that are becoming prevalent in society, with the present lifestyle and food style followed by the active age group. The wide diversity of vegetable germplasm available needs exploration to further strengthen the gene pool in this regard.

With such a high production potential of vegetables and their potential to contribute towards a balanced diet, it is a prime duty to make vegetables available to common people at modest prices and to inculcate the habit of making the prescribed vegetables a part of the daily diet. Children and youth may be encouraged to consume more vegetables by formulating new recipes, which would go a long way in alleviating the most common deficiency disorders reported among youth, children and women, especially pregnant women. While efforts to sustain the production and productivity of vegetables amid climate resilience need to be strengthened, the importance of proper post-harvest management practices for vegetables also assumes greater significance in the present context of the Indian and global nutritional status of common people.

Further, the supply of safe vegetables to consumers is also receiving priority, as vegetables can be contaminated by biological hazards, such as pathogenic organisms, including bacteria, viruses and parasites, as well as chemical and physical hazards.

Article Information

Disclaimer (Artificial Intelligence): The author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.), and text-to-image generators have been used during writing or editing of manuscripts.

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