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From Farm to Pharmacy: Exploring the Medicinal and Nutraceutical Potential of Vegetables

*Priyanga S, V. Kanthaswamy, M. S. Marichamy, V. Krishnan, N. Bavya and B. Bavithra
Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Pondicherry University, Karaikal-609603, U.T. of Puducherry, India
*Corresponding Author's email: priyanga6122002@gmail.com

Vegetables are essential components of a healthy diet and important sources of vitamins, minerals, dietary fibre and bioactive compounds. In addition to their nutritional contribution, vegetables contain phytochemicals such as polyphenols, flavonoids, carotenoids, glucosinolates and organosulfur compounds that are being investigated for their antioxidant, inflammatory and metabolic effects. Several commonly consumed Indian vegetables illustrate this potential. Bitter gourd (*Momordica charantia*) and fenugreek (*Trigonella foenum-graecum*) have been studied for possible effects on glucose metabolism; moringa (*Moringa oleifera*) leaves provide micronutrients and phenolic compounds; and leafy vegetables contribute folate, iron and carotenoids. Tomato, carrot, cruciferous vegetables, garlic, onion and brinjal provide additional nutrients and phytochemicals of physiological interest. However, the presence of a bioactive compound does not by itself establish a therapeutic effect. Health outcomes depend on composition, bioavailability, preparation, quantity consumed and the strength of human evidence. This review discusses the bioactive potential of vegetables, their relevance to dietary diversity and preventive nutrition, and opportunities for horticultural production, postharvest management and value addition. Vegetables should be considered components of a varied, balanced diet and not substitutes for prescribed medicines.

Keywords: Bioactive compounds; Functional foods; Indian vegetables; Medicinal potential; Nutraceuticals; Phytonutrients; Preventive nutrition

Introduction

Vegetables supply essential nutrients and dietary fibre and contribute to dietary diversity. Growing interest in plant-derived bioactive compounds has expanded their importance beyond the prevention of nutrient deficiencies. Polyphenols, carotenoids, glucosinolates and organosulfur compounds are studied for their possible effects on oxidative processes, inflammatory signalling and metabolic pathways. Their effects in humans, however, depend on the amount consumed, bioavailability, food preparation and the overall dietary pattern (Narra *et al*., 2024; Saini *et al*., 2015). India's varied agroclimatic conditions support the cultivation of leafy vegetables, gourds, solanaceous crops, crucifers, roots and tubers. The second advance estimates for 2023–2024 placed Indian vegetable production at approximately 204.96 million tonnes, indicating the scale and importance of the sector (Press Information Bureau, 2024). This production base offers opportunities to strengthen dietary diversity and develop value-added products. The World Health Organization recommends more than 400 g of fruits and vegetables per day as part of a healthy diet (WHO, 2023), while Indian dietary guidance provides a separate national recommendation for vegetables and fruits (ICMR–NIN, 2024).

In this review, the expression 'farm to pharmacy' describes the pathway from cultivating vegetables containing bioactive compounds to understanding their possible health relevance. It does not imply that vegetables can replace medicines or clinical treatment.

Bioactive Compounds in Vegetables

Phytonutrients, also called phytochemicals, are naturally occurring plant substances involved in pigmentation, flavour, aroma, adaptation and defence. Many are not classified as essential nutrients, but selected compounds may influence biological processes. Important groups found in vegetables include:

• Polyphenols and flavonoids: Present in onions, leafy vegetables and brinjal; they are investigated for antioxidant and other biological activities.

• Carotenoids: Beta-carotene, lutein and lycopene occur in carrots, dark-green leafy vegetables and tomatoes. Their biological availability varies with the food matrix and preparation.

• Glucosinolates: Characteristic of cruciferous vegetables such as cabbage, cauliflower and broccoli; tissue disruption can promote the formation of biologically active breakdown products.

• Organosulfur compounds: Found in garlic and onion and responsible for characteristic flavours; they have been investigated in laboratory studies for several biological activities.

• Dietary fibre: Supports bowel function and can influence glucose absorption and intestinal microbial activity.

Bioactive compounds must be released from the food matrix, absorbed and metabolised before they can exert effects in the body. Laboratory antioxidant activity or an effect observed with an isolated extract cannot automatically be interpreted as a clinical benefit from eating the whole vegetable (Narra *et al*., 2024; Saini *et al*., 2015).

Potential Health Relevance

Antioxidant activity and oxidative stress

Oxidative stress occurs when reactive molecules exceed the capacity of biological antioxidant and repair systems. Vitamin C, carotenoids and several polyphenols have been investigated for their interactions with reactive oxygen species and related processes. Tomatoes provide lycopene, carrots provide beta-carotene, and dark-green leafy vegetables contain lutein and beta-carotene. Concentrations vary with genotype, maturity, growing conditions and handling. Laboratory antioxidant assays do not establish the magnitude of a health benefit in humans; dietary and clinical evidence is also required (Saini *et al*., 2015).

Inflammation and cardiovascular health

Polyphenols and compounds derived from glucosinolates have been investigated for their influence on inflammatory signalling. Vegetables also provide fibre, potassium, folate and vitamins that contribute to overall dietary quality. A vegetable-rich dietary pattern may support cardiovascular health, particularly when combined with appropriate sodium intake and other healthy lifestyle practices. The effects of an individual vegetable should not be separated from the wider diet and lifestyle (WHO, 2023; Narra *et al*., 2024).

Glucose regulation and metabolic health

Some forms of dietary fibre can slow digestion and carbohydrate absorption and may support satiety and bowel health. Bitter gourd contains constituents being investigated for possible effects on glucose metabolism, while fenugreek seeds contain soluble fibre, including galactomannan. Findings vary with preparation, dose and study population. Evidence from extracts or supplements should not be assumed to apply to ordinary food servings. People with diabetes should not reduce or discontinue prescribed medication because they consume these vegetables; concentrated preparations require particular caution.

Gut health

Vegetables provide different types of dietary fibre and fermentable carbohydrates. Their fermentation by intestinal microorganisms can produce short-chain fatty acids, including acetate, propionate and butyrate, which contribute to intestinal and metabolic functions. A

varied intake of leafy greens, gourds, roots and cruciferous vegetables supplies a broader range of fibre components than relying on a single vegetable. Gut microbial composition is influenced by several dietary and lifestyle factors, so specific microbiome claims require appropriate human evidence.

Indian Vegetables with Nutraceutical Potential

Bitter gourd (*Momordica charantia*): Bitter gourd, commonly known as karela, is widely used in Indian cuisine. Its phenolic compounds and other constituents have been investigated for possible effects on glucose utilisation and metabolic pathways. Results differ among preparations and study designs. It is best regarded as a nutritious vegetable with research interest, not as a replacement for diabetes medication. Individuals using glucose-lowering medicines should seek professional advice before taking concentrated preparations.

Moringa (*Moringa oleifera*): Moringa leaves and immature pods are consumed in soups, curries and other preparations. The leaves contain protein, dietary fibre, minerals, vitamins and phenolic compounds, making them useful for dietary diversification. Laboratory and animal studies have examined antioxidant and metabolic properties of moringa extracts, and some human research has explored possible effects. Current evidence is not sufficient to establish moringa as a treatment for a specific disease. Its practical value is as a locally available leafy vegetable that contributes nutrients to everyday meals.

Fenugreek (*Trigonella foenum-graecum*): Fenugreek is used as a leafy vegetable, spice and seed crop. Its seeds contain soluble fibre, including galactomannan, as well as saponins and other constituents. Research has examined possible effects on post-meal glucose and blood lipid levels, but outcomes depend on the preparation, dose and population studied. Findings from seed supplements should not be treated as proof that ordinary servings of fenugreek leaves produce identical effects.

Green leafy vegetables: Amaranth, spinach, fenugreek leaves and moringa leaves provide varying quantities of folate, carotenoids, vitamin C, minerals and dietary fibre. Iron and folate are important for normal blood formation. Plant-derived iron is generally less readily absorbed than haem iron, and compounds such as phytates can influence its absorption. Consuming vitamin C-rich foods such as guava, amla or lemon alongside plant sources of iron can improve non-haem iron absorption. Established anaemia requires appropriate assessment and treatment; leafy vegetables alone may not correct it.

Tomato (*Solanum lycopersicum*) and carrot (*Daucus carota*): Tomato is a dietary source of lycopene, the carotenoid responsible for the red colour of many varieties. Heating and the addition of a modest amount of oil can improve lycopene bioaccessibility in some preparations, although heat-sensitive nutrients may be reduced. Carrot is an important source of beta-carotene, which the body can convert into vitamin A. Vitamin A supports normal vision, immune function, growth and epithelial tissue maintenance. Beta-carotene content varies with cultivar, maturity, storage and preparation.

Cruciferous vegetables: Cabbage, cauliflower and broccoli belong to the family Brassicaceae and contain glucosinolates. When plant tissues are cut, chewed or otherwise disrupted, glucosinolates can be converted into breakdown products, including isothiocyanates. These compounds have been studied for their influence on cellular defence pathways. Research on cruciferous vegetable intake and chronic disease risk does not justify describing these vegetables as stand-alone cancer-preventive medicines (IARC, 2003).

Garlic, onion and brinjal: Garlic and onion contain organosulfur compounds; onion also contains flavonoids such as quercetin. Their biological activities have been investigated mainly in laboratory and other experimental settings, and findings from concentrated extracts cannot automatically be applied to normal culinary servings. Brinjal (Solanum melongena) contains phenolic compounds, including chlorogenic acid, while purple-skinned types contain anthocyanin pigments. The composition varies among genotypes and growing environments, creating opportunities to consider nutritional traits alongside yield, fruit quality and consumer preference in breeding programmes.

Vegetables, Functional Foods and Preventive Nutrition

Vegetables are valuable as foods because they combine essential nutrients, fibre and diverse bioactive compounds. Their possible health benefits are most appropriately considered within the overall dietary pattern. No single vegetable supplies every essential nutrient or prevents all chronic diseases. The Dietary Guidelines for Indians emphasise dietary diversity and the inclusion of different vegetables and fruits (ICMR–NIN, 2024). Different colours can help consumers diversify their choices: green leafy vegetables provide folate and carotenoids; orange-coloured vegetables provide beta-carotene; tomatoes provide lycopene; and cruciferous vegetables provide glucosinolates. Colour is not a complete measure of nutritional quality, but it is a practical guide to including a range of vegetables. Locally available crops such as amaranth, drumstick, pumpkin, carrot, tomato, okra, brinjal, cabbage and gourds can contribute to dietary diversity. WHO recommends more than 400 g of fruits and vegetables daily; this is a combined fruit-and-vegetable recommendation, not a recommendation for vegetables alone (WHO, 2023). The ICMR–NIN 2024 guideline separately recommends at least 400 g of vegetables and 100 g of fresh fruits daily. These recommendations should be quoted distinctly.

Processing, Preparation and Postharvest Management

The nutritional quality of vegetables can change between harvest and consumption. Genotype, maturity, storage temperature, transportation, cutting, cooking and processing influence nutrient retention and bioavailability. Thermal processing may increase or decrease individual compounds depending on the vegetable and processing conditions (Narra *et al*., 2024). Vegetables should be washed before cutting or peeling. Prolonged soaking and washing after cutting can increase the loss of some water-soluble nutrients. Steaming can limit leaching because vegetables are not immersed in water. Boiling may transfer nutrients into the cooking water, which can be used in soups or gravies. Short stir-frying can preserve some nutrients, and a modest amount of oil may improve the absorption of fat-soluble carotenoids. Raw consumption preserves some heat-sensitive nutrients but is not necessarily optimal for every vegetable. No single cooking method is best for all crops. High temperatures, mechanical injury, unsuitable humidity and prolonged storage can affect appearance, texture and nutrient composition. Appropriate cooling, packaging, handling and transportation help maintain quality and reduce postharvest losses. These practices are important for fresh vegetables and for produce marketed on the basis of nutritional or functional properties.

Opportunities for Horticulture and Value Addition

Consumer interest in nutrition creates opportunities for horticultural systems to focus on yield, quality, nutritional traits and market demand. Genetic variation within vegetable crops can influence the concentration of nutrients and bioactive compounds. Breeding programmes can evaluate these traits alongside yield, shelf life, pest and disease resistance, processing suitability and consumer acceptance. A high concentration of one compound alone does not guarantee profitability; cultivar selection must also consider agronomic performance, input costs and market access. Bioactive composition can be influenced by genotype, temperature, light, soil fertility, irrigation, maturity and biotic or abiotic stress. Organic and conventional systems can both produce nutritionally valuable vegetables. It is not scientifically justified to claim that one production system always increases antioxidant content by a fixed amount. Good agricultural practices, balanced nutrient management, appropriate irrigation, integrated pest management and timely harvesting remain important for safe, high-quality produce.

Potential value-added products include dried leafy vegetable powders, dehydrated flakes, frozen or minimally processed vegetables, vegetable-based soups and standardized food ingredients. Suitable processing by-products may also be used where food-safety requirements are met. Development of nutraceutical products requires evidence on composition, safety, stability, bioavailability and health effects. Disease-related claims must comply with applicable regulatory requirements.

Public Health, Food Safety and Consumer Awareness

Vegetables can contribute to micronutrient adequacy and dietary diversity, but their benefits depend on affordability, availability, food safety and household food practices. Seasonal crops, locally adapted varieties, kitchen gardens, community gardens and diversified production can improve access to fresh produce. Better storage, transport and marketing infrastructure can reduce losses and support a consistent supply. Food safety is as important as nutrient content. Contamination may arise from unsafe irrigation water, poor handling, environmental pollutants or inappropriate pesticide use. Farmers should follow registered pesticide labels and pre-harvest intervals and adopt integrated pest management where appropriate. Produce should be handled and washed properly, and monitoring against applicable residue limits is important for consumer protection. Consumers can improve dietary diversity by including different vegetables across the week, combining leafy vegetables with gourds, roots and other seasonal crops, pairing plant sources of iron with vitamin C-rich foods, and using suitable cooking methods. Vegetables should be treated as components of a balanced diet rather than substitutes for prescribed medicines.

Conclusion

Vegetables are important sources of essential nutrients, dietary fibre and diverse bioactive compounds. Indian vegetables such as bitter gourd, moringa, fenugreek, leafy greens, tomato, carrot, crucifers, garlic, onion and brinjal offer opportunities for nutritional diversification and research on functional food properties. However, the presence of phytochemicals or biological activity in experimental studies does not establish that a vegetable can treat or prevent a disease. Future work should strengthen human evidence, assess realistic dietary quantities and bioavailability, and integrate nutritional quality into crop improvement, postharvest management and value addition. Linking sustainable vegetable production with dietary diversity and consumer education can contribute to nutrition security and public health.

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