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Nutritional value and safety risks of fruits and vegetables: An integrated review

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Abstract

Fruits and vegetables are indispensable components of human nutrition, supplying essential vitamins, minerals, antioxidants, dietary fiber, and phytochemicals that collectively sustain physiological functions and reduce the risk of chronic diseases. Their consumption has been consistently associated with improved cardiovascular health, enhanced immunity, reduced obesity prevalence, and protection against certain cancers. Recent research highlights that these benefits are increasingly compromised by contamination risks across the farm to market supply chain. Pesticide residues, heavy metals, and microbial pathogens represent major hazards, with chronic exposure linked to endocrine disruption, carcinogenesis, renal and neurological disorders, and recurrent food borne outbreaks.

Keywords: Fruits and vegetables, nutritional benefits, food safety, pesticide residues, heavy metal contamination

1. Introduction

Fruits and vegetables constitute a cornerstone of human nutrition, providing essential vitamins, minerals, antioxidants, and dietary fiber that collectively sustain physiological functions and mitigate the risk of chronic diseases (WHO, 2023). Their regular intake has been consistently associated with improved cardiovascular health, enhanced immune function, reduced obesity prevalence, and protection against certain cancers (Kala and Singh, 2022) [14]. However, the nutritional benefits of fresh produce are increasingly undermined by contamination risks that arise during cultivation, harvesting, transportation, storage, and marketing. These risks are particularly acute in developing countries, where regulatory oversight and infrastructure remain inadequate, thereby amplifying concerns for food safety and public health (FAO, 2024). India, with its extensive agricultural base and reliance on wholesale markets, exemplifies these challenges. Wholesale markets serve as critical distribution hubs, ensuring affordability and accessibility of fresh produce to millions of consumers. Yet, studies and media reports have repeatedly highlighted issues such as unhygienic handling, pesticide residues, heavy metal accumulation, and microbial contamination (Yadav, 2023; Times of India, 2022; Dainik Bhaskar, 2022) [35, 31, 4]. Similar concerns have been documented across other developing nations, underscoring a global pattern of weak regulatory enforcement, poor infrastructure, and limited awareness among vendors and consumers (Jairath and Purohit, 2025) [12]. The World Health Organization estimates that unsafe food contributes to over 600 million illnesses and 420,000 deaths annually worldwide, with fruits and vegetables ranking among the most common sources of contamination (WHO, 2023).

Chemical contaminants, particularly pesticide residues and heavy metals, represent pressing hazards. Excessive or improper pesticide application leaves residues that have been linked to endocrine disruption, fertility problems, neurological disorders, and carcinogenesis (Sutradhar, 2024) [30]. Heavy metals such as lead, cadmium, and arsenic enter the food chain through industrial pollution and improper waste disposal, accumulating in edible tissues and posing long term risks including kidney damage and developmental abnormalities (Chauhan and Sharma, 2025) [2]. Microbial pathogens such as *Escherichia coli*, *Salmonella*, and *Listeria* mono cytogenes further compromise food safety, especially under conditions of poor sanitation and inadequate storage (Wang and Wu, 2026) [32].

Vulnerable populations, including children, the elderly and immune compromised individuals, are disproportionately affected by such contamination. Within India, regional agricultural practices intensify these risks. In Rajasthan, extensive use of fertilizers and pesticides to counter arid soils and enhance productivity has been linked to residues exceeding recommended safety limits (Yadav, 2023) ^[35]. Industrial and mining activities further contribute to heavy metal contamination of soil and water, which in turn affects crops and consumers (Chauhan and Sharma, 2025) ^[2]. Wholesale markets, while socio-economically vital, often lack adequate infrastructure, sanitary facilities, and regulatory enforcement, creating an environment conducive to contamination (Jairath and Purohit, 2025) ^[12].

The public health implications of consuming contaminated produce are profound, ranging from acute gastrointestinal illness to chronic conditions such as cancer and neurological disorders (Sutradhar, 2024) ^[30]. Despite the scale of the problem, systematic studies that integrate nutritional quality, contaminant levels, and health risks remain limited. This review therefore aims to synthesize existing evidence on the safety of fruits and vegetables in wholesale markets, with particular reference to contamination pathways, health outcomes, and regulatory challenges. By consolidating current knowledge, the review seeks to highlight gaps in research, inform policy development, and propose strategies for strengthening food safety standards.

2. Review of Literature

Fruits and leafy vegetables are rich in vitamins, minerals, fiber, and phyto chemicals that promote immunity, cardiovascular health, and disease prevention. Their bioavailability is influenced by anti nutritional factors and

preparation methods, while phyto chemicals such as flavonoids and carotenoids provide antioxidant and chemo preventive effects. Despite nutritional benefits, contamination risks persist across supply chains due to pesticide residues, heavy metals, and microbial pathogens. Chronic pesticide exposure is linked to endocrine disruption and carcinogenesis, while heavy metals like lead and cadmium bioaccumulate, causing renal, neurological, and developmental disorders. Microbial hazards including *E. coli* and *Salmonella* further compromise food safety under poor sanitation and storage. Collectively, the literature highlights the dual role of fruits and vegetables as essential for health yet vulnerable to contamination, necessitating stricter regulation, sustainable practices, and improved infrastructure.

2.1 Nutritional and Functional Roles of Fruits and Leafy Vegetables

Fruits and leafy vegetables are indispensable in human nutrition, serving as reservoirs of vitamins, minerals, dietary fiber, and bioactive compounds that collectively sustain physiological well-being and reduce chronic disease risk. Micronutrients such as vitamin A, C, and E, along with iron, calcium, magnesium, and potassium, play critical roles in immune defense, collagen synthesis, antioxidant protection, hemoglobin formation, bone mineralization, and cardiovascular regulation (Table 1). Their bioavailability is influenced by anti nutritional factors (oxalates, phytates) and preparation methods, with evidence showing that vitamin C enhances iron absorption and dietary fats improve carotenoids uptake (Pathak, 2022; Devirgiliis *et al.*, 2024) ^[21, 5].

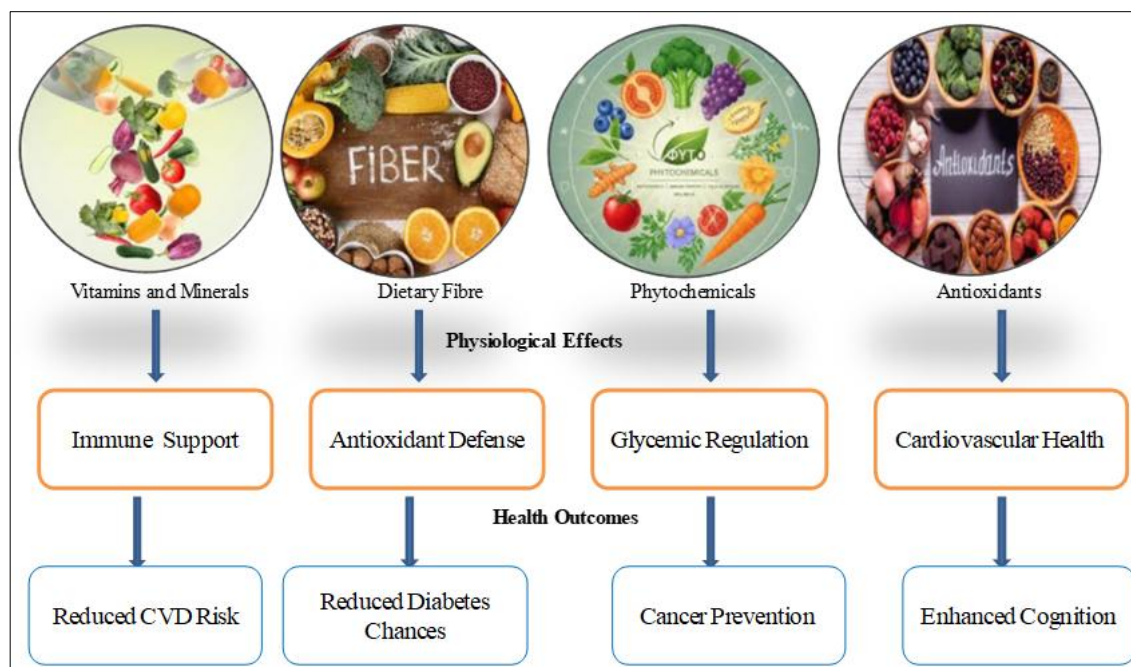


Fig 1: Nutritional Pathways and Health Benefits of Fruits and Vegetables

Phytochemicals including flavonoids, carotenoids, polyphenols, glucosinolates, and phytosterols exhibit antioxidant, anti inflammatory and chemo preventive properties. Lutein and zeaxanthin protect against age related macular degeneration, while polyphenols modulate oxidative stress pathways implicated in cancer and neurodegenerative

disorders (Have a Plant, 2026) ^[11] (Fig.1). Dietary fiber contributes to glycemic control, cholesterol reduction, and gastrointestinal health, reinforcing the role of fruits and vegetables in preventing non communicable diseases (WHO, 2023).

Table 1: Micronutrients in Fruits and Leafy Vegetables: Composition, Bioavailability and Health Roles

Micronutrient	Primary Sources	Physiological Role	Bioavailability Factors	Disease Prevention Function	Public Health Relevance	References
Vitamin A (β-carotene)	Spinach, carrots, pumpkin	Vision, epithelial integrity, immune defense	Enhanced with dietary fats; reduced by cooking losses	Prevents night blindness, supports immunity	Critical for child health in developing regions	Kala <i>et al.</i> , 2020 [13]
Vitamin C	Citrus fruits, strawberries, spinach	Collagen synthesis, antioxidant, iron absorption	Heat sensitive; enhanced in raw intake	Reduces cardiovascular risk, prevents scurvy	Improves iron absorption in vegetarian diets	FAO, 2020 [8]
Vitamin E	Nuts, leafy greens	Antioxidant protection, immune modulation	Requires lipid medium for absorption	Lowers oxidative stress, reduces inflammation	Important in aging populations	Komal Sharma and Meena, 2023 [26]
Iron	Spinach, amaranthus, broccoli	Hemoglobin synthesis, oxygen transport	Enhanced by vitamin C; inhibited by phytates	Prevents anemia, supports cognition	Maternal and child health priority	Parihar and Choudhary, 2023 [18]
Calcium	Broccoli, kale, fenugreek leaves	Bone mineralization, neuromuscular function	Reduced by oxalates; improved with vitamin D	Prevents osteoporosis, supports skeletal health	Essential for elderly and women's health	Kala <i>et al.</i> , 2020 [13]
Potassium	Bananas, spinach, lettuce	Fluid balance, blood pressure regulation	Stable in raw produce	Reduces hypertension, lowers stroke risk	Cardiovascular disease prevention	FAO, 2020 [8]
Magnesium	Leafy greens, legumes	Enzyme cofactor, energy metabolism	Bioavailability influenced by phytates	Reduces metabolic syndrome risk	Diabetes prevention strategy	Parihar and Choudhary, 2023 [18]

2.2 Food Safety Challenges in Fresh Produce Supply Chains

Despite their nutritional importance, fresh produce supply chains are vulnerable to contamination at multiple stages. At the farm level, indiscriminate pesticide use and irrigation with polluted water introduce chemical hazards. Post harvest handling practices such as inadequate washing and poor sanitation facilitate microbial contamination, while weak cold chain management exacerbates spoilage (WHO, 2022; Pearson *et al.*, 2024) [33, 22]. Wholesale markets often lack proper sanitation and waste management, compounding risks. These systemic weaknesses highlight the need for integrated monitoring, vendor training, and adoption of modern technologies such as block chain traceability.

2.3 Toxicological Perspectives on Pesticide Residues

Pesticide residues remain a pressing toxicological concern. Chronic ingestion has been linked to endocrine disruption, neurotoxicity, reproductive impairment, and carcinogenesis. Organo chlorines persist in adipose tissue, while organophosphates inhibit acetyl cholinesterase activity, leading to neurological dysfunction. Recent reviews confirm that pesticide residues in fruits and vegetables can offset the health benefits of consumption, particularly when residues exceed permissible limits (Bansal, 2023; Sandoval-Insausti *et al.*, 2022; WHO, 2022) [1, 25, 33].

2.4 Heavy Metal Contamination in Agricultural Produce

Heavy metals such as lead, cadmium, arsenic, and mercury are non biodegradable and accumulate in soil, water, and crops. Industrial effluents, fertilizers, and wastewater irrigation contribute significantly to contamination pathways. Chronic exposure has been associated with nephrotoxicity, hepatotoxicity, neurodegenerative disorders, and carcinogenesis. Recent studies emphasize seasonal variability in contamination, with higher accumulation during monsoon driven runoff (Kamal and Yadav, 2026; Rashid *et al.*, 2023) [16, 24]. Mitigation strategies include phytoremediation, stricter enforcement of permissible limits, and sustainable agricultural practices.

2.5 Microbial Hazards in Fruits and Vegetables

Fresh produce provides an ideal environment for microbial colonization due to high moisture and nutrient content. Pathogens such as *E. coli* O157:H7, *Salmonella* spp., and *Listeria mono cyto* genes contaminate crops through wastewater irrigation and poor sanitation. Post-harvest handling and inadequate storage amplify risks, while outbreaks of food borne illness continue to be linked to contaminated produce (FAO and WHO, 2023; Food Safety News, 2023) [6, 9]. Preventive measures such as good agricultural practices (GAPs), hygiene protocols, and hazard analysis systems remain essential.

Table 2: Microbial Contaminants in Fruits and Vegetables: Sources, Risks and Outbreak Evidence

Pathogen	Common Produce Affected	Transmission Pathway	Health Impact	Vulnerable Groups	Example Outbreaks/Regi ons	References
<i>E. coli</i> O157:H7	Leafy greens, sprouts, cucumbers	Irrigation with contaminated water, manure	Severe diarrhea, hemolytic uremic syndrome	Children, elderly	US spinach outbreak (2006)	Kumar <i>et al.</i> , 2021; Singh and Meena, 2022 [17, 29]
<i>Salmonella</i> spp.	Tomatoes, melons, papayas	Soil, water, poor handling practices	Gastroenteritis, systemic infection	All populations	US tomato outbreak (2008)	Patel and Desai, 2020; Sharma <i>et al.</i> , 2021 [20, 28]
<i>Listeria monocytogenes</i>	Ready to eat salads, cut fruits	Cross contamination during storage/packaging	Miscarriage, neonatal infection, meningitis	Pregnant women, newborns	US cantaloupe outbreak (2011)	Chauhan and Yadav, 2021; Rao and Verma, 2019 [3, 23]
Norovirus	Berries, lettuce,	Infected handlers,	Vomiting, diarrhea,	All populations	European berry	Sharma <i>et al.</i> , 2021;

	frozen fruits	contaminated irrigation	dehydration		outbreaks (2012-2014)	Singh and Meena, 2022 [28, 29]
Hepatitis A virus (HAV)	Strawberries, pomegranates	Contaminated water, infected handlers	Liver inflammation, jaundice	All populations	US frozen pomegranate outbreak (2013)	Patel and Desai, 2020; Chauhan and Yadav, 2021 [20, 3]
<i>Cyclospora cayentanensis</i>	Basil, lettuce, raspberries	Wastewater irrigation, poor sanitation	Prolonged diarrhea, fatigue	Immunocompromised individuals	US imported basil outbreak (2019)	Rao and Verma, 2019; Singh and Meena, 2022 [23, 29]
<i>Giardia lamblia</i>	Leafy greens, cucumbers	Irrigation with untreated wastewater	Gastrointestinal illness, mal absorption	Children, immunocompromised	South Asian vegetable studies	Gupta and Meena, 2020; Sharma <i>et al.</i> , 2021 [10, 28]
<i>Cryptosporidium spp.</i>	Spinach, lettuce, herbs	Contaminated irrigation water	Diarrhea, dehydration, chronic infection	HIV/AIDS patients, children	UK salad outbreak (2015)	Chauhan and Yadav, 2021; Patel and Desai, 2020 [3, 20]
<i>Shigella spp.</i>	Leafy greens, carrots	Poor hygiene during handling	Dysentery, fever, abdominal cramps	Children, elderly	India vegetable outbreaks	Kumar <i>et al.</i> , 2021; Rao and Verma, 2019 [17, 23]
<i>Clostridium perfringens</i>	Cooked vegetables, salads	Improper storage, temperature abuse	Food poisoning, diarrhea, cramps	All populations	Global salad outbreaks	Sharma <i>et al.</i> , 2021; Singh and Meena, 2022 [28, 29]
<i>Aspergillus spp.</i> (fungal)	Stored nuts, dried fruits	Poor storage, humidity	Mycotoxin exposure (aflatoxins → liver cancer)	All populations	Documented in tropical climates	Gupta and Meena, 2020; Patel and Desai, 2020 [20]

2.6 Role in Disease Prevention and Health Promotion

Regular intake of fruits and leafy vegetables is strongly associated with reduced risk of non communicable diseases. Their synergistic mix of vitamins, minerals, fiber, and phytochemicals protects against cardiovascular disorders, type-2 diabetes, obesity, and certain cancers. Antioxidants such as vitamin C, vitamin E, and carotenoids neutralize free radicals, lowering oxidative stress and slowing the progression of atherosclerosis and neurodegenerative conditions. Dietary fiber improves glycemic control, reduces cholesterol, and supports gastrointestinal health, thereby preventing metabolic syndrome and colorectal cancer.

Phytochemicals including flavonoids, polyphenols, and glucosinolates further enhance protection by modulating inflammation, improving endothelial function, and strengthening immune regulation. Compounds like lutein and zeaxanthin reduce age related macular degeneration, while polyphenols in berries and grapes exhibit chemo preventive effects. Beyond disease prevention, the nutrient density of fruits and vegetables promotes growth, cognitive development, and physical performance. Public health initiatives worldwide recognize increased consumption as a cost-effective strategy to improve population health and reduce healthcare burdens.

Table 3: Functional Components in Fruits and Vegetables and Their Health Promotion Effects

Functional Component	Examples	Mechanism of Action	Health Promotion Outcome	Evidence Strength	Target Population	References
Dietary Fiber	Leafy greens, apples, beans	Improves bowel motility, regulates glycemia, lowers cholesterol	Prevents constipation, reduces colorectal cancer risk	Strong epidemiological evidence	General population	FAO, 2020 [8]
Flavonoids	Citrus fruits, berries	Anti inflammatory, antioxidant	Reduces cardiovascular disease risk, modulates immunity	Moderate to strong	Adults with CVD risk	Kala <i>et al.</i> , 2020 [13]
Carotenoids (Lutein, Zeaxanthin)	Spinach, kale	Protects retinal cells, antioxidant	Prevents age related macular degeneration	Strong clinical evidence	Elderly populations	Parihar and Choudhary, 2023 [18]
Polyphenols	Grapes, pomegranate, green tea	Modulates oxidative stress pathways	Chemo-preventive effects against cancer, supports neuro-protection	Emerging evidence	Cancer risk groups	Komal Sharma and Meena, 2023 [26]
Glucosinolates	Cruciferous vegetables	Induce detoxification enzymes	Reduces carcinogenesis risk	Moderate evidence	Populations with high cancer burden	Kala <i>et al.</i> , 2020 [13]
Phytosterols	Leafy greens, nuts	Compete with cholesterol absorption	Lower LDL cholesterol, improve lipid profile	Strong evidence	Individuals with hyperlipidemia	Parihar and Choudhary, 2023 [18]

Conclusion

Fruits and leafy vegetables remain indispensable for human health, offering a wide spectrum of micronutrients, dietary fiber, and phytochemicals that collectively reduce the burden of chronic diseases. However, the literature consistently demonstrates that their nutritional benefits are undermined by contamination risks across the supply chain. Pesticide residues, heavy metals, and microbial pathogens

pose significant toxicological and epidemiological concerns, with documented links to endocrine disruption, carcinogenesis, renal and neurological disorders, and widespread food borne illnesses. The dual role of fruits and vegetables as essential for nutrition yet vulnerable to contamination underscores the urgent need for integrated interventions. Stricter regulatory enforcement, investment in hygienic infrastructure, adoption of sustainable agricultural

practices, and vendor and consumer awareness are critical to safeguarding food safety. Future research should focus on systematic monitoring, innovative mitigation strategies such as phytoremediation and block chain traceability, and region specific risk assessments. By bridging nutritional promotion with contamination control, public health outcomes can be strengthened, ensuring that fruits and vegetables fulfill their role as safe, accessible, and health protective components of the human diet.

CRedit authorship contribution statement

- **Ekti Sharma:** Writing - original draft, Validation, Funding acquisition, Formal analysis, Data curation, Conceptualization.
- **Deepika Yadav:** Editing, Visualization, Supervision.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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