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Pesticide Residues in Commonly Consumed Vegetables: Impacts on Human Health and Safety Measures

Lavate K. U.

P. G. Department of Zoology, Sant Gadage Baba Amaravati University (SGBAU), Camp Area, Near Tapovan Gate, Amaravati, Maharashtra 444602, India

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Abstract: Pesticides are typically used due to their ability to control or kill biological organisms such as insects, plant diseases, and weeds. Pesticide chemicals frequently reach consumers in the form of food residues. Presence of pesticide residues in foods raises the question as to what risks are consumers facing as they consume ubiquitous pesticide residues in their diet. Modern formulations of pesticides are said to be safe. Many scientific reports have demonstrated that pesticide residues from the food can produce long-term negative effects on the health of fauna, humans and the environment. This review mainly focuses on the vegetables (definition, nutritive and therapeutic benefits); pesticides (definition, types, benefits and adverse effects); and pesticide residues with detailed emphasis on pesticide residues recorded in common vegetable crops, health effects after exposure to pesticide residues, and safety measures for pesticide residues in vegetables along with strategies to be adopted to reduce pesticide residues in vegetables. This study recommends conduction of health risk assessment based on adequate daily intake and continuous monitoring together with a sample traceability system is recommended to protect consumers' health. New technologies should be developed for the safety of the agricultural products to protect consumers health and strict follow up of government regulations. To maintain the healthy ecosystems and better human health, correct and justified application of chemicals in the agriculture should be applied.

Keywords: Pesticide residues, Vegetables, Health risk assessment, Maximum Residue Limits (MRL)

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Introduction

Food safety is an important issue that attracts all of us. While the consumers are concerned about the safety of what they eat, the governments on their side are concerned with finding ways to reduce food related risks and illnesses (Keikotlhaile, 2011). Vegetables are segments of plants that serve as food to humans and other animals. It is often regarded collectively as edible plant matter, including flowers, fruits, stems, leaves, roots, and seeds (Ebabhi and Adebayo, 2021). Vegetables constitute a major part of the human diet by contributing to the dietary requirements of nutrients (vitamins and minerals) of a balanced diet (Ovaskainen *et al*., 2008).

Vegetables are annual or perennial horticultural crops, with certain sections (roots, stalks, flowers, fruits, leaves, etc.) that can be consumed wholly or partially, cooked or raw (NIN, 2011). Adequate consumption of vegetables is important for better human health due to their biochemical composition containing carbohydrates (simple sugars, starch, dietary fiber), proteins, fats, water, minerals (Na, K, Ca, Fe, P), antioxidant vitamins (vitamin A, B6, C and E) and calories (Ulger *et al*., 2018).

Ebabhi and Adebayo (2021) argued that health benefits of vegetables include: antiviral, anticancer and antibacterial properties; reduce the risk of chronic diseases (cardiovascular diseases, diabetes, certain cancers, and obesity); strengthen the immune system; protect against carcinogenic substances; reduce inflammation and oxidative stress that causes cancer; promote health; disease protection and regression, and biological activity against chronic diseases (Ramya and Patel, 2019).

Pesticides: Definition, Types, Benefits and Adverse effects:

Any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest (insects, mites, nematodes, weeds, rats, etc.), including insecticide, herbicide, fungicide, and various other substances used to control pests are called as pesticides (EPA, 2009). Pesticide is a generic name for a variety of agents that may be classified more specifically on the basis of pattern of use and organism killed (Megha *et al*., 2018).

Hassaan and Nemr (2020) classified pesticides on the basis of mode of action and/or mode of entry or the approach by which a pesticide controls or kills the target pest, chemical structure, the features of pesticides, and the character of the target pests. Pesticides are categorized into organochlorine (Aldrin, DDT, Lindane, Chlordane, Endosulfan); organophosphate (Malathion, Diazinon, Parathion, Chlorpyrifos); pyrethroids (Pyrethrins, Deltamethrin, Fenpropathrin); Carbamates (Carbaryl, Aldicarb, Carbofuran); and Bio-pesticides (*Bacillus thuringiensis* (Bt) and its subspecies) (Nayak and Solanki, 2021)

According to Textbook of Forensic Medicine and Toxicology, pesticides are classified into acaricides (kill mites, ticks and spiders e.g. Azobenzene, Chlorobenezilate etc); fungicides (kill fungi and moulds e.g. Captan, Captofol etc.); herbicides (kill weeds or prevent growth of weeds e.g. Parquat, Atrazine etc.), insecticides (kill or repel insects and related species e.g. Organophosphates); molluscicides (kill snails, slugs etc. e.g. Metaldehyde, Thiaclaprid); nematicides (kill nematodes e.g. Ethylene bromide); rodenticides (kill rats, mice, moles and other rodents e.g. Arsenic, Strychnine); and miscellaneous pesticides (kill or repel pests of all types e.g. Compounds of lead, Copper, Mercury, nicotine etc).

Gyawali (2018) stated that pesticides have applications in various sectors such as:

- Agriculture: For control of weeds, pests, rodents etc.
- Domestic: Household and garden spray. Control of animals and birds.
- Material building: Incorporation of paints, glues, plastic protection sheeting, foundation of buildings etc.
- Personal: For application of clothing and skin care.
- Public health: For control of malaria, dengue fever, cholera

Poudel *et al*. (2020) reported that environmental impacts of pesticides include contamination on natural environment (water, soil, air); impact on food safety, non-target organisms; and threats to aquatic and terrestrial biodiversity. According to Shah (2020), impacts of pesticides on human health include neurotoxic, genotoxic, carcinogenic, and reproductive effects.

Pesticide Residues:

Pesticide residues include any derivative of a pesticide, such as conversion products, metabolites, reaction products and impurities considered to amounts of residues primarily depend on nature of pesticides, environmental conditions, good agricultural practices, waiting periods and storage conditions. They are bio-accumulated and bio-magnified through the food chain resulting in deleterious effects on human health. Pesticide residues are any specified substance in food, agricultural commodities or animal feed resulting from the use of a pesticide (Mondal *et al*., 2021). The amounts of pesticide residues primarily depend on nature of pesticides, environmental conditions, good agricultural practices, waiting periods and storage conditions (Racke, 2007).

According to Silva *et al*. (2019), pesticides are commonly used in agriculture to enhance crop production and control pests. After application of pesticides to soil or used to treat crops, they are capable of migrating within various environments and, ultimately, accumulate in food chains or persist as degradation products. Pesticide residues can persist in the environment and agricultural crops. It can produce long-term negative effects on the health of humans and animals and stability of ecosystems by molecular mechanisms that mediate the start of a cascade of adverse effects (Valeriya *et al*., 2021).

Chauhan *et al.* (2021) reported that pesticides have become most essential inputs in modern agriculture for ensuring food security particularly in the developing countries where population far exceeds the agricultural growth. Vegetable crops are attacked by a number of insect-pests and diseases. For better yield and quality, insecticides are repeatedly applied during the entire period of growth and even at fruiting stage (Bempah and Donkor, 2011). Indiscriminate use of pesticides to protect the crop and non-adoption of safe waiting period, leads to accumulation of pesticide residues in edible portion of crop, which may be hazardous to humans beings (Waghulde *et al*., 2011). Therefore, vegetables have given a lot of attention in monitoring programs because of higher pesticide residue levels than other food groups, and most of them are eaten raw (Al-Nasir *et al*., 2020).

Therefore, the objective of present study was to review the concentration of pesticide residues in commonly consumed vegetables and to generate awareness about the lethal effects of these pesticides on human beings as well as to estimate the potential health risks associated with the pesticide residue with regard to consumers.

Articles relevant on pesticide residues in vegetables were searched in EMBASE, Google Scholar, Medline, NCBI, PubMed, Science Direct, Scopus, and Web of Science databases. Data and information was collected from the thorough study of the journal articles, research papers, reports and various literatures. The keywords used for reviewing the literature were the ones that refer to the issues concerning the 'vegetables' and 'pesticide residues'. For literature search, keyword "vegetables" is combined with: pesticide residues, health and safety measures, risk assessment, hazard to human health and the environment.

Pesticide residues recorded in common vegetable crops:

For the collection of primary data on pesticides residues in vegetables, research articles (scientific papers and review articles) published in reputed journals were reviewed. Details on the vegetables, pesticides applied, area of the study, and reference is presented in Table 1.

Similar observations on pesticide residues in vegetables were also reported by Botwe *et al.* (2011) from vegetables in Ghana; Johnson *et al*. (2011) in India; Ramesh and Murthy (2013) in Bangalore Rural District of Karnataka, India; Szpyrka *et al*. (2015) in central and eastern region of Poland; Pujeri *et al.* (2016) in Bijapur district of Karnataka; Mwanja *et al*. (2017) in Monze district, Zambia; Sebastian *et al*. (2017) in North Central agricultural areas of Chile; Shalaby *et al.* (2021) in

Table 1: Pesticides detected in vegetable crops (Source: Nishant and Upadhyay, 2016)

Vegetables	**Detected pesticides**	**Area**	**Reference**
Okra, Bitter gourd, Smooth gourd, Cucumber, Tomato, Brinjal	Lindane, DDT, Endosulphan, Aldrin, Permethrin, Cypermethrin, Fenvalerate, Deltamethrin,	Hisar, Haryana, India	Beena Kumari *et al*. (2002)
Cauliflower	Diazinon, Malathion, Chlorpyrifos, Cypermethrin	Bangladesh	Islam *et al*. (2009)
Bitter gourd, Chilies, Cucumber, Okra, Tomato	Cypermethrin, Mancozeb, Lambda cyhalothrin	Pakistan	Khan *et al*. (2011)
Cabbage, Carrot, Cucumber, Lettuce, Green pepper, Okra, Onion, Tomato	Aldrin, Cyfluthrin, Cypermethrin, Deltamethrin, Dieldrin, Endrin, Fenvalerate, Gamma-HCH, DDT, Methoxychlor, DDE, Permethrin	Kumasi Metropolis, Ghana	Bempah *et al*. (2011b)
Egg plant/Brinjal, Bell Peppers	Chlorpyrifos, Diphenylamine	Hyderabad, Secunderabad	Dasika *et al*. (2012)
Carrot, Cucumber, Eggplant, Green beans, Okra, Onion, Peas, Pepper, Potato, Squash, Tomato,	Chlorpyrifos, Profenofos, Malathion	Egypt (Cairo, Giza, Qualubiya, Ismailia and Fayium)	GadAlla *et al*. (2013)
Kales, French beans	Organphosphates (Dimethoate, Chlorpyrifos), Synthetic pyrethroids (Cyhalothrin, Cypermethrin), Organochlorines and Carbamates.	Kenya	Mutai *et al*. (2015)
Chinese kale/ Chinese broccoli	Carbaryl, Deltamethrin, Diazinon, Fenvalerate, Malathion, Carbofuran, Chlorpyrifos, Chlorothalonil, Cypermethrin, Dimethoate, Metalaxyl/Profenofos	Thailand	Wanwimolruk *et al*. (2015)
Peas, Beans, Eggplant, Spinach and other vegetables.	Sulphur, Endosulfan, Mancozeb, Phorate, Methyl parathion, Monocrotophos, Cypermethrin, Isoproturon, Chlorpyrifos, Malathion, Carbendazim, Butachlor, Quinalphos, Copper oxychloride, Dichlorvos	India	Grewal *et al*. (2017)
Carrots, Spinach, Peppers, Cucumbers, Turnips	Carbendazime, Chlorothalonil, Chlorpyriphos ethyl, Cypermethrin, Dithiocarbamates, Pendimethalin, Prothioconazole	Lome (southern Togo)	Ahoudi *et al*. (2018)
Cucumber, Tomato	Malathion, Fenitrothion, Deltamethrin	Jeddah, Saudi Arabia	Shabbaj *et al*. (2018)

Cabbage, Lettuce, Onion	c-HCH, Heptachlor, Aldrin, α-Endosulfan, Dieldrin, Endrin, DDT, Methoxychlor	Kumasi, Ghana	Vincent *et al*. (2018)
Jute, Spinach	Cypermethrin, Lamda Cyhalothrin,	Nasarawa State, Nigeria	Abdullahi *et al*. (2019)
Cucumber, Potato, Tomato	Aldrin, Dieldrin, Endrin, Heptachlor, Heptachlorepoxide	Jordan	Tarawneh *et al*. (2019)
Carrot	Aldrin, Dieldrin, Endosulfan-α, -β, and -Sulphate, HCH-α, HCH-β, HCH-γ. Heptachlor, Acephate, Dichlorvos, Chlorpyriphos, Monocrotophos, Phorate, Profenofos, Cyfluthrin-β, Cyhalothrin, Cypermethrin, Deltamethrin, Fenvalerate	5 Districts of Karnataka, India	Ananda *et al*. (2020)
Onion, eggplant, pumpkin, potato, okra, capsicum, eggplant, cabbage, coriander, spinach, garlic, jute mallow, watercress, carrot, beans, cucumber, mint, broccoli, lettuce, celery, cauliflower, zucchini, parsley and tomato.	Acetamiprid, Imidacloprid, Carbendazim, Methomyl	Riyadh, Saudi Arabia	Khatri *et al*. (2020)
Cauliflower, Tomato	Diazinon, Quinalphos	Northern part of Bangladesh	Nahar *et al*. (2020)
Brinjal, Cabbage, Chilli, Okra, Tomato	A total of 111 pesticides (insecticides, fungicides, herbicides, and miticide)	Navsari district of Gujarat, India	Pawan Kumar *et al*. (2020)
Chili pepper, Cucumber	Methomyl, Imidacloprid, Metalaxyl, Cyproconazole	Asir Region, Saudi Arabia	Ramadan *et al*. (2020)
Brussels sprouts, Carrot, Celery, Chillies, Chinese cabbage, Chinese parsley, Corn, Daikon, Green amaranth, Heading broccoli, Kale, Kithen mint, Lettuce, Onion, Phak chiang da, Sweet basil, Thai basil, Thai eggplant, Water spinach, Yardlong bean	Phosphamidon, Chlorpyriphos methyl, Parathion methyl, Fenitrothion, Malathion, Chlorpyrifos, Parathion ethyl, Pirimiphos ethyl, Methidathion, Tetrachlorvinphos, Triazophos, Azinphos ethyl, Coumaphos, Heptachlor, DDD, Endrin, beta-Endosulfan, DDT, Bifenthrin, Tetramethrin, Fenpropathrin, Flucythrinate, Etofenprox, Fluvalinate	Wang River, Lampang, Thailand,	Supawat and Roi-et (2020)
Brinjal, Cabbage, Capsicum, Cauliflower, Okra, Potato, Tomato	DDT, HCH, Aldrin, Dieldrin, Endrin, Heptachlor, Heptachlorepoxide	India	Chauhan *et al*. (2021)
Cucumbers, Tomatoes, Peppers	Acetamiprid, Azoxystrobin, Boscalid, Bifenazate, Clofentezine, Famoxadone, Fluopyram, Hexythiazox, Kresoxim-methyl,	Tokat province of Turkey	Balkan and Kara (2022)

	Metrafenone, Penconazole, Pirimicarb+, Pirimicarbdesmethy, Pyridaben, Pyrimethanil, Tebuconazole, Tetraconazole, Thiacloprid		
Tomato, Potato	Chlorpyrifos, Cypermethrin, Carbendazim	Egyptian governorates	Ibrahim *et al*. (2022)
Green bean, Cowpea, Ginger, Yam, Cucumber, Leek, Tomato, Pepper, Eggplant, Sweet pepper, Spinach, Cabbage, Celery, Lettuce and Edible Mushroom	Procymidone, Lambda-cyhalothrin, Cypermethrin, Pendimethalin, Isocarbophos	Henan Province of China	Ma *et al*. (2022)
Leek, Cabbage, Cucumber, Murphy	Omethoate, Pirimicarb, Metalaxyl, Triazolone, Malathion, Fenitrothion, Pendimethalin, Methidathion	China	Meng *et al*. (2022)
Lettuce, Bok choy, Oriental mustard	Carbendazim, Chlorantraniliprole, Emamectin-benzoate, Indoxacarb, Gibberellic acid	Hanoi, Hue, and Ho Chi Minh City in Vietnam	Ngo *et al*. (2022)
Green onions, Mustard greens	Cypermethrin, Difenoconazole, Fenobucarb	Central Vietnam	Nguyen *et al*. (2022)
Vegetables collected from farms, markets, streets, restaurants and homes.	Organophosphates, Carbamates, Pyrethroids, Dithiocarbamates, Neonicotinoids, Chloroacetamide, Anilinopyrimidine, Pyrimidine, Imidazole, Tetramic acid, Benzoylurea, Benzimidazole, Triazole, Hydroxyanilide, Quinoline, Quinazolinone, Strobilurin, Aryloxyphenoxypropionate, Phenylamide, Isoxazolidinone,	Kampala Metropolitan Area, Uganda	Ssemugabo *et al*. (2022)

Egypt; Alsaikhan *et al.* (2021) in Unaizah city, Saudi Arabia; Sivaperumal *et al*. (2022) in Gujarat State, India; Nguyen *et al*. (2022) in Central Vietnam; Pitoi *et al.* (2022) in Indonesia; and Park *et al*. (2022) in Incheon, Korea.

Health Effects after exposure to pesticide residues:

High-risk groups:

Foetuses, infants, growing children, pregnant and nursing mothers, and women of childbearing age are most at risk for adverse health outcomes from exposure to pesticides. Children are more at risk than adults because children eat more relative to their body weight than adults eat. Exposures during vulnerable periods of development can be particularly dangerous (Neme and Satheesh, 2016).

Valeriya *et al*. (2021) stated that children is the most sensitive population and is affected severely by toxic pollutants of food. Pesticides may be hazardous to the health of people of all ages, they present the greatest hazard to children – the most sensitive population. As children are still developing and consume greater amounts of food and fluids relative to their bodyweight, they are more susceptible and adversely impacted (Kim *et al*., 2017).

Table 2: Impacts of pesticide residues in vegetables on human health

Impact	Description	Reference
General symptoms	• Headache, nausea, sweating, diarrhoea, coordination system disruptions, and sometimes death. • Body weakness, abdominal pain, blurred vision, muscle shuddering, respiratory and nervous system disorders. • Paranesthesia, unwanted sensations, burning and partial numbness, "pins and needles", skin problems. • Night-waking, mental confusion, cancer, respiratory damage, reproductive organs, immune system and endocrine disruptions, birth defects, etc.	Nicolopoulou-Stamati *et al*. (2016), Riyaz *et al*. (2021)
Acute toxicity	• Headaches, stomach aches, vomiting, skin rash,.respiratory disorders, eye irritation, sneezing, convulsions, coma, and even death.	Valeriya *et al*. (2021)
Long-term effects on children	• Cancer, asthma, neurobehavioral disorders, learning and developmental disabilities, and congenital defects.	Raschke and Burger (1997)
Chronic toxicity	• Cancer, asthma, dermatitis, endocrine disorders, reproductive dysfunctions, immunotoxicity, neurobehavioral disorders, and congenital defects.	Alleva *et al*. (2018), Pogrmic-Majkic *et al.* (2018)

Routes of uptake, distribution, and excretion of pesticide residues:

According to Yousaf *et al*. (2016), pesticides can affect humans both directly and indirectly, via various routes:

- Absorption through dermal contact.
- Ingestion through mouth.
- Inhalation through nose and mouth.

Page *et al*. (2017) noted that food is the primary source of direct consumption of toxic substances by humans. Vegetables grown on contaminated agricultural soils accumulate pesticides in their edible and non-edible parts in concentrations that are high enough to cause clinical problems in animals and humans. Pesticides penetrate the human body through skin, mouth, eyes, and respiratory system and, are responsible for various acute diseases (Valeriya *et al*., 2021).

Impacts of pesticide residues in vegetables on human health:

Table 2 illustrates the various impacts of residues of pesticides in vegetables on human health.

Safety Measures for pesticide residues in vegetables:

According to Bajwa and Sandhu (2014), the level of pesticide residues is affected by washing, preparatory steps, heating or cooking, processing during product manufacturing and post harvest handling and storage. The extent of reduction varies with nature of pesticide molecule, point of location, type of commodity, processing steps and product prepared.

Strategies to reduce pesticide residues in vegetables:

- Washing of vegetables is the simplest way to reduce the pesticide residue.
- Washing with chlorine water is more effective.
- Precautions should be taken to dislodge the residues from vegetables.
- Judicious and systematic approach be followed to adopt pre-harvest practices and postharvest

treatments to minimize the residue levels in vegetables.

- To monitor the pesticide residues to standardize the application doses.
- To find new pesticide molecules with high effectiveness and fast degrading capabilities.
- Health education within the community to minimize human exposure to pesticides (Bajwa and Sandhu, 2014).
- The awareness of the farmers to reduce application of chemical pesticides and use of organic manures and biopesticides (Gyawali, 2018).
- Development of Strategic Farming Practices: Use of spray nozzles to produce larger spray droplets or lowering the boom of a sprayer (Riyaz *et al*., 2021).
- An Integrated Pest Management (IPM) can help in control pests without pesticides.
- Easy and cheap access to biological pesticides and biological control measures to the farmers through government and non-governmental organizations (Riyaz *et al*., 2021).
- Farmers continue to be able to maintain a sustainable pest management regime that includes the judicious use of pesticides (CAST, 2019).
- Worldwide agreement on good agriculture practices is an urgent to ensure the success of safe food production (Carvalho, 2017).
- To monitor pesticide residues in vegetables on an ongoing basis to determine the dynamics of pesticide presence in vegetables that are freshly consumed (El-Sheikh *et al*., 2022).

Conclusion

Pesticides are commonly used in agriculture to enhance crop production and control pests. Therefore, pesticide residues can persist in the environment and agricultural crops. It was stated that modern formulations are relatively safe to non-target species, numerous experimental data demonstrated that pesticide residues can produce long-term negative effects on the health of humans and animals and stability of ecosystems. It is necessary to conduct health risk assessment based on adequate daily intake for the safety of the contaminated samples. Also, continuous monitoring together with a sample traceability system is recommended to protect consumers' health from the cumulative effects of other contaminated dietary products. It is suggested that, to reduce the proportion of hazardous formulants in pesticide products, new technologies should be actively developed. The safety of the agricultural products to consumers should be ensured by strict follow up of government regulations. Correct and justified application of chemicals in cultivation of vegetables and increasing environmental awareness about impact of pesticides is the main preventive measure for the healthy ecosystems and better human health.

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