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Heavy Metal Contamination in Vegetables: Source of Nutrition or Health Hazard?

Aeshna Nigam[1], KiranBamel[2], Darshan Malik[3] and Shashi Nijhawan[4]

[1]Department of Zoology Shivaji College
[2]Department of Botany Shivaji College
[3,4]Department of Biochemistry Shivaji College
E-mail: [1]aeshna.nigam@gmail.com, [2]kbamel@yahoo.in,
[3]darshanmalik@yahoo.com, [4]shashi.nijhawan@gmail.com

Abstract—*Vegetables form an essential part of human diet. They are the main source of nutrients, fibre and antioxidants, which are important for our health. It has been a tradition, all over the world to grow these vegetables on the fringe of urban areas. However, recent trends in industrialization and unplanned urbanization have resulted in deterioration of environment of these periurban regions. Air, water and soil, which form the growth media for the vegetables, are heavily polluted with industrial effluents, wastewater, untreated sewage water and vehicular emission. These pollutants include heavy metals like Cu, Pb, Cd Cr, Hg, and As, some of which are highly toxic even at low concentration. These toxic elements enter the food chain by consumption of vegetables, which are often grown in contaminated environment. Depending on the nature of vegetables, different vegetables accumulate variable concentration of metals in different parts of the vegetable crop. Green vegetables are seen to accumulate highest concentration of these heavy metals. Long term exposure to these metals have detrimental effects on the health causing a range of diseases including cancer, brain, kidney, liver and heart problem or even general weakness. This paper aims at reviewing and creating awareness about the sources, the global status on heavy metal contamination of vegetables, their effect on human health and how consumption of organic vegetables does not really prevent exposure to these toxic elements. It is important to reduce and check pollution at the source itself to prevent environmental biomagnification of heavy metals and ensure food quality control.*

1. INTRODUCTION

Vegetables are an essential source of carbohydrates, proteins, fibre, minerals and antioxidants. Besides, all living beings require two groups of elements macro-(required in >100mg/day, eg: Ca, S, P, etc) and micro-elements (required in trace quantities, eg: Cu, Zn, Se, F). Vegetables are a rich source of these microelements. These trace elements, which are often heavy metals, play an important role in various chemical and metabolic reactions. Inadequate supply of the microelements can result in various deficiency syndromes [57]. Last few years have observed an increase in consumption of vegetables especially in urban population because of the increased awareness of their food value[47].

Heavy metals are defined as metallic elements with density higher than water [9]. They are present at ultratracelevelsin the environment but unchecked anthropogenic activities have significantly increased their levels [32]. In the last 50 years industrial revolution [19]and haphazard, unplanned urbanization has resulted in exponential increase in levels of heavy metals in the environment of developing countries like China [59] and India [25, 32, 41,53]

Throughout the world it has been a tradition to cultivate vegetables in the periurban areas to avoid the hustle of the cities. However these lands are now laden with pollutants, which are contributed, by industrial effluents, vehicular emission, sewage water and excessive use of pesticides. Most of these pollutants include heavy metals like Cu, Zn, Mg, Mo and Co which are toxic at elevated levels and others like As, Cd, Cr that act as carcinogens [10, 52] Pb and Hg [11, 35] are associated with developmental abnormalities in children.These metals are non-biodegradable, have a long biological half-life and therefore persist in the environment. Of all the contaminating heavy metals Pb, As, Cd, Cr and Hg are the five most toxic metals. The reactive oxygen species and oxidative stress result in the toxic and carcinogenic nature ofthese metals[33-34, 44-46, 48-50, 54, 62-65]. They enter the food chain through contaminated food crops resulting in bioaccumulation, biomagnification and geoaccumulation. Heavy metal contamination in vegetable can no longer be ignored as vegetables form an important component of human diet, especially Indian diet. The prolonged consumption of these cytotoxic, carcinogenic and mutagenic metals pose a serious threat to living beings including human.

Heavy metal contamination of food is not been an alien concept. History cites examples of incidences of lead poisoning in Roman Empire as they used lead cooking pots and jugs for wine and grape drinks. However over the past few years, human exposure to heavy metals has increased drastically because of extensive pollution.National and international bodies of food regulation have lowered the

maximum permissible levels of these metals in food because of increased awareness of their toxicity.

Sources of heavy metal contamination and their uptake by plants

To improve the standards of living, more and more natural resources have been diverted for industrial, domestic and commercial sector resulting in deterioration of quality of the natural resources. Air, water as well assoil pollution contribute to heavy metal contamination in vegetables. The main pollutants in the urban and sub-urban areas are industrial effluents, which are disposed in river water or lakes, untreated sewage water that is often used for irrigation and vehicular effluents. Deposition of heavy metals on vegetables can occur through emission from industries and vehicles during their production and transportation. Also, the vegetables that have been in the market for a long time are prone to heavy metal deposition. Cultivable land near highway isexposed to metal aerosols. These aerosols are deposited on the soil and adsorbed by the plant or directly through deposition on leaves and fruits. Instances of high Pb, Cr and Cd accumulation, which are common air pollutants as a result of industrial activities, was found in Thessaloniki, Greece due to atmospheric deposition [55]. Heavy metal accumulation due to air pollution was also reported from local markets of Riyadh, Saudi Arabia [2], Varanasi [41] and New Delhi [24] India.Energy supplying plantsespecially the coal plants which use low quality coal, brick kiln, diesel generators, resuspended road dust also add to the heavy metal deposition through aerosolin India [24].

Vegetables are most commonly contaminated with heavy metalsdue to water pollution. Both natural processesand unchecked anthropogenic activity are the source of their contamination in water. Natural activity includes weathering of rocks whereas anthropogenic activity includes wastewater from mining, smelting, electroplating or chemical industries and use of untreated sewage water for irrigation. Discharge of industrial and sewage influents in lakes creates a serious problem. The ecosystem of lake does not have a self-cleaning system resulting in accumulation of metals in it. A study was carried out on Bellandur Lake, Bangalore where partially treated and untreated wastewater was discharged. The lake water and the vegetables irrigated with the lake water were tested and found to contain very high heavy metal contamination [21]. Study of vegetables grown close to Lake Victoria in Uganda has shown a high contamination of lead and cadmium [16]. Excessive disposal of wastewater in river also creates a problem. This reduces the dilution capacity of river.One such river is Yamuna which flows through a number of North Indianstates to finally confluence with Ganga at Allahabad, India. For many years it has been used as a dumping ground with major source of pollution being sewage water, immersion of idols, garbage and dead bodies [27]. A study was conducted which showed heavy metal contamination in vegetables grown on and around the Yamuna bank[39]. Benti carried out a similar study in in 2014 on the Awash River of Ethiopia where industrial effluents are discharged. Spinach, cabbage and lettuce grown inareas irrigated by this river water had high content of Pb, Cd and Cr [5].

For socio-economic benefit vegetables grown in sub- urban areas are irrigated with treated/untreated sewage water. The sewage effluents have high organic content increasing the fertility of soil but they also have considerable concentration of heavy metals. Experimental studies on Vasai creek, Maharashtra show contamination of Fe, Pb and Hg[22].Another study atVinayakiya region of Jodhpur detected heavy metal contamination in green leafy vegetables grown irrigated by sewage water[4].

The polluted air and water both contaminate the soil, which serve as the medium of growth of the plants. Deposition of metal containing aerosols and flooding of the riverbanks with polluted river water contaminates the soil. Irrigating vegetables grown on such soil with wastewater or sewage water and subsequent death and decay of vegetable crops further recycle the heavy metals in the soil. The uptake and mobility of these metalsby the plants depends on the solubility of the metal in the water [30,12] and thermodynamic activity of uncomplexed ions [15] because for the root uptake of the metal, it needs to be present close to root for a finite time period.Soil pH, redox potential, density, any change in soil colloids and area available for reaction influence heavy metals solubility [17].Heavy metal contamination is also influenced by the topography of the area, near surface parent material, climatic factors and other physical and biological processes which in turn influence the nature of the soil [7].

Various characters of the plant also influence the route and rate of accumulation of heavy metals. These include the physical factors such as root intrusion, water and ion fluxes and their relationship to the kinetics of metal solubilization in soils and biological factors, including kinetics of membrane transport, ion interactions, and metabolic fate of absorbed ions. The accumulation of the metals depends on ability of plants to tolerate metabolically the increasing concentration of toxic elements[51].

There has been an observed variation in distribution of the toxic metals in different vegetables. Green leafy vegetables accumulate a higher concentration of metals[40]. Herbaceous plants have a high concentration of metals in their roots and stems than leaves and fruits [62]. Root vegetables were found to accumulate a high concentration of soil Cd in comparison to other metals[55].A study was conducted by Indian Agricultural Research Institute to investigate the metal distribution in different parts of vegetable crops. The content of Zn was found to be highest in stem of tomato, Cu in root of fenugreek and stem of soybean, Pb in the leaves of potato and brinjal, Cd in roots of potato and onion, Ni in roots of cauliflower and brinjal and stem of fenugreek[43].

Health Hazards of heavy metals

Long-term exposure to heavy metals has severe health implications. Uptake of these metals interferes with physiological processes of the plants, decreasing the crop yield. Accumulation of these metals in kidney and liver of human causescomplicationsin various biochemical processes which finally leads to cardiovascular, kidney and bone disorders [56, 14]. At cellular level they affectthe cell membrane, mitochondrial, lysosome, endoplasmic reticulum, nuclei, and some enzymes involved in metabolism, detoxification, and damage repair [60]. Metal ions interact with the DNA causing mutation leading to interference in cell cycle, cancer and apoptosis[6, 8, 60]. The daily intake of the metal decides its toxicity level.Copper is an essential microelement, which at trace level acts as a cofactor of many oxidative stress-related enzymes. However, excessive exposure to Cu causes cellular damage leading to Wilson's disease[44].As at low concentration causes nausea, vomiting,decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and sensation of "pins and needles" in hands and feet. At a high concentration it can result in death of the individual. Cd is very toxic and a carcinogen. Long term exposure to low concentrations cause kidney disease, lung damage and fragile bones. Ingestion at very high concentration severely irritates the stomach,leading to vomiting and diarrhea. Cr as Cr^{3+} serves as a microelement but is a known carcinogen in its Cr^{4+}oxidative state. Long-term exposure causes damage to liver, kidney, circulatory, nerve tissues and cause skin irritation. Pb is very toxic and a carcinogen. It has the potential to affect each and every organ of the body. Exposure to high lead levels can severely damage the brain and kidneys,causemiscarriage in pregnant women, damage the sperm production organs and ultimately cause death. Hg derivatives, mercuric chloride and methylmercury are carcinogens. Short-term exposure to high concentrations can cause lung damage, nausea, vomiting,diarrhea whereas long term exposure can permanently damage the brain, kidneys, and developing foetus [26]. Table 1 summarizes the biological half-life andharmful effects of some known toxic metals.

Table 1: Half life andeffects of some known heavy metalson human

Metal	Effect at low concentra-tion	Effectat high concentration	Biolo-gical half -life in blood
Cu	Microelement	Cellular damage leading to Wilson disease	4 weeks
As	Nausea, vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels	Death	4 days
Cr	Microelement	Long-term exposure causes damage to liver, kidney, circulatory, nerve tissues and skin irritation	30 days
Pb	Reduced kidney function, lower birth weights in pregnant women	Severely damage the brain and kidneys, Miscarriage in pregnant women, Damage the organs responsible for sperm production and ultimately cause death	28-36 days
Hg		Short term exposure cause lung damage, nausea, vomiting, diarrhea; long term exposure can permanently damage the brain, kidneys, and developing foetus	65 days

Due to increased awareness of health hazards by exposure to heavy metals several regulatory bodies all over the world have set a maximum permissible limit of the metals in food (Table 2)

Table 2: Maximum permissible level of heavy metals set by some International regulatory bodies in mg/kg

Metal	*WHO/ FAO	*USFDA	*EFSA	Indian standards
Cu	40	-	30	30
Pb	2	10	0.3	2.5
As	0.1	0.3	0.02	5
Hg	0.5	0.5	1.0	1
Cr	1.3	-	-	0.02
Cd	0.05-0.2	0.3	0.2	1.5

*WHO/FAO- World Health Organization/ Food and Agricultural Organization of United Nations, USFDA- Food and Drug Administration of US Department of Health and Human Department,EFSA- European Food Safety Authority

Global Status of Heavy Metals in Vegetable samples

Assessment of heavy metal contamination in vegetables from market site has been carried out both in developed and developing countries [42].Radwan and Salama (2006) investigated the uptake of heavy metals like lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn) in various fruits and vegetables sold in Egyptian markets and found high levels of cadmium. The concentration of the metals was almost similar to those reported from some other parts of the world for similar fruits and vegetables [37].Mapanda et al., 2007

reported that the amounts of Cd in leafy vegetables irrigated with wastewater at two sites in the city of Harare were well above the recommended levels [23]. In 2003, Alam et al., showed high levels of heavy metal Pb in Arsenic contaminated groundwater in Samta village in the Jessore district of Bangladesh [3]. The team showed that some vegetables accumulate heavy metals with concentrations of Pb greater than Cd while some other vegetables such as bottle ground leaf, ghotkol, taro and elephant foot had much higher concentrations of Pb. Whereas, leafy and root vegetables, had higher levels of Zn and Cu. Interestingly, besides the water pollution, atmospheric deposition also results in the metal toxicity in vegetables [41]. Vegetable samples were tested for heavy metal level inGilgit, northern Pakistan[18]The edible parts
of *Malvaneglecta*, *Brassicaoleracea*, *Menthasylvestris* and *Br assica campestris* contained the high concentrations of Cu, Ni, Pb and Zn respectively. The amount of Cd, Cu and Zn was above the permissible limits in the soil samples, though the plant transfer factor (PTF) values were lower for all the selected heavy metals, except for Cd.Vegetable samples grown in New York City and Buffolo were tested and found to have Pb concentrations above maximum permissible levels [28].Premrathna and coworkers[28] have shown accumulation of heavy metals in agricultural areas in Sri Lanka where agrochemicals are overused. They have reported elevated levels of heavy metals like Cd, Cu, Ni, Pb and Zn in leafy vegetable crops grown in 40 agricultural soils [36]. In market vegetables in Chongqing of China investigations indicated towards the levels of Pb and Cd that were higher than the recommendations of FAO/WHO and Chinese regulations [61]. Mn, Zn, Cd, Cu, Pb levels were analysed in the vegetable parsley roots and leaves, carrot roots, cabbage and cucumber in old mining areas of Romania. The concentration of all metals was found to be exceeding the safe levels [13]. Similarly, vegetable samples of spinach, lettuce, cabbage and onion harvested from four different locations of Biu Local Government Area, Borno State, North Eastern Nigeria also contained heavy metals with values higher than those recommended by Food and Agricultural Organization (FAO) and the WHO/EU joint limits. Leaves showed higher concentration than roots and stems [1].

Organic Vegetables: An escape from heavy metal contamination?

Organic farming has become one of the fastest growing sector in agriculture [58]. Organic vegetables are those, which are grown in soil enriched by crop rotation, green manure and compost. Biological pest control is used to protect the crop plants. By adopting organic farming, the world is once again introducing traditional methods of farming, which has been used since prehistoric times before the prevalence of synthetic fertilizers and pesticides.Increasing awarenessabout harmful effects of synthetic fertilizers and pesticides awareness has resulted in a shift towards consumption of organic food. But are organic vegetables free from heavy metals? There have been some evidences of higher heavy metals content in organic soil. George Kuepper, an agricultural specialist reported in 2003 that composting manure concentrates the fertilizer's metal contentleading to greater levels of the contaminants in organic soil. In 2007, researchers conducted an analysis of wheat grown on various farms in Belgiumwhich showed consumers of organically grown wheat take in more than twice as much lead, slightly more cadmium, and nearly equivalent levels of mercury in comparison to wheat produce of conventional farms [29].Moreover the possibility for heavy metals to be absorbed by vegetable crops on their concentration in the soil irrespective of cultivation technique; whether it is organic or conventional farming [31]. Thus consumption of organic vegetables doesnot reduce the exposureto heavy metals.

Conclusion

This review aims to bring to the light the bioaccumulation of metals in the food chain. The short-term foresightedness of industrialization and haphazard urbanization has polluted our environment that has resulted in biomagnification of heavy metals some of which are toxic elements. Long-term exposure to these metals through consumption of contaminated vegetableshas detrimental effect on our health. Various remedial techniques i.e. bioremediation using microorganisms and phytoremediation have been introduced to remove the toxic elements from soil. However they have their limitations. Moreover consumption of organic vegetables is not the route to avoid exposureto heavy metals.Thus there should be continuous monitoring to assess the level of heavy metal contamination in vegetables. Strict regulations must be imposed to keep a check on the disposal of these toxic elements in the environment to prevent pollution and subsequent entry into the food chain.

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