

Pesticide Residues in Food Grains, Vegetables and Fruits: A Hazard to Human Health

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Abstract

Pesticides are widely used in agriculture mainly to increase crop yields to cater huge supply of food products for increasing world population as well as to protect crops from pests and control insect-borne diseases. Increased use of pesticides results in contamination of the environment and the excess accumulation of pesticide residues in food products, which has always been a matter of serious concern. Pesticide residues in food and crops are directly related to the irrational application of pesticides to the growing crops. Accumulated pesticide residues in food products have been associated with a broad variety of human health hazards, ranging from short-term effects to long-term toxic effects. The preventive measures for pesticide residues in the developing countries are limited due to a shortage of funds and lack of defined government regulations. The impact of pesticide residues can be minimized by taking certain measures such as the rational use of pesticides, promoting organic farming, exploit natural and bio pesticides, and proper implementation and amendment of pesticide-related laws. The present article has been planned to review various aspects of pesticide residues including their accumulation in food products, impact on human health, and the preventive measures to counter their toxic effects.

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Introduction

The term pesticide covers a broad variety of compounds including insecticides, fungicides, herbicides, rodenticides, molluscicides, nematocides, plant growth regulators and others^[1]. Depending on the chemical structure pesticides can be classified as organochlorines (endosulfan, hexachlorobenzene), organophosphates (diazinon, omethoate, glyphosate), carbamic and thiocarbamic derivatives, carboxylic acids and their derivatives, urea derivatives, heterocyclic compounds (benzimidazole and triazole derivatives), phenol and nitro phenol derivatives, hydrocarbons, ketones, aldehydes and their derivatives, fluorine containing compounds, copper-containing compounds, metal organic and inorganic compounds, and natural and synthetic pyrethroids^[2]. Ever since the origin of civilization, it has been

the major task of man to engage in a continuous endeavor to improve his living conditions. One of the main tasks in which human beings have been engaged is securing relief from hunger. Secondly, the control of insects, weeds, fungi and other pests of economic or public health is of utmost importance to our government^[3]. Pesticides have consistently revealed their worth through increased agriculture productivity, reduced insect-borne, endemic diseases and protection as well as restoration of plantations, forests, harvested wood products, homes and fiber^[4]. Currently, pesticides are very valuable in developing nations, particularly those in tropical are as looking for an entry in the global economy by providing off-season fresh vegetables and fruits to nations in more temperate weathers. However, these goals cannot be achieved without the increased use of pesticides,



mainly insecticides, herbicides and fungicides^[5]. Ideal pesticides must act selectively against certain pest organisms without adverse effects to non-target organisms. However, it is difficult to achieve absolute selectivity and most pesticides are also toxic to humans and other non-target organisms. Pesticide use raises a number of environmental worries, including human and animal health hazards. Food products contaminated with toxic pesticides are associated with severe effects on the human health. More than 95% of sprayed insecticides and herbicides reach a destination other than their target species, including non-target species, air, water and soil^[6]. Pesticide contamination of both surface and ground waters can affect aquatic animals and plants, as well as human health when water is used for public consumption^[7]. The increased use of chemical pesticides has resulted in contamination of the environment and also caused many associated long-term effects on human health. Pesticides have been associated with a wide spectrum of human health hazards, ranging from short-term impacts such as headaches and nausea to chronic impacts like cancer, reproductive harm and endocrine disruption^[8]. Pesticide residues in food and crops are a direct result of the application of pesticides to crops growing in the field, and to a lesser extent from pesticide residues remaining in the soil^[9]. The present work has been planned to review various aspects of pesticide residues including accumulation of pesticide residues in food grains and various hazards to human health due to pesticide residues as well as preventive measures for the minimization of the impact of pesticide residues on human health.

Pesticide residues in food grains, vegetables, and fruits

Pesticide residue refers to the pesticides or metabolic products of the pesticides that may remain in food grains, vegetables and fruits after they are applied to crops. Many of these chemical residues, especially derivatives of chlorinated pesticides, exhibit bioaccumulation which could build up to harmful levels in the body as well as in the environment^[10]. Persistent chemicals can be magnified through the food chain and have been detected in products ranging from meat, poultry, and fish, to vegetable oils, nuts, and various fruits and vegetables^[11]. Insects and pests can cause a loss in the quality and quantity of grains and their products. The application of pesticide is widely used for grains before harvest and after harvest to protect the grains from damage or loss. Cultivation and storage of grains often require an intensive use of pesticides, which may then be found in grains and in foods prepared from them^[12]. Cereal grains are treated with degradable pesticides, including organophosphates, carbamate, synthetic pyrethroids and insect growth regulators, both in storages and prior to shipment in order to prevent insect infestation^[13]. The most consumed pesticides for vegetables, fruits and food grains in India include sulphur, endosulfan, mancozeb, phorate, methyl parathion, monocrotophos, cypermethrin, isoprotruron, chlorpyrifos, malathion, carbendazim, butachlor, quinalphos, copper oxychloride, and dichlorvos (Source: <http://indiaforsafefood.in>). Maximum residue level is the highest level of a pesticide residue that is legally tolerated in or on food or feed when pesticides are applied correctly. International parties such as the European Union, Codex Alimentarius Commission, and North American Free Trade Agreement have attempted to harmonize pesticide legislation by providing maximum residue limits, but globally these limits remain variable. In India, Food Safety and Standards Authority of India sets the maximum resi-

due limits for pesticides in crops, foods, vegetables and fruits^[14]. The Food and Agriculture Organization and World Health Organization have recommended residue limits for bioresmethrin, bromophos, Carbaryl, chlorpyrifos-methyl, deltamethrin, dichlorvos, etrimfos, fenitrothion, fenvalerate, malathion, methacrifos, permethrin, phenothrin, pirimiphosmethyl and pyrethins used for the protection of grains^[15]. The study in Poland revealed that out of 380 samples of the cereal grains, 34% were found to contain pesticide residues^[16]. According to their investigation out of the analyzed cereals, the smallest amount of plant protection products residues was in mixed cereal grains (below 10%) and Avena grains (below 15%) whereas *Hordeum* and *Triticum* grains contained the highest content of pesticide residues (over 50%). A study in Nigeria on organochlorine pesticide residues in cereal grains showed the presence of aldrin, dichloran, dieldrin, endrin, endosulfan, heptachlor epoxide, dichlorodiphenyl-trichloroethane lindane, methoxychlor, and mirex^[17]. A study in Pakistan on pesticide residue of cereals showed that wheat contained the highest concentration of tested pesticides than maize and rice and maize contained a much higher concentration of pesticides than rice^[18]. The accumulation of pesticide residues depends on the physiochemical properties of the pesticide molecules as well as food^[19]. The use of pesticides during production often leads to the presence of pesticide residues in fruits and vegetables after harvest. Most farmers and commercial producer treat vegetables and fruit with pesticides on several occasions during growing because pesticides decrease toxins produced by food infecting organisms, increase productivity and are less labor intensive. According to a study, the cucumber was the crop with the highest number of pesticide residues with the predominant presence of methomyl, metalaxyl, and imidacloprid. Methomyl is a carbamate insecticide with restricted use because of its high toxicity to humans. The other pesticide residues found in cucumber samples were boscalid, chlorpyrifos, cyprodinil, fenhexamid, imidacloprid, metalaxyl and tebuconazole^[20]. Many commodities contained more than one residue per product, up to 9 residues in grapes and tea were determined, up to 5 - 9 residues in citrus fruits like orange, mandarins, lemons, peaches, pears and up 3 - 5 residues in pomegranates, plums, cucumbers, tomatoes, strawberries. The most frequently detected pesticide residues were imazalil, thiabendazole, chlorpyrifos, maneb group, procymidone, methidathion, lambda-cyhalothrin, carbendazim, iprodione, orthophenylphenol, vinclozolin, endosulfan, pyrimethanil, fenhexamid, prochloraz, cyprodinil, boscalid. Apples, papayas, sweet peppers and strawberries were among products with the highest percentage of samples with residues above the maximum residue limit found in the Brazilian pesticide residues monitoring program. High level of pesticide residues in pears, grapes, citrus fruit, peppers, cucumbers, tomatoes, carrots were obtained in Lithuania^[21]. A study in Belgium revealed that pesticide residues were detected in 72% of the samples and standards were exceeded for 6% of the samples^[22]. High level of pesticide residues was determined in imported blackberries, strawberries and other berries as well as mangoes, papaya, pepinos, bitter melon, peas, beans, eggplant, spinach and other vegetables. The commodities with the highest level of pesticide residues found in China were cabbage, legumes and leaf mustard^[23]. The insecticide residues reported in market samples of grapes were acephate, methamidophos, chlorpyrifos, monocrotophos and quinalphos^[24]. The residues of lambda-cyhalothrin in acid

lime were persisted for 20 days and in juice samples maximum residues were observed for 10 days^[25]. A study on analysis of pesticide residue concentration in vegetables revealed that the risk to consumers varies with the season and it was reported that the winter season has the highest pesticide concentration in vegetables^[26]. A study on the levels of pesticides in soft drinks available in the market indicates pesticide residues 24 times higher than Bureau of Indian Standards (BIS) norms. The levels of pesticide residue lindane exceeded the BIS standards by 140 times in some samples. Heptachlor, which banned in India, was found in 71 per cent of the samples, at levels four times higher than BIS standards. Chlorpyrifos was found 200 times more than the BIS standard in a sample manufactured in Thane. The average amount of pesticide residues found in all the samples was 24 times higher than the BIS standards for total pesticides in soft drinks (Source: The Hindu). Organochlorine pesticides, mainly isomers of hexachlorohexane, dichloro-diphenyl-trichloroethane, endosulphan, endrin, aldrin, dieldrin, and heptachlore, were identified from potable water samples collected from all over India^[27].

Toxic effects of pesticide residues on human health

Many pesticides achieve their intended use of killing pests by disrupting the nervous system. Due to similarities in brain biochemistry among many different organisms, there is much assumption that these chemicals can have a negative impact on humans as well^[28]. There are epidemiological studies that show positive correlations between exposures to pesticides through occupational hazard, which tends to be significantly higher than that ingested by the general population through food, and the occurrence of certain cancers^[29]. Although most of the general population may not expose to a large portion of pesticides, many of the pesticide residues that are attached tend to be lipophilic and can bio-accumulate in the body^[11]. Toxic effects of pesticides depend upon their toxicological properties, the level of residues and degree of exposure of human beings to residues. The presence of pesticide residues in grains does not necessarily mean that it is hazardous. To be toxic, the residues have to be present in quantities large enough to be considered unsafe^[30]. The organophosphate, organochlorine and related pesticides act by binding to the enzyme acetylcholinesterase, disrupting nerve function, resulting in paralysis and may cause death^[31]. They may produce acute effects manifesting as meiosis, urination, diarrhea, diaphoresis, lacrimation, excitation of central nervous system and salivation. The chronic exposure in volves neurotic and behavioral effects. Specific effects of pesticides can include damage to the central and peripheral nervous systems, cancer, allergies and hypersensitivities, reproductive disorders and disruption of the immune system^[32].

Neuronal damage due to cholinergic neuronal excitotoxicity and dysfunction: Following exposure to organophosphates, accumulation of acetylcholine at synapses results in rapid and profound excitotoxicity and dysfunction of cholinergic neurons in the brain. Overstimulation of muscarinic acetylcholine receptors may also disrupt the balance of excitatory and inhibitory mechanisms to cause neuronal excitotoxic lesions leading to seizures and respiratory depression^[33]. Seizures may result from over release of glutamate from glutamatergic neurons, triggering excessive calcium release in post-synaptic neuronal cells^[34].

Seizures caused by cholinergic neuronal excitotoxic lesion in the brain may play a synergistic role in development of irreversible brain damage and long-term neurological and behavioural disorders^[35]. Therapeutic intervention to control the convulsions is unable to halt progressive neural injury and neuronal cell death caused by organophosphate poisoning^[36]. Secondary neuronal damage is an indirect consequence of the initial lesion and a major contributor to the ultimate neuronal cell death and neural loss in the injured brain leading to serious neuropsychiatric impairments, including memory loss, inability to concentrate, speech problems, motor and sensory deficits, and behavioural problems^[37]. In the first few hours after organophosphate poisoning, as the result of the cholinergic neuronal excitotoxicity, extensive intracellular edema, cerebral hemorrhages, intracellular calcium overload, oxidative stress and increased neuro-inflammatory responses were generally observed in the affected brain regions^[38-42]. The altered calcium influx activates lipases, proteases, kinases, phosphatases, and endonucleases in potentially harmful metabolic cascades, thus arresting protein synthesis and depriving cells of enzymes or trophic factors essential to their survival^[43]. Many studies have demonstrated that obvious neuronal cell death, neural loss, and axonal degeneration were observed in different species of animals exposed to organophosphates^[44].

Long-term neuropsychiatric and neurological disorders:

Exposure to organophosphates involve damage to cholinergic neurons of basal forebrain and the limbic system, which may cause memory, cognitive, mental, emotional, motor and sensory deficits by disrupting this putative sensory-limbic gating mechanism^[45]. In 1991, US soldiers were exposed to sarin and cyclosarin when two large chemical ammunition caches were destroyed at Khamisiyah, Iraq during the Gulf War^[46]. The Gulf War-deployed veterans exposed to sarin and cyclosarin were reported to be suffering from neurological and neuropsychiatric disorders^[47]. In 1995, a Japanese cult and terrorist organization carried out the sarin gas attack at multiple locations in the Tokyo subway^[48]. Of the 5500 victims who sought emergency medical care, approximately 1000 were moderately poisoned, 50 were severely poisoned, 47 were certified as disabled, and 12 died due to respiratory failure^[49]. Many victims could recover from acute cholinergic symptoms of sarin poisoning within a couple of weeks, but mental sequelae lasted for years^[50]. These chronic neuropsychiatric consequences are serious public health problems caused by accidental and suicidal organophosphate poisonings and chemical terrorist attacks, which result in the losses of many years of productive life and incur large healthcare costs^[38].

Persistent memory and cognitive deficits: Memory and cognitive deficits are one of the most common and persistent behavioral sequelae in victims exposed to organophosphates. Exposure to organophosphatessarin and cyclosarin at Khamisiyah resulted in long-term cognitive and memory impairments in the Gulf War-deployed veterans in 1991^[47]. Chronic memory and cognitive impairments were also observed in the victims of the Tokyo subway sarin attack^[51]. 7 years after the Tokyo subway sarin attack, a chronic decline of memory function still existed in 23 subway workers exposed to sarin. The exposed subway workers performed less well in the memory function tests, and their digit number of the backward digit span test was signifi-

cantly smaller^[38]. Loss of cholinergic neurons in the basal forebrain with aging results in a decline in cognitive capacity^[52].

Psychomotor performance deficits and somatic complaints:

Clinical study has demonstrated that the Gulf War-deployed veterans exposed to sarin and cyclosarin at Khamisiyah suffered impaired fine psychomotor dexterity, reduced visuospatial abilities and deficits in motor function and coordination^[47]. After the Tokyo subway sarin attack, a chronic decline of psychomotor function existed in 23 subway workers exposed to sarin for 7 years. The high-exposure subway workers had a significantly slower performance of the finger tapping tests of both the dominant and non-dominant hands than control group^[38]. In another clinical study, most of the victims of the Tokyo subway sarin attack were found to have long-lasting somatic complaints (such as gastrointestinal problems, constipation, heartburn, nausea, vomiting, colitis, migraines, headaches, backaches, and skin disorders) at 5 - 6 years after poisoning. The long lasting somatic complaints and decreased psychomotor function of the victims exposed to organophosphates may be associated with neuronal damage in the cortex and thalamus^[53].

Oxidative stress: In sub chronic or chronic organophosphate exposition induction of oxidative stress has been reported as the main mechanism of organophosphate toxicity^[54]. Oxidative stress is induced in both acute and chronic intoxication with organophosphate compounds in humans and experimental animals^[55]. Hyperglycaemia is one of the mechanism of oxidative stress in organophosphate intoxication^[56]. Studies on chronic exposure to carbamate insecticides and case reports of long-term exposure give equivocal results^[57]. An extensive survey of the toxicology of the common insecticide, carbaryl, reports a variety of reversible neurobehavioral and neurotoxic effects in vertebrates, all associated with acute poisoning symptoms^[58]. The carbamate, carbofuran, has been observed to accentuate oxidative stress in rat brain by inducing lipid peroxidation and diminishing the antioxidant defense^[59].

Development of cancer: The studies on cancer analyze the risks associated with the consumption of specific products which have some pesticide residues. These consumption products include fish, water, seafood, and milk or other dairy products. In general, these studies find a small but statistically significant association between cancer risks and some specific pesticide residues, such as dichlorodiphenyltrichloroethane and dichlorodiphenyltrichloroethane. Specifically polychlorinated biphenyls present a higher risk for consumers. Organochlorine pesticide residue levels were reported significantly higher in the cancer patients^[60-63].

Reproductive disorders: Results indicated that increase of insecticides in blood level in vertebrates causes reproductive dysfunction and suggested that for human beings food like fish, chick and goat containing beyond permissible limit of insecticides must be avoided^[64]. Consumption of high pesticide residue fruits and vegetables was associated with lower total sperm count, ejaculate volume and percentage of morphologically normal sperm among men attending a fertility clinic^[65]. Pesticides exposure may lead to reduced fertility, early and late pregnancy loss, prolonged time-to-pregnancy, spontaneous abortion, and premature birth in female and genetic alterations in sperm, re-

duced sperm count, damage to germinal epithelium and altered hormone function in male^[66].

Preventive measures to reduce pesticide residues in food grains, vegetables, and fruits

Different types of pesticides are used in different countries for different types of crops to prevent pests, insects, and weeds. Because of the expansion of worldwide trade, more foods which are treated by pesticide are being imported into different countries. These worldwide trades increase the expansion of pesticide residues in different areas of the world and it's the issue of public health concern. There are a number of strategies which can be used to minimize pest and disease problems and reduce pesticide residues in food grains, vegetables and fruits^[67].

Organic farming: One of the methods used to reduce the effect of pesticide residue in food is to eat organic foods than non-organic ones. According to standard meta-analyses the frequency of occurrence of detectable pesticide residues was four times higher in non-organic crops than organic crops^[68]. There is evidence that indicated organic food consumption can reduce exposure to pesticide residues in food^[69]. Organic crops, on average, have higher concentrations of antioxidants and a lower incidence of pesticide residues than the non-organic foods across regions and production seasons. It is advisable to consume foods rich in antioxidant to reduce effects of the chronic disease by suppressing oxidative activity. An increased dietary intake of antioxidant rich foods protect against chronic diseases, including cardio vascular diseases, certain cancers (e.g. prostate cancer) and neurodegenerative diseases^[70].

Washing food products: The second methods reported to reduce pesticide residue in food is washing. Washing may reduce pesticide residue in food commodities. Washing with water and various chemical solutions for domestic and commercial applications is necessary to decrease the pesticide residues. The efficiency of the washing treatments on pesticide removal depends on the washing solution, the chemical properties of the pesticide, the surface area, the nature of the food, the length of time the pesticide is in contact with the food, and the formulation and application method of the pesticide. Usually, the pesticide is lodged in the outer wax-like layers and then moves to the inside, making washing and removal of the pesticides less effective^[71,72].

Processing food products: An important factor leading to a reduction of any residues left on crops at harvest are processing treatments such as washing, peeling, canning or cooking that the majority of foods receive prior to consumption^[73]. Pesticide residue levels in fruit and vegetables may change due to processing, such as peeling, boiling, frying, fermentation, grinding^[22]. Cooking also reduces pesticide residues in food; boiling may remove 35 - 60% of organophosphate residues and 20 - 25% of organo chlorines^[73]. Husking and immersing of fruit and vegetables are reported to reduce pesticide residues especially organophosphates^[16].

Rational use of pesticides: Rational use of pesticides involves selection of correct pesticides, dosage rates, dilutions, timing, and frequency of application, treatment intervals, and method of application, precautions, and limitations. Rational use of pesti-

cides can be useful to reduce pesticide residues in food products. In many cases, there may not be any need of a pesticide, particularly where cultural or biological methods are effective^[74].

Use of natural pesticides and biopesticides: Bio-pesticides are biodegradable so no harmful residues are produced and are eco-friendly. Bio-pesticides encompasses a broad array of microbial pesticides, biochemical's derived from micro-organisms and other natural sources that confer protection against pest damage. Some insect repellents can also be used for the prevention of pesticide residues accumulation in the food grains, vegetables and fruits^[75]. Natural pesticides such as extracts and compounds from neem tree are also very useful for the prevention of pesticide residues accumulation in the food products^[76].

Implementation and amendment of pesticide-related laws:

In India, the agriculture ministry regulates the manufacture, sale, transport, distribution, export, import and use of pesticides under the Insecticides Act, 1968. Still awaiting Parliamentary approval is the Pesticide Management Bill of 2008, which is meant to replace the Insecticides Act, 1968. The pesticide-related laws should be implemented strictly and amended so as to reduce the cases of pesticide residues in food grains^[77].

Conclusion and future perspective

The excess consumption of pesticides contributes in the accumulation of pesticide residues in food grains and vegetables associated with variety of human health hazards, including damage to central and peripheral nervous systems, cancer, allergies and hypersensitivities, reproductive disorders, and disruption of the immune system. The impact of pesticide residues can be minimized by preventive measures such as rational use of pesticides, washing and proper processing of food products, practising organic farming, use of natural pesticides and bio-pesticides, and strict implementation and amendment of pesticide-related laws.

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