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ASSESSMENT OF CADMIUM LEVELS IN SELECTED LOCAL AND IMPORTED FRUITS AND VEGETABLES IN MULTAN PAKISTAN: A STUDY ON HEALTH RISKS

Original Research

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ABSTRACT

Background: Heavy metals represent one of the most pressing environmental hazards, with cadmium being a highly toxic element that adversely affects both crop quality and human health. Agricultural soils in developing countries, including Pakistan, are increasingly contaminated due to the use of phosphate fertilizers, untreated wastewater, and industrial effluents. Such contamination promotes cadmium accumulation in edible crops, where consumption poses risks of kidney dysfunction, osteoporosis, and cancer. Monitoring cadmium levels in food products is therefore essential to safeguard consumer health.

Objective: The study was designed to evaluate cadmium concentrations in the peels and pulp of locally grown and imported fruits and vegetables commonly consumed in Multan, Pakistan.

Methods: A total of 22 samples representing 11 types of fruits and vegetables, including apples, oranges, cucumbers, and potatoes, were analyzed. Each sample was separated into peel and pulp, dried at 190°C for 24 hours, ground, and digested using a mixture of nitric and perchloric acids. Cadmium concentrations were quantified using atomic absorption spectrophotometry. Data were statistically evaluated to compare cadmium levels between peels and pulps as well as across different plant types and origins.

Results: The results showed that in 10 out of 11 samples, cadmium concentrations were higher in the pulp than in the peel. The highest pulp concentration was observed in cucumbers from Multan Saddar (0.43 ppm), exceeding the WHO permissible limit of 0.1 ppm by 0.33 ppm. Oranges obtained from fruit vendor shops also exceeded the safe threshold with a pulp concentration of 0.16 ppm. Conversely, the lowest levels were recorded in peels of Multani apples (0.00093 ppm) and oranges (0.00031 ppm). Potatoes showed a unique pattern with higher cadmium accumulation in peels (0.16 ppm) than in pulp (0.034 ppm).

Conclusion: The study highlighted the presence of cadmium contamination in fruits and vegetables from Multan, with certain commodities surpassing permissible safety limits. These findings emphasize the need for strict monitoring of irrigation water and fertilizers, alongside promoting sustainable agricultural practices, to reduce cadmium accumulation and ensure food safety.

Keywords: Cadmium, Environmental Monitoring, Food Contamination, Food Safety, Heavy Metals, Pakistan, Vegetables.

INTRODUCTION

Heavy metals are among the most hazardous environmental contaminants, posing significant risks to both human health and ecological systems due to their toxicity, persistence, and bioaccumulative nature (1). Defined as elements with densities greater than 5 g/cm³, such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and nickel (Ni), they enter the environment largely through anthropogenic activities including industrial emissions, mining, vehicular exhaust, and the indiscriminate use of fertilizers and pesticides (2). Additional contributions stem from untreated wastewater and industrial effluents, which raise the concentrations of heavy metals in soil and groundwater, thereby creating direct exposure pathways for agricultural crops and, subsequently, for humans (2,3). Agricultural soils serve as the primary interface between environmental contamination and food production. Plants absorb heavy metals from contaminated soil and transfer them into edible tissues including leaves, fruits, and roots (3). Several studies have demonstrated significant accumulation of heavy metals in agricultural crops, particularly vegetables that are consumed frequently and in large quantities. For instance, leafy greens such as spinach and lettuce, when cultivated in proximity to highways or industrial zones, often show elevated levels of lead and cadmium (4-6). This contamination has direct consequences for dietary exposure, as food consumption represents the most common pathway for heavy metals to enter the human body, alongside contaminated water and polluted air (7). Once absorbed, heavy metals accumulate in vital organs such as the liver, kidneys, and bones, leading to chronic and often irreversible health outcomes. The liver, in particular, is highly susceptible to toxic insults, as evidenced not only in viral hepatitis but also in cases of environmental toxin exposure, where cumulative injury can predispose to chronic liver disease (5). Lead, for example, is a potent neurotoxin that disproportionately affects children, causing developmental delays and impaired cognitive functions (4). Similarly, cadmium is recognized as a human carcinogen that primarily accumulates in renal tissues, predisposing individuals to kidney dysfunction and osteoporosis (6). Long-term exposure has also been linked to an increased risk of cardiovascular disease, neurological impairment, and various cancers (7). Recognizing these hazards, international health organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) have established maximum permissible limits for heavy metals in food, including 0.1 mg/kg for lead and 0.05 mg/kg for cadmium in vegetables (8). However, research consistently reports that crops from certain agricultural regions surpass these thresholds, thereby endangering consumer safety (9).

Beyond their direct effects on humans, heavy metals also exert detrimental impacts on the environment. Contaminated soils experience reduced fertility, altered microbial diversity, and impaired ecosystem functions (10). Furthermore, metals entering aquatic systems bioaccumulate in fish and other organisms, ultimately magnifying their presence throughout the food web and compounding the risks to human health via seafood consumption (11,12). The dual threat to both human health and ecological sustainability underscores the urgency of systematic monitoring and intervention strategies. The situation is particularly concerning in Pakistan, where agricultural reliance on untreated wastewater irrigation and industrial discharges has led to alarming levels of heavy metal contamination in both soil and water. In Multan, several studies have documented that lead and cadmium concentrations in locally grown crops frequently exceed permissible international limits, raising significant concerns for public health (13,14). The ongoing use of untreated wastewater for irrigation, coupled with industrial and vehicular emissions, continues to exacerbate the issue. Against this backdrop, the present study seeks to analyze the concentrations of heavy metals—specifically lead and cadmium—in both locally produced and imported fruits and vegetables available in Multan, Pakistan. By employing advanced analytical techniques such as acid digestion and spectrophotometry, the study aims to provide precise quantification of contamination levels. The overarching objective is to identify potential sources of contamination, assess associated health risks, and propose practical strategies to mitigate exposure. In doing so, this research addresses a pressing environmental and public health challenge while contributing evidence-based insights that can inform effective food safety regulations and policy development (15,16).

METHODS

This experimental study was designed to determine the concentrations of heavy metals, particularly cadmium (Cd), in selected fruits and vegetables commonly consumed in Multan, Pakistan. Four commodities were included: apples, oranges, cucumbers, and potatoes, with both locally grown and imported varieties assessed. Samples were collected purposively from local markets to represent consumer-accessible produce. For each fruit and vegetable type, both the peel and pulp were analyzed separately to assess variations in heavy metal accumulation between external and internal tissues. The samples were first washed thoroughly with deionized water to remove surface contaminants. In the case of apples, the waxy layer was carefully removed prior to peeling. Each fruit or vegetable was divided into two portions: the peel and the pulp. The separated portions were placed on labeled metallic sheets for proper identification and to prevent cross-contamination. The pulp was cut into smaller pieces, while the peels were spread evenly, ensuring consistency in sample handling. All specimens were then placed in a thermal oven at 190°C for 24 hours until completely dried. After drying, the samples were ground into a fine powder using an electric grinder, with care taken to clean the grinder thoroughly between samples to avoid contamination. Digestion of the powdered material was carried out using an acid mixture composed of nitric acid (HNO_3) and perchloric acid ($HClO_4$). For each sample, one gram of dried powder was treated with 5 mL of nitric acid, followed by the addition of 5 mL of perchloric acid. The mixture was initially left for 24 hours to promote partial digestion, after which it was heated on a hot plate at 80°C for one hour. During this process, the solution gradually changed in color from dark brown to clear, indicating the breakdown of organic matter. The digested material was then cooled to room temperature, filtered through Whatman No. 42 filter paper, and the filtrate volume was made up to 10 mL using deionized water.

Heavy metal quantification was performed using atomic absorption spectrophotometry (AAS), which is considered a sensitive and reliable analytical technique for trace metal detection in biological and environmental samples. Calibration of the spectrophotometer was conducted with standard solutions to ensure accuracy. Each measurement was repeated in triplicate to minimize analytical error, and mean values were used for statistical analysis. Descriptive statistics, including mean and standard deviation, were calculated for each group of samples. Comparative analysis was performed to assess differences between local and imported varieties as well as between pulp and peel samples. Ethical considerations were taken into account before initiating the study. Since the research did not involve human participants or animal testing, informed consent was not applicable. However, ethical approval was sought from the institutional review board to ensure methodological rigor and safe laboratory practices. The study adhered to internationally accepted laboratory safety protocols for handling concentrated acids and hazardous materials.

RESULTS

The analysis of cadmium concentrations in fruits and vegetables revealed marked variations between the pulp and peel, as well as among different plant types and sampling origins. Overall, cadmium levels in the pulp were consistently higher than those in the peel across most samples, with the exception of potatoes. Among all samples, the highest cadmium concentration was observed in cucumbers from Multan Saddar, where the pulp contained 0.43 ppm and the peel 0.0023 ppm. This was followed by Syrian cucumbers, which showed pulp concentrations of 0.41 ppm, exceeding the World Health Organization (WHO) permissible limit of 0.1 ppm (8). In contrast, the lowest concentrations were recorded in the peels of locally grown apples and oranges, with values of 0.00093 ppm and 0.00031 ppm, respectively. Locally cultivated produce generally showed lower cadmium accumulation compared to imported or market-sourced varieties. For instance, Multan City cucumbers demonstrated pulp and peel concentrations of 0.02 ppm and 0.01 ppm, respectively, while apples from Shujaabad showed pulp levels of 0.0054 ppm and peel levels of 0.00031 ppm. By comparison, market-sourced apples exhibited higher pulp levels of 0.07 ppm and peel levels of 0.009 ppm. Similarly, oranges purchased from fruit vendor shops displayed pulp concentrations of 0.16 ppm and peel concentrations of 0.0025 ppm.

Potato samples displayed a unique pattern, where peels consistently showed higher cadmium levels than pulp. For example, Multan Saddar potatoes demonstrated pulp levels of 0.034 ppm compared to peel levels of 0.16 ppm. This trend contrasted with cucumbers, apples, and oranges, where pulp levels remained the dominant site of accumulation. These findings collectively indicate variability in cadmium contamination across different regions and plant tissues, with certain crops—particularly cucumbers—showing elevated concentrations that exceed international safety limits. The results further highlighted that while cadmium contamination was evident across multiple fruit and vegetable samples, only a limited number of commodities exceeded the World Health Organization (WHO) permissible limit of 0.1 ppm in the edible pulp (8). Specifically, cucumbers from Multan Saddar demonstrated the highest exceedance, with a pulp concentration of 0.43 ppm, surpassing the limit by 0.33 ppm. Oranges obtained from fruit vendor shops also exceeded the standard, recording a pulp concentration of 0.16 ppm, which was 0.06 ppm above the threshold. These findings indicate that although most samples remained within safe limits, certain produce available in local markets posed potential health risks due to elevated cadmium accumulation in the edible portions.

Table 1: Cadmium Concentration in the Peel and Pulp of Selected Fruits and Vegetables from Multan

No.	Origin	Plant Type	Cadmium Concentration in Pulp (ppm)	Cadmium Concentration in Peel (ppm)
1	Multan City	Cucumber	0.02	0.01
2		Potato	0.1	0.071
3		Apple	0.007	0.00093
4		Orange	0.04	0.00031
5	Jalal Pur Pirwala	Cucumber	0.1	0.048
6	Multan Saddar	Potato	0.034	0.16
7		Cucumber	0.43	0.0023
8	Shujaabad	Apple	0.0054	0.00031
9		Orange	0.0181	0.0025
10	Fruit Markets	Apple	0.07	0.009
11	Fruit Vendor Shops	Orange	0.16	0.0025

Table 2: Fruits and Vegetables Exceeding WHO Cadmium Limit

Origin	Plant Type	Pulp (ppm)	Peel (ppm)	Exceedance Above Limit (ppm)
Multan Saddar	Cucumber	0.43	0.0023	0.33
Fruit Vendor Shops	Orange	0.16	0.0025	0.06

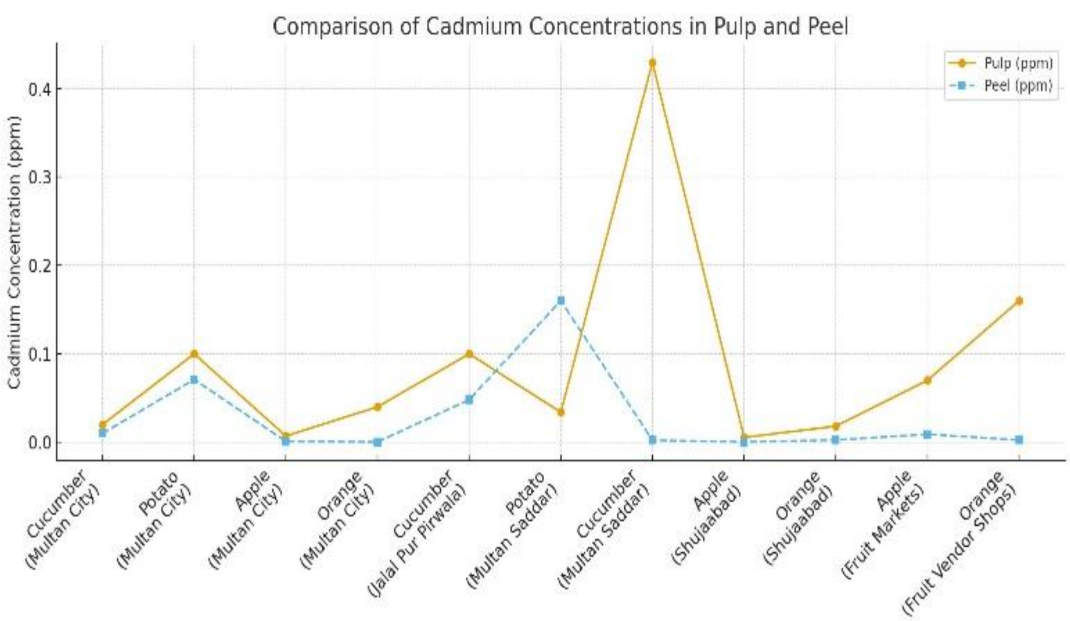

Figure 1 Comparison of Cadmium Concentrations in Pulp and Peel

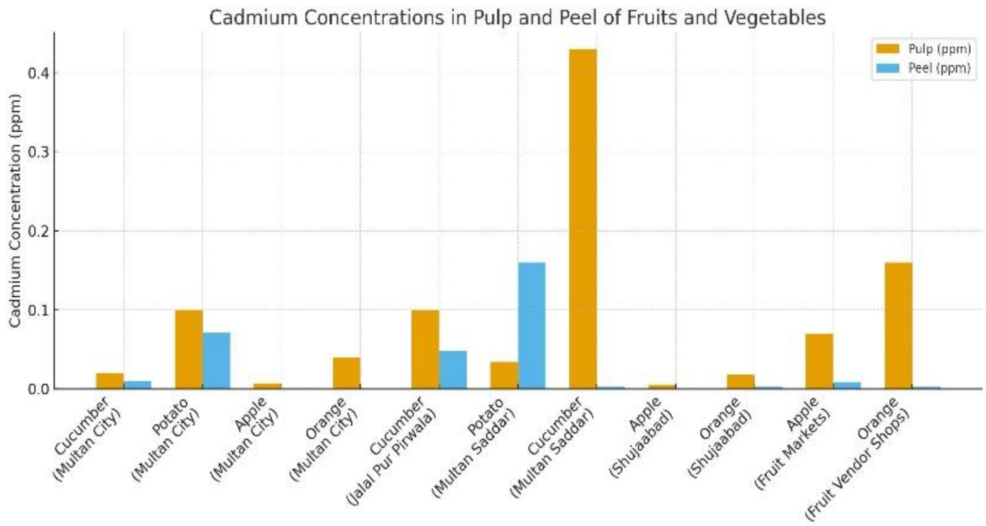

Figure 2 Cadmium Concentrations in Pulp and Peel of Fruits and Vegetables

DISCUSSION

The findings of this study demonstrated notable variability in cadmium concentrations among different fruits and vegetables, as well as between the peel and pulp of the same samples. In most cases, cadmium accumulation was higher in the pulp than in the peel, with the exception of potatoes. This observation suggests that cadmium is predominantly absorbed by plants through the root system from contaminated soil and irrigation water, and subsequently translocated to edible tissues. Potatoes, however, exhibited greater accumulation in the peel, which may be explained by the deposition of cadmium-laden atmospheric dust on the outer layers, particularly in areas with heavy vehicular traffic or industrial activity (12,17). The influence of soil properties was also evident, with higher cadmium concentrations recorded in produce grown in conditions favorable to increased metal solubility. Acidic soils (pH < 6.5) enhance cadmium bioavailability and uptake, whereas alkaline soils mitigate absorption. The elevated cadmium levels observed in Egyptian oranges, for example, may have been a consequence of cultivation in acidic soils or the application of nitrogen-based fertilizers that reduce soil pH (18,19). These findings are consistent with earlier studies highlighting the role of soil chemistry, fertilizer quality, and irrigation practices in heavy metal contamination of agricultural products. From a public health perspective, the detection of cadmium concentrations exceeding the permissible limit in certain samples, such as cucumbers and oranges, is concerning. Regular consumption of such contaminated produce may contribute to chronic cadmium exposure, increasing the risk of kidney dysfunction, skeletal damage, and carcinogenesis in human populations (20,21). The results underscore the importance of systematic monitoring of heavy metals in fruits and vegetables, particularly in regions where untreated wastewater and industrial effluents are commonly used for irrigation. This is especially relevant in developing countries where food safety standards are often poorly enforced and agricultural practices are highly variable (22).

The strengths of this study lie in its methodological approach, which involved the use of atomic absorption spectrophotometry, a sensitive and reliable technique for trace metal analysis. Additionally, the separation of peel and pulp allowed for more precise insights into tissue-specific accumulation patterns. However, the study had notable limitations. Although the stated objective included analysis of both cadmium and lead, only cadmium concentrations were reported. The absence of lead data restricted the comprehensiveness of the findings and limited the evaluation of cumulative health risks associated with multiple heavy metal exposures. Furthermore, the drying of samples at an unusually high temperature of 190°C may have impacted sample integrity, although heavy metals themselves remain stable at such temperatures. Future studies should incorporate multi-metal analysis, including lead, arsenic, and mercury, to provide a broader perspective on heavy metal contamination in food. Comparable concerns have also been raised in biomedical fields, where exposure to engineered metal-based particles, such as silver nanoparticles used in periodontal therapy, has prompted debate on their long-term safety and systemic effects (23). Larger sample sizes covering multiple cultivation sites and seasonal variations would strengthen the generalizability of the results. Soil, water, and fertilizer samples should also be analyzed alongside agricultural produce to identify specific contamination sources. In addition, epidemiological studies linking dietary exposure to measurable health outcomes in local populations would add significant value to risk assessment. The practical implications of this research emphasize the need for monitoring irrigation water quality, regulating fertilizer use, and adopting soil management practices such as liming to reduce cadmium bioavailability. Encouraging farmers to adopt organic fertilizers and to avoid wastewater irrigation would further minimize contamination. Regular screening of fruits and vegetables, particularly those destined for export, is essential to ensure compliance with international safety standards. By addressing these challenges, future research and policy interventions can contribute to safeguarding both food safety and public health in vulnerable regions.

CONCLUSION

This study concluded that cadmium contamination in fruits and vegetables varied across different plant types and origins, with notable differences between peels and edible portions. The findings underscored that agricultural practices, soil properties, and irrigation sources strongly influence the extent of heavy metal accumulation, with certain commodities surpassing permissible safety limits. By highlighting these patterns, the research contributes valuable evidence for food safety monitoring and emphasizes the urgent need for sustainable agricultural practices, stricter quality control of fertilizers and irrigation water, and routine screening of produce to protect public health and ensure compliance with international standards.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Usama Aslam*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Esha Aslam	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Shahbaz*	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Zaima Riaz	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Zaveeba Arif	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published

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