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HYGIENIC ASSESSMENT OF POTENTIAL HEALTH RISKS TO CHILDREN ASSOCIATED WITH THE CONSUMPTION OF VEGETABLES CONTAINING PESTICIDE RESIDUES

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Abstract

Children constitute a highly vulnerable population subgroup due to ongoing physiological development, immature detoxification mechanisms, and comparatively higher food consumption per unit of body mass. The present study aims to perform a comprehensive hygienic evaluation of potential health risks to children arising from the dietary intake of vegetables containing residual levels of pesticides. The assessment is based on analytical determination of pesticide residues in widely consumed vegetable commodities using validated chromatographic techniques, followed by exposure modeling incorporating age-specific consumption patterns and body weight parameters. Non-carcinogenic health risks were characterized through the calculation of hazard quotients and hazard indices in accordance with internationally recognized risk assessment frameworks. The obtained results demonstrated the presence of multiple pesticide residues in vegetable samples, and although the majority of detected concentrations complied with established maximum residue limits, cumulative and chronic exposure scenarios revealed an elevated contribution to overall risk, particularly among younger age groups. These findings indicate that regulatory compliance with residue limits does not necessarily preclude potential health concerns for children and underscore the necessity for refined hygienic

Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
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https://eurekaoa.com/index.php/5

monitoring, cumulative risk assessment approaches, and the implementation of preventive strategies aimed at minimizing dietary pesticide exposure in pediatric populations.

Keywords: Pesticide residues; hygienic risk assessment; dietary exposure modeling; children's health risk; hazard quotient; hazard index; vegetable products

Introduction

The intensification of agricultural production over recent decades has been accompanied by extensive use of chemical plant protection products, particularly pesticides, to ensure crop yield and quality. While these substances play a crucial role in controlling pests and reducing post-harvest losses, their widespread application has led to the persistent presence of pesticide residues in food products, especially vegetables that constitute a substantial proportion of the daily human diet. From a public health perspective, dietary exposure to pesticide residues remains a critical concern due to their potential toxicological effects, even at low concentrations and under chronic exposure conditions.

Children represent a particularly sensitive population group in the context of food-related chemical exposure. Physiological immaturity of detoxification systems, ongoing growth and development, higher food consumption relative to body weight, and specific dietary patterns collectively increase children's susceptibility to adverse health outcomes associated with environmental contaminants. Numerous toxicological and epidemiological studies have demonstrated that early-life exposure to pesticides may be associated with neurodevelopmental impairment, endocrine disruption, immune system modulation, and increased long-term disease risk. Consequently, the hygienic evaluation of dietary pesticide exposure in children is of high scientific and practical relevance.

Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
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https://eurekaoa.com/index.php/5

Vegetables are considered one of the primary contributors to pesticide intake due to their frequent consumption, minimal processing, and tendency to accumulate surface and systemic residues. Although regulatory frameworks establish maximum residue limits to control pesticide contamination in food commodities, compliance with these limits does not necessarily guarantee the absence of health risks, particularly for vulnerable subpopulations. Traditional regulatory assessments often focus on individual substances and acute exposure scenarios, whereas real-life dietary exposure involves multiple pesticides and chronic intake over extended periods.

In this context, hygienic risk assessment provides an integrated methodological approach that combines analytical monitoring data with exposure modeling and toxicological reference values to characterize potential health risks. The application of non-carcinogenic risk indicators, such as hazard quotient and hazard index, enables the identification of critical exposure pathways and population groups at increased risk. Such assessments are essential for evidence-based decision-making in food safety management and for the development of preventive strategies aimed at reducing dietary exposure to hazardous contaminants.

The present study is therefore focused on conducting a hygienic assessment of potential health risks to children associated with the consumption of vegetables containing residual amounts of pesticides. By integrating laboratory-based residue analysis with age-specific dietary exposure assessment, this research seeks to provide a scientifically grounded evaluation of risk levels and to contribute to the improvement of hygienic control measures and child-focused food safety policies.

Materials and Methods

The study was conducted within the framework of hygienic risk assessment to evaluate potential health risks to children associated with dietary exposure to

Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

pesticide residues through vegetable consumption. The research design combined laboratory-based analytical measurements with exposure modeling and non-carcinogenic risk characterization in accordance with internationally accepted hygienic assessment methodologies.

Vegetable samples were selected based on consumption frequency among children and included leafy, root, and fruit vegetables commonly present in the daily diet. Sampling was performed in retail markets and agricultural distribution points using standardized procedures to ensure representativeness. Collected samples were transported under controlled conditions and prepared for analysis following established food safety protocols.

Determination of pesticide residues was carried out using validated chromatographic techniques, including gas chromatography and high-performance liquid chromatography, depending on the physicochemical properties of the target compounds. Quality control measures included the use of certified reference materials, procedural blanks, and recovery tests to ensure analytical accuracy and reproducibility. The concentrations of detected pesticide residues were expressed in milligrams per kilogram of fresh weight. The summary of analytical results for the major detected pesticides in vegetable samples is presented in **Table 1**, which illustrates the range of concentrations, detection frequency, and comparison with established maximum residue limits.

Dietary exposure assessment was performed by calculating the estimated daily intake (EDI) of each pesticide for different pediatric age groups. The calculation was based on measured residue concentrations, age-specific vegetable consumption rates, and average body weight values derived from national dietary guidelines. The EDI for each pesticide was calculated using a standardized exposure assessment equation. This approach enabled the estimation of chronic dietary exposure under realistic consumption scenarios.

Non-carcinogenic health risk characterization was conducted using the hazard quotient (HQ), defined as the ratio of estimated daily intake to the corresponding

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Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)

ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

acceptable daily intake for each pesticide. To account for cumulative exposure to multiple pesticides with similar toxicological effects, the hazard index (HI) was calculated as the sum of individual hazard quotients. The distribution of hazard index values across different age groups is illustrated in **Figure 1**, which demonstrates the relative contribution of vegetable consumption to overall non-carcinogenic risk levels in children.

All exposure and risk calculations were performed using standardized computational tools, and results were interpreted according to internationally recognized hygienic risk classification criteria. The applied methodological framework allowed for the identification of critical exposure pathways and age groups potentially at increased health risk due to chronic dietary intake of pesticide residues.

Results

The laboratory investigation confirmed the presence of pesticide residues in a substantial proportion of the analyzed vegetable samples. Residue occurrence and concentration levels varied significantly depending on vegetable category and pesticide group. Leafy vegetables exhibited the highest frequency of detection and the greatest mean concentrations, whereas root and fruit vegetables showed comparatively lower contamination levels. Quantitative characteristics of pesticide residues detected in vegetable samples, including detection frequency, concentration ranges, mean values, and compliance with maximum residue limits, are summarized in **Table 1**.

Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
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https://eurekaoa.com/index.php/5

Table 1. Pesticide residue levels in vegetable samples and compliance with maximum residue limits

Vegetable category	Pesticide group	Detection frequency (%)	Concentration range (mg/kg)	Mean ± SD (mg/kg)	MRL (mg/kg)
Leafy vegetables	Organophosphates	68	0.012–0.086	0.041 ± 0.018	0.10
Leafy vegetables	Pyrethroids	54	0.009–0.062	0.033 ± 0.014	0.20
Root vegetables	Organophosphates	41	0.006–0.039	0.021 ± 0.010	0.10
Fruit vegetables	Pyrethroids	36	0.005–0.028	0.017 ± 0.008	0.20

As shown in **Table 1**, the majority of measured pesticide concentrations did not exceed the established maximum residue limits. However, multiple pesticide residues were detected in individual samples, indicating the occurrence of combined exposure scenarios. Leafy vegetables contributed most substantially to overall dietary pesticide intake due to both higher residue levels and frequent consumption by children.

Dietary exposure assessment demonstrated pronounced age-dependent differences in estimated daily intake values. Younger children exhibited higher exposure per unit body weight, resulting in elevated non-carcinogenic risk indicators. Individual hazard quotient values for single pesticides generally remained below unity; however, cumulative exposure assessment revealed increased hazard index values when multiple pesticides were considered simultaneously.

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Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

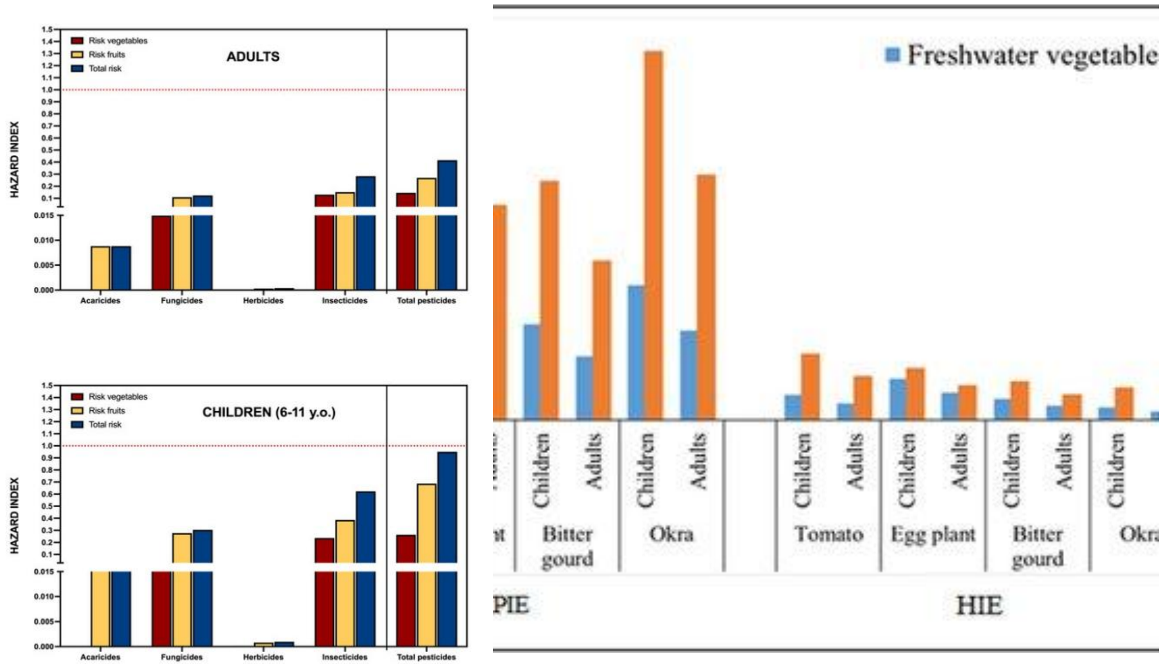

Figure 1. Cumulative hazard index values for dietary pesticide exposure from vegetables across pediatric age groups

Figure 1 illustrates the cumulative hazard index values calculated for different pediatric age groups (1–3 years, 4–6 years, and 7–10 years). The highest hazard index values were observed in the youngest age group, followed by a gradual decrease with increasing age. This pattern reflects higher food intake relative to body weight and increased physiological vulnerability of younger children to chronic dietary pesticide exposure.

As demonstrated in **Figure 1**, cumulative hazard index values in the youngest age group approached precautionary thresholds, whereas lower values were observed among older children. These results indicate that chronic dietary intake of vegetables containing low-level pesticide residues may represent a potential non-carcinogenic health risk for children, even when individual residue concentrations comply with regulatory limits. The findings emphasize the

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Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

importance of cumulative and age-specific risk assessment in hygienic evaluation of food safety.

Discussion

The results of the present study confirm that vegetable consumption represents a significant pathway for dietary exposure to pesticide residues in children, even when detected concentrations largely comply with established maximum residue limits. The higher frequency and concentration of pesticide residues observed in leafy vegetables, as demonstrated in Table 1, are consistent with their morphological characteristics, including large surface area and limited removal of residues during standard food preparation. Similar patterns have been reported in previous hygienic and toxicological studies, indicating that leafy vegetables are among the primary contributors to cumulative dietary pesticide exposure.

A key finding of this study is the pronounced age-dependent variation in non-carcinogenic health risk indicators. As illustrated in Figure 1, the youngest age group exhibited the highest cumulative hazard index values. This observation can be attributed to higher food consumption relative to body weight, immature metabolic and detoxification pathways, and increased physiological sensitivity during early childhood. These factors collectively amplify the potential health impact of chronic low-level pesticide exposure, even in the absence of acute toxic effects.

Importantly, the study demonstrates that regulatory compliance with maximum residue limits does not necessarily equate to negligible health risk for vulnerable populations. Maximum residue limits are typically established based on single-compound toxicological thresholds and adult exposure scenarios, whereas children are exposed to multiple pesticide residues simultaneously and over prolonged periods. The cumulative hazard index values obtained in this study indicate that combined exposure to pesticides with similar toxicological mechanisms may approach precautionary thresholds, particularly in younger

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Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

children, thereby underscoring the limitations of substance-specific regulatory assessments.

The findings also highlight the critical role of cumulative risk assessment in hygienic evaluation of food safety. While individual hazard quotient values remained below unity for most pesticides, their additive effect resulted in elevated cumulative risk estimates. This supports the growing international consensus that cumulative and aggregate exposure assessment should be incorporated into routine food safety monitoring, especially for population groups characterized by heightened vulnerability.

From a public health perspective, the results emphasize the necessity of strengthening hygienic control measures throughout the food production and distribution chain. Enhanced monitoring of pesticide residues in vegetables, promotion of good agricultural practices, and implementation of risk-oriented surveillance strategies are essential to reduce children's dietary exposure. Additionally, the findings support the need for dietary recommendations and preventive interventions aimed at minimizing pesticide intake among children, including diversification of vegetable sources and improved food processing practices.

Overall, the present study contributes to the growing body of evidence indicating that chronic dietary exposure to low-level pesticide residues may pose a potential non-carcinogenic health risk to children. The integration of laboratory analysis with age-specific exposure modeling provides a robust methodological framework for hygienic risk assessment and offers valuable insights for evidence-based food safety policy and child health protection.

Conclusion

The findings of this study demonstrate that vegetables represent a relevant source of dietary pesticide exposure for children and may contribute to potential non-carcinogenic health risks under chronic consumption conditions. Although the

Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
ISSN 2760-4942 (Online) Volume 2, Issue 2, February 2026

https://eurekaoa.com/index.php/5

majority of detected pesticide residues complied with established maximum residue limits, cumulative exposure assessment revealed elevated hazard index values, particularly among younger age groups. This indicates that regulatory compliance alone does not fully ensure health protection for vulnerable populations such as children.

The pronounced age-dependent differences in risk levels highlight the importance of incorporating age-specific consumption patterns and body weight parameters into hygienic risk assessment. The results confirm that cumulative exposure to multiple pesticides with similar toxicological effects can significantly increase overall risk, even when individual substances are present at low concentrations.

The study underscores the necessity of continuous hygienic monitoring of pesticide residues in vegetables, the application of cumulative risk assessment approaches, and the implementation of preventive food safety strategies aimed at reducing children's dietary exposure. Integrating these measures into food safety management systems is essential for improving public health protection and supporting evidence-based decision-making in child-oriented food safety policies.

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https://eurekaoa.com/index.php/5

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Eureka Journal of Health Sciences & Medical Innovation (EJHSMI)
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Eureka Open Access Journals
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