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IONOMETRIC METHODS FOR THE ANALYSIS AND DETERMINATION OF HEAVY METALS IN ENSURING FOOD SAFETY OF FOOD PRODUCTS

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Abstract: Ensuring food safety requires reliable monitoring of heavy metal contamination in food products, as excessive levels of toxic metals pose serious risks to human health. In recent years, increased industrial activity, intensive agriculture, and environmental pollution have contributed to the accumulation of heavy metals in food raw materials. This study focuses on the application of **ionometric methods** for the analysis and determination of heavy metal content in food products as part of an improved food safety control system. Ionometric analysis is based on the measurement of ion activity using ion-selective electrodes, allowing rapid and cost-effective detection of metal ions such as lead, cadmium, copper, and zinc. The methodological aspects of sample preparation, electrode calibration, and measurement conditions were optimized to ensure analytical reliability and reproducibility. The results demonstrate that ionometric techniques are well suited for preliminary screening and routine monitoring of heavy metals in food matrices. Integration of ionometric analysis into food safety assessment frameworks enhances monitoring efficiency, reduces analytical costs, and supports timely decision-making for confirmatory instrumental analysis.

Keywords: food safety; heavy metals; ionometric analysis; ion-selective electrodes; metal ion determination; quality control; PXSI-216F ionometer

Introduction

Food safety is one of the most important components of public health protection and sustainable development. Among the various contaminants that threaten the quality and safety of food products, **heavy metals** occupy a special place due to their high toxicity, ability to accumulate in biological systems, and long-term adverse effects on human health. Elements such as lead (Pb), cadmium (Cd), mercury (Hg), copper (Cu), and zinc (Zn) may enter food chains through contaminated soil, water, atmospheric deposition, industrial emissions, and the extensive use of agrochemicals[1-6].

In many developing and agriculturally intensive regions, including Uzbekistan, the risk of heavy metal contamination in food products is increasing as a result of industrial growth, irrigation with mineralized water, and the application of mineral fertilizers and pesticides. Fruits, vegetables, cereals, and processed food products can accumulate heavy metals, making their regular monitoring an essential requirement for ensuring food safety and compliance with national and international standards[7-12].

Conventional methods for the determination of heavy metals in food matrices are mainly based on advanced instrumental techniques such as atomic absorption spectrometry, inductively coupled plasma mass spectrometry, and voltammetry. Although these methods provide high sensitivity and accuracy, they are often expensive, time-consuming, and require sophisticated equipment and highly qualified personnel. This limits their widespread application in routine monitoring and regional quality control laboratories[13-18].

Ionometric analysis using ion-selective electrodes represents a practical alternative for the rapid and cost-effective determination of heavy metal ions in food products. The ionometric method is based on direct measurement of ion activity in solution and allows selective detection of specific metal ions with sufficient sensitivity for screening purposes. The simplicity of operation, relatively low cost, and portability of ionometers make them particularly suitable for preliminary assessment and routine food safety monitoring.

The present study is aimed at evaluating the applicability of ionometric methods for the analysis and determination of heavy metals in food products, with the objective of improving food safety control systems. The integration of ionometric techniques into existing monitoring frameworks can enhance analytical efficiency, support regulatory compliance, and contribute to the protection of consumer health.

Materials and Methods

Food product samples commonly consumed in Uzbekistan, including fruits, vegetables, cereals, and processed foods, were selected for analysis. Samples were collected from local markets and agricultural production areas in accordance with national food safety and sanitary sampling guidelines. Each sample was placed in clean polyethylene containers, transported to the laboratory, and stored at 4 °C prior to analysis to prevent secondary contamination and chemical changes.

Sample preparation involved washing (for fresh produce), drying, and homogenization. A representative portion of each sample (10–20 g) was subjected to acid extraction using diluted nitric acid (1.0 mol l^{-1}) under controlled conditions to transfer heavy metal ions into the aqueous phase. The extracts were filtered and diluted with deionized

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water to the required volume. All reagents used were of analytical grade, and deionized water was used throughout the experiments.

Ionometric measurements were carried out using a **PXSI-216 F ionometer** equipped with appropriate ion-selective electrodes for heavy metal ions, including Pb^{2+}, Cd^{2+}, Cu^{2+}, and Zn^{2+}. Prior to analysis, the ionometer was calibrated using a series of standard metal ion solutions covering the expected concentration ranges. Calibration curves were constructed by plotting electrode potential against the logarithm of ion concentration(fig-1).

Figure-1. PXSI-216 F ionometer

Measurements were performed at room temperature (20–25 °C) with constant stirring to ensure equilibrium. Each sample extract was analyzed in triplicate, and the average value was recorded. Quality control procedures included blank measurements and periodic recalibration of electrodes to verify stability and accuracy. The obtained ionometric results were compared with permissible limits established by national food safety regulations and international guidelines.

The ionometric method was evaluated in terms of repeatability, sensitivity, and suitability for routine monitoring. Selected samples were recommended for further confirmatory analysis using advanced instrumental techniques when measured concentrations approached or exceeded regulatory limits.

Results and Discussion

Ionometric analysis of food product samples using the **PXSI-216F ionometer** revealed measurable differences in heavy metal ion concentrations depending on the type of product and its origin. The obtained results confirm that ionometric methods are effective for the preliminary assessment of heavy metal contamination and for identifying samples that may pose potential food safety risks.

As presented in **Table 1**, the concentrations of lead (Pb^{2+}), cadmium (Cd^{2+}), copper (Cu^{2+}), and zinc (Zn^{2+}) in most samples were within the maximum permissible limits established by national and international food safety standards. However, several market samples exhibited elevated levels of Pb^{2+} and Cd^{2+}, indicating possible environmental or technological sources of contamination.

Table 1. Heavy metal content in selected food products determined by ionometric analysis

№	Food product	Origin	Pb^{2+} (mg/kg)	Cd^{2+} (mg/kg)	Cu^{2+} (mg/kg)	Zn^{2+} (mg/kg)	Assessment
1	Apple	Reference area	**0.03 ± 0.01**	**0.01 ± 0.00**	**1.2 ± 0.1**	**4.5 ± 0.3**	Safe
2	Apple	Market	**0.09 ± 0.02**	**0.04 ± 0.01**	**1.8 ± 0.2**	**5.6 ± 0.4**	Borderline
3	Tomato	Reference area	**0.02 ± 0.01**	**0.01 ± 0.00**	**1.5 ± 0.1**	**3.9 ± 0.2**	Safe
4	Tomato	Market	**0.07 ± 0.02**	**0.03 ± 0.01**	**2.1 ± 0.2**	**4.8 ± 0.3**	Borderline
5	Wheat grain	Reference area	**0.04 ± 0.01**	**0.02 ± 0.01**	**2.4 ± 0.2**	**18.5 ± 1.2**	Safe
6	Wheat grain	Market	**0.11 ± 0.03**	**0.05 ± 0.01**	**2.9 ± 0.3**	**21.4 ± 1.5**	Suspected
7	Canned vegetables	Market	**0.10 ± 0.02**	**0.04 ± 0.01**	**3.2 ± 0.3**	**16.8 ± 1.1**	Suspected

The repeatability of ionometric measurements was satisfactory, with relative standard deviations not exceeding 6 %. The observed increase in Pb^{2+} and Cd^{2+} concentrations in some market samples may be associated with contaminated irrigation water, soil pollution, or processing and packaging conditions. In contrast, essential trace elements such as Cu^{2+} and Zn^{2+} were generally present within acceptable nutritional and safety ranges.

Although ionometric analysis does not provide multi-element ultra-trace sensitivity comparable to spectrometric techniques, the results demonstrate its strong potential as a screening and routine monitoring tool. The use of the PXSI-216F ionometer allows rapid identification of samples that exceed or approach regulatory limits and therefore require confirmatory analysis by atomic absorption spectrometry or inductively coupled plasma techniques.

Overall, the integration of ionometric methods into food safety monitoring frameworks improves analytical efficiency, reduces costs, and enhances the capability of regional laboratories to control heavy metal contamination in food products.

Conclusion

The conducted study confirms that **ionometric methods** using ion-selective electrodes are an effective and practical approach for the analysis and determination of heavy metals in food products. The application of the PXSI-216F ionometer enables rapid detection of toxic metal ions such as Pb^{2+} and Cd^{2+}, as well as essential trace elements Cu^{2+} and Zn^{2+}, providing valuable information for food safety assessment.

The obtained results demonstrate satisfactory repeatability and analytical reliability, making ionometric analysis suitable for preliminary screening and routine monitoring in food safety control systems. Although this method does not replace highly sensitive spectrometric techniques, it significantly reduces analytical time and costs by allowing the early identification of potentially contaminated samples requiring confirmatory analysis.

Integration of ionometric techniques into food safety monitoring frameworks can enhance the efficiency of heavy metal control, support compliance with regulatory standards, and strengthen consumer health protection. Overall, the use of ionometric analysis represents a promising and accessible tool for improving food safety assurance, particularly in regional and routine laboratory practice.

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