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The effectiveness of implementing the HACCP system to ensure the quality of food products in regions with ecological problems

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This study developed and implemented a specific HACCP plan for the meat pate “Phirmennyi” at the small meat processing enterprise “Alteev” in Semey, Kazakhstan. The research, conducted in collaboration with the Department of Food Production Technology and Biotechnology at Shakarim University, was carried out in an area affected by the ecological consequences of the former Semipalatinsk Nuclear Test Site. The study aimed to identify critical control points (CCPs) and assess potential risks following the Technical Regulations of the Customs Union. Additionally, it evaluated the effectiveness of the HACCP plan in reducing contaminants, such as heavy metals, radionuclides, and pesticides, while considering the region’s environmental impact on food safety and quality. Standard procedures were followed for hazard analysis, CCP identification, setting critical limits, monitoring, corrective actions, verification, and record-keeping. Heavy metals were measured using inductively coupled plasma mass spectrometry, while Cs-137 radionuclides were analyzed with scintillation and semiconductor gamma spectrometers. Statistical analysis was conducted in Microsoft Excel to compute mean values, standard deviations, and correlations, with significance defined at $p \leq 0.05$. Five CCPs were identified during the production of an experimental batch of meat pâté, including raw material acceptance, blanching, cooking, cooling, and packaging/storage. Implementing this plan resulted in a reduction in contaminants, including a decrease in lead from 0.55 to 0.51 mg/kg, arsenic from 0.12 to 0.07 mg/kg, and Cs-137 from 7.2 to 6.8 Bq/kg. By addressing both the contaminants and the specific environmental context of the region, this research demonstrates the critical role of a well-structured food safety plan. The HACCP system not only improved food quality but also ensured compliance with safety standards, providing reassurance to consumers. This case study advocates for broader adoption of food safety management in regions with similar ecological challenges, promoting a more sustainable and secure food supply chain.

KEYWORDS

meat-processing enterprise, HACCP, meat pate, ecology, quality of food products

1 Introduction

Ensuring food safety and quality is a critical concern in the food industry, particularly in regions facing ecological challenges. The Hazard Analysis and Critical Control Points (HACCP) system has emerged as a robust framework for identifying, evaluating, and controlling food safety hazards throughout the production process (Chavan et al., 2024). While this system has proven effective in various settings, its implementation in ecologically compromised areas presents unique challenges that require specific attention.

Regions with environmental hazards often face significant obstacles in establishing comprehensive food safety systems. The presence of environmental contaminants, including heavy metals, radionuclides, and pesticide residues, complicates the monitoring and control of food safety risks (Polivkina et al., 2021; Moldagazyeva et al., 2022). To overcome these challenges, tailored strategies that incorporate environmental considerations into food safety protocols are essential, ensuring the protection of public health and the enhancement of food quality under adverse conditions.

The city of Semey, Kazakhstan, exemplifies such challenges. The legacy of the former Semipalatinsk nuclear test site has resulted in widespread contamination of soil, water, and air, adversely impacting public health in the region (Krivitskiy et al., 2022; Kunduzbayeva et al., 2022; Duysembayev et al., 2023; Krasnopyorova et al., 2023; Turchenko et al., 2023). This contamination has been linked to increased rates of cancer (Gusev et al., 1998), birth defects (Abylgazina et al., 2016), and various health problems among the local population (Iwata et al., 2004; Teleuov, 2007; Semenova et al., 2021).

In this context, integrating the Food Safety Management System into Semey's food processing industry is crucial. The small-scale meat products enterprise (SMPE) "Alteev" has taken the initiative to implement this system in its production process to ensure the safety and quality of its meat products. This study aims to evaluate the effectiveness of the HACCP approach in mitigating food safety hazards in this ecologically challenged area.

The specific objectives of this research include investigating the presence of heavy metals and radionuclides, such as Cs-137, as well as antibiotic and pesticide residues in the final products, particularly those containing meat and bone paste derived from beef rib bones (MBP). Furthermore, the study will assess changes in contamination levels before and after the implementation of the HACCP framework. By conducting this research, we aim to demonstrate the potential benefits of the system in improving food safety and quality under challenging environmental conditions.

This study contributes to the existing literature by providing empirical evidence on the effectiveness of the HACCP framework in an ecologically unfavorable area, highlighting unique challenges and potential solutions for implementing food safety management systems in such contexts. The findings are expected to inform policymakers, food industry stakeholders, and public health authorities about the importance of integrating environmental considerations into food safety protocols to protect consumer health and enhance food quality.

2 Literature review

The HACCP system plays a pivotal role in safeguarding food safety and enhancing quality across various food processing industries.

Its integration can significantly improve overall food quality by fostering consistency, minimizing variability, and ensuring adherence to established standards. This is essential for building consumer confidence and maintaining market competitiveness, particularly in regions where environmental or resource limitations present challenges to food safety.

Focusing on Semey, Kazakhstan—a region impacted by nuclear contamination—this study examines contamination levels in meat products before and after the integration of this safety management system, aiming to demonstrate its effectiveness in improving food safety and quality amid significant environmental challenges.

2.1 HACCP system and food safety

Previous studies have demonstrated the effectiveness of the HACCP framework in reducing foodborne illnesses and improving overall food quality. For instance, Radu et al. (2023) found that implementing this system in a food processing facility led to a significant decrease in foodborne illness outbreaks. Similarly, Wallace and Mortimore (2016) reported that the methodology helped identify and control potential hazards in a seafood processing plant, resulting in enhanced product safety and quality.

However, applying this framework can be challenging in ecologically unfavorable areas, such as those with limited resources or inadequate infrastructure. Bolat (2002) identified obstacles including a lack of trained personnel, insufficient monitoring and control measures, and limited resources for maintaining records and documentation in developing countries. Despite these challenges, there is increasing recognition of the potential advantages of this approach in such contexts. For example, Torres (2000) highlighted how the system could improve food safety and quality in small-scale fisheries in developing regions, leading to better market access and competitiveness. Njoagwuani et al. (2023) suggested that implementing this framework could help address food safety challenges faced by vulnerable populations, such as children and the elderly, in resource-limited settings.

In addition to these examples, other regions across the world have successfully applied the HACCP system in areas facing similar ecological challenges. For instance, in post-Chernobyl Ukraine, the implementation of food safety protocols, including HACCP, proved essential in addressing the contamination of agricultural products with radionuclides. Studies have highlighted the importance of food safety protocols, including HACCP, in managing contamination risks. Research has shown that these protocols are crucial for ensuring safety in agricultural products affected by radionuclides. A technical report by Greenpeace discusses the contamination of agricultural products in the Chernobyl region and the methods used to address it, including HACCP implementation (Labunska et al., 2016).

Similarly, in the aftermath of the Fukushima nuclear disaster in Japan, Bai et al. (2023) reported that local food industries utilized HACCP to systematically monitor and control contamination risks in seafood and agricultural products, achieving compliance with international safety standards. In both cases, the adaptability of the HACCP system to mitigate risks in compromised environments demonstrates its robustness under extreme conditions.

In regions like sub-Saharan Africa, where water scarcity and poor sanitation pose significant risks to food safety, the HACCP system has

also proven effective. Studies have demonstrated HACCP's effectiveness in regions with water scarcity and poor sanitation, particularly in improving livestock product safety (Oguntoyinbo, 2012). These global examples underscore the adaptability of the HACCP framework, even in challenging environmental conditions.

2.2 Ecological challenges in Semey, Kazakhstan

The city of Semey, Kazakhstan, serves as a stark reminder of the enduring challenges faced by regions burdened with significant ecological issues. Established in 1948, the former Semipalatinsk nuclear test site conducted an extensive series of nuclear tests totaling at least 468 between 1949 and 1989 (Adamdar, 2019). The lasting legacy of these tests has profoundly impacted the region's environment and public health, resulting in widespread contamination of soil, water, and air (Bauer et al., 2013; Apsalikova et al., 2024). This contamination has been linked to elevated rates of cancer, birth defects, and other health issues among the local population (Grosche et al., 2015).

In such an ecologically compromised area, the implementation of robust food safety measures becomes not only essential but also challenging. Despite ongoing efforts to clean up and rehabilitate the site, Semey continues to contend with persistent soil contamination, water pollution, and health risks associated with radioactive materials (Stepanenko et al., 2006; Timonova et al., 2020; Krivitskiy et al., 2022). This underscores the critical and ongoing need for rigorous monitoring, comprehensive assessment, and effective mitigation strategies to address both environmental degradation and public health concerns (Grosche et al., 2002).

The HACCP system in Semey's food processing industry is particularly crucial amidst these challenges. By implementing HACCP protocols, local enterprises can systematically identify, evaluate, and control food safety hazards, thereby enhancing consumer protection and ensuring compliance with rigorous safety standards (Sperber et al., 2018). This approach not only mitigates risks associated with environmental contamination but also fosters resilience against ecological adversities, safeguarding both public health and the integrity of the food supply chain (Aruoma, 2006).

As Semey continues to navigate the complex aftermath of its nuclear history, the adoption of proactive and science-based food safety practices remains pivotal. Such measures are vital not only for restoring confidence in local food products but also for promoting sustainable development and ensuring the well-being of the community in the face of ongoing environmental challenges.

2.3 HACCP implementation in ecologically unfavorable areas

SMPE "Alteev" in Semey has undertaken the integration of the HACCP framework into its production process to ensure the safety and quality of its meat offerings. This study aims to investigate the presence of heavy metals, radionuclides, antibiotics, and pesticide residues in final products containing MBP. Additionally, it will assess changes in contamination levels before and after the system's implementation.

Through this research, the potential benefits of adopting this framework in improving food safety and quality under challenging environmental conditions will be demonstrated. The study contributes to existing literature by providing empirical evidence on its effectiveness in ecologically unfavorable areas, highlighting unique challenges and potential solutions for food safety management systems in such contexts.

The findings are expected to inform policymakers, industry stakeholders, and public health authorities on the necessity of incorporating environmental considerations into food safety protocols to protect consumer health and enhance product quality. By addressing these specific challenges through a comprehensive safety management system, the study aims to illustrate the potential for improving food safety and quality, even in regions facing significant environmental hurdles. This literature review emphasizes the critical importance of such a system and sets the stage for evaluating its effectiveness in the Semey context, while drawing on global examples of HACCP implementation in similarly challenged regions, such as Chernobyl, Fukushima, sub-Saharan Africa, and small Pacific islands.

3 Materials and methods

This study was carried out at the SMPE—"Alteev" in Semey city, East Kazakhstan. The company produces meat products such as sausages, patties, and cutlets.

3.1 Sample collection

The following ingredients were sourced from nearby farms to ensure high freshness and minimal structural alterations in the meat:

- Beef (Grade I)
- Meat and bone paste from beef rib bones (MBP)
- Blanched pork fat
- Blanched beef liver
- Wheat flour
- Skimmed milk powder
- Chicken eggs
- Spices

3.2 Study design

The study aimed to investigate the presence of heavy metals, radionuclides, antibiotics, and pesticide residues in final products containing MBP. Data collection occurred during two periods: November 2022–April 2023 (prior to HACCP implementation) and November 2023–April 2024 (post-implementation). All analyses were conducted at the certified testing center of JSC "National Center for Expertise and Certification" in Semey, Kazakhstan, following the approved standards of the Republic of Kazakhstan.

3.3 Methodology for HACCP development

The HACCP framework is a preventive approach to food safety that targets physical, chemical, and biological hazards throughout

production processes. It comprises seven key principles (Figure 1), each crucial for ensuring food safety (Zakharova and Gorbunchikova, 2021; Standart of Republic of Kazakhstan ST RK 1179-2003, 2003).

Risk and hazard analysis was performed in accordance with State Standard GOST R 51705.1-2001 (2001) “Quality systems. HACCP principles for food products quality management. General requirements.” This involved utilizing a risk analysis diagram to evaluate the potential consequences of hazardous factors, categorized into four severity levels: mild, moderate, severe, and critical. Additionally, the likelihood of these hazards occurring was assessed across four levels: practically zero, insignificant, significant, and high. A qualitative risk assessment diagram was constructed to plot the probability of occurrence against the severity of potential consequences, thus delineating the acceptable risk threshold.

3.4 Determination of heavy metal content

The concentration of heavy metals (lead, cadmium, arsenic, and mercury) was analyzed using inductively coupled plasma mass spectrometry (State Standard GOST 34141-2017, 2017). The method involves mineralizing samples with nitric acid in a microwave oven under pressure, followed by measuring the concentrations of the metals in the resulting solution. Calibration curves were constructed based on the signal intensity against the concentration of the elements, derived from a series of standard calibration solutions.

3.5 Determination of Cs-137 radionuclides

The content of Cs-137 radionuclides was measured according to the Standard of Republic of Kazakhstan 1623–2007 “Radiation monitoring. Strontium-90 and caesium-137. Food products. Sampling, analysis, and hygienic assessment” (Standart of Republic

of Kazakhstan ST RK 1623-2007, 2007). This method involves dissolving food ash in 3N nitric acid to transfer Cs-137 into solution. The radionuclide is then concentrated on a nickel ferrocyanide precipitate at a pH of 3–5 and isolated as antimony iodide or hexachlortellurite salt. The isolated Cs-137 is quantified using low-background beta-radiometers or beta-gamma spectrometers in the sample measurement mode following radiochemical analysis, with a minimum detectable activity of 0.8 Bq.

3.6 Statistical analysis

Statistical analysis was performed using Microsoft Excel to calculate mean values, standard deviations, and correlations. Differences were considered statistically significant when the *p*-value was equal to or less than 0.05.

4 Results

4.1 Initial data for the development of the HACCP system

This section outlines the entire production process of the meat pâté “Phirmennyi” with the addition of MBP from beef rib bones, covering each stage from raw material acceptance to the final storage of the product. This detailed description helps map out the sequence and nature of operations involved in production.

Object of Study: The object of this study is meat pâté with MBP. This product belongs to a group of meat products made from raw meat subjected to blanching, grinding, cutting, cooking in casings, cooling, and packaging. It is intended for direct consumption, with straight shells, loaves no longer than 25 cm, and a diameter of 35 mm, weighing 100–110 g.

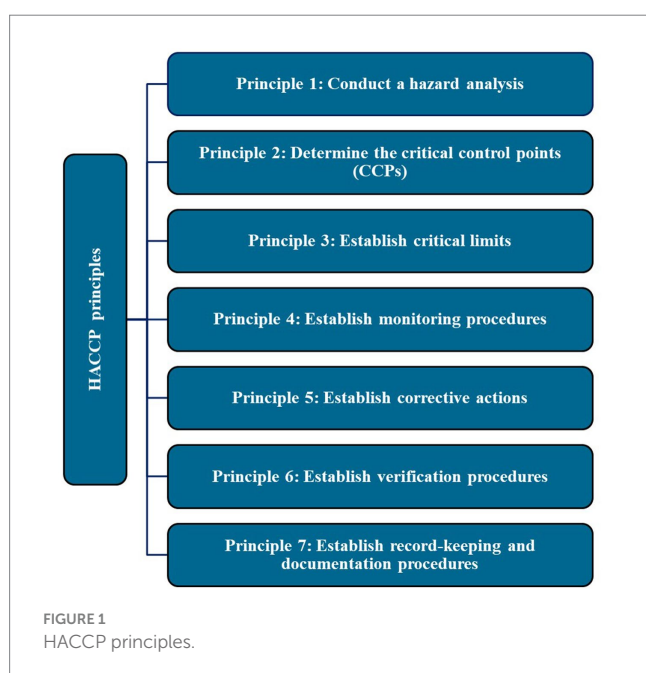
Regulatory Framework: The primary document that regulates the quality and safety of meat products in Kazakhstan is the Technical Regulations of the Customs Union, “On the Safety of Meat and Meat Products” (TR CU 034/2013). The production must comply with these standards to ensure the product is safe for consumers.

Composition and Properties: Table 1 details the composition and ingredients of the pâté, while Table 2 specifies its physical, chemical, and microbiological properties. These parameters provide a baseline for the safety and quality standards that must be maintained throughout the production.

Risk Factor Analysis: The first principle of HACCP requires a comprehensive analysis of risk factors across the production chain of “Phirmennyi” pâté. This involves identifying critical control points (CCPs) in the technological process where potential hazards could occur. The analysis was conducted according to the Standart of Republic of Kazakhstan ST RK 1179-2003, 2003.

The weaknesses identified during the process were classified as either equipment-related or non-equipment-related. Dangerous factors were analyzed based on the Technical Regulations of the Customs Union (TR CU 034/2013) and are outlined in Table 3.

External Control: Documentation was established to confirm the functioning of the HACCP system. This documentation is



available for review by external inspectors or contractors, ensuring that the system remains transparent and compliant with industry standards.

4.2 Identification of critical control points

A critical control point (CCP) is a step in the production process where control can be applied to prevent, eliminate, or reduce a food safety hazard to an acceptable level (Raihanah and Norazmir, 2020). However, not every point identified with hazards and preventive measures will qualify as a CCP. A structured decision-making process is employed to ascertain whether a process step is a CCP. The condition for the appointment of CCP is the ability to control it and the ability to effectively control the threat. It should be added that the quality of system functioning is not confirmed by the number of designated critical control points.

To identify CCPs, a detailed flow chart of the technological process for meat pate production is constructed (Figure 2). This flow chart outlines each step of the process, from raw material reception to the final packaging, allowing for a systematic analysis of potential hazards and the identification of points where control measures are crucial to ensuring food safety.

To determine the CCPs, the following algorithm is used (Awuchi, 2023) as shown in the Figure 3. This algorithm ensures a structured and systematic approach to identifying and managing critical points in the production process where intervention is necessary to guarantee food safety.

The definition of CCPs in production is detailed in Table 4. As a result, five CCPs in the production of meat pate “Phirmennyi” with MBP from beef rib bones were determined: blanching, cooking, cooling, packaging, and storage. These critical control points were identified based on their significance in preventing or reducing food safety hazards to acceptable levels. Each of these stages plays a crucial role in ensuring the safety and quality of the final product, aligning with the principles of the HACCP system. Proper monitoring and control at these CCPs are essential to

mitigate risks associated with potential hazards such as microbial contamination, chemical residues, and physical hazards throughout the production process.

4.3 Determination of critical parameters and limits

The CCPs identified in the production process (Table 4) are the key stages where food safety hazards are controlled. The table provides a comprehensive breakdown of the critical parameters for each CCP, including:

- Dangerous factors
- Critical limits
- Monitoring procedures
- Corrective actions
- Verification processes
- Record-keeping measures in compliance with HACCP principles

Each CCP in the HACCP plan is vital for maintaining food safety and product quality. These points are monitored and managed with the aim of reducing the risk of hazards to an acceptable level.

Summary of CCPs: Table 5 summarizes the CCPs identified for the production of “Phirmennyi” pâté at the small-scale enterprise “Alteev” in Semey, Kazakhstan. Each CCP includes specific controlled parameters, limit values, monitoring procedures, and corrective actions necessary to maintain safety standards throughout the production process.

Field Testing: Field tests of the production technology for “Phirmennyi” pâté with fermented MBP at “Alteev” demonstrated the practical applicability of the technology. The CCPs and technological modes were effectively implemented, confirming the reliability and safety of the process under real production conditions.

5 Discussion

The research highlights the significance of integrating environmental considerations into food safety management systems, particularly in regions facing environmental challenges such as poor soil quality, water contamination, and air pollution.

The findings underscore the importance of the HACCP system in ensuring food safety and quality, even in areas with ecological issues (Reilly and Kaferstein, 1997; Kvenberg et al., 2000; Okpala and Korzeniowska, 2021). Previous studies have demonstrated the effectiveness of HACCP in reducing foodborne illness outbreaks and improving product quality in various settings (Panisello et al., 2000; Kafetzopoulos et al., 2013; Singha et al., 2022; Awuchi, 2023). However, research into the implementation of HACCP systems in environmentally challenging areas is needed. These areas pose unique challenges, including assessing contaminants such as radioactive materials, heavy metals, and chemical residues that could enter the food chain through soil, water, or air, potentially affecting agricultural produce (Apsalikova et al., 2024; Aktayev et al., 2024).

TABLE 1 Recipe of meat pate with MBP kg/100 kg of raw materials.

Raw materials and basic materials	Raw material consumption kg per 100 kg
Beef veined grade I blanched	15
Meat and bone paste from beef rib bones	20
Pork, veined, fat, blanched	33
Liver veined beef blanched	20
Wheat flour	5
Skimmed milk powder	3
Chicken egg	2
Table salt, food	1,5
Granulated sugar	0,4
Ground nutmeg	0,05
Ground black pepper	0,03
Ground cinnamon	0,02

TABLE 2 Product characteristics.

List of questions about the source information	Standard
1. Product name	Meat pate with meat and bone paste
2. Product composition	Ground beef of the first grade blanched, mbp, fat-blanched pork, blanched beef liver, spices
3. Main features of the products	
3.1 Physico-chemical	
Mass fraction of protein, g, no more	16,80
Mass fraction of fat, g, no more	29,20
Mass fraction of carbohydrates, g, no more	5,50
Mass fraction of ash content, % no more	2,50
Mass fraction of moisture content, % max	48
4. Safety indicators	
4.1 Microorganisms	
QMAFAnM	No more than $1 \cdot 10^3$ CFU/g
<i>Escherichia coli</i> group bacteria	Not allowed
Pathogenic m/o including salmonella	Not allowed in 25.0 g
<i>S. aureus</i>	Not allowed
Sulfite-reducing clostridium	Not allowed
<i>L. monocytogenes</i>	Not allowed in 25.0 g
4.2 Antibiotics	
Levomyctin	Not allowed
Tetracycline group	Not allowed
4.3 Toxic elements	
Lead	Not more than 0.5 mg/kg
Arsenic	Not more than 0.1 mg/kg
Cadmium	Not more than 0.05 mg/kg
Mercury	Not more than 0.03 mg/kg
4.4 Pesticides	
Hexachlorocyclohexane (α , β , γ -isomers)	Not more than 0.1 mg/kg
DDT and its metabolites	Not more than 0.1 mg/kg
4.5 Radionuclides	
Cs-137	Not more than 200 Bq/kg

The ecological situation in Semey, particularly due to the legacy of the former Semipalatinsk nuclear test site, serves as a poignant example of the environmental challenges faced by certain regions. Despite efforts to clean up and rehabilitate the site, the city continues to grapple with soil contamination (Panitskiy et al., 2023; Timonova et al., 2024), water pollution (Krasnopyorova et al., 2023), and health risks associated with radioactive contamination (Semenova et al., 2021). This underscores the ongoing need for monitoring, assessment, and mitigation efforts to address environmental and health concerns.

In a recent study conducted between November 2022–April 2023 and November 2023–April 2024, researchers observed a significant reduction in the levels of heavy metals, radionuclides,

TABLE 3 Potential hazards in the production of meat pate:

Technological process, potential danger	
Controlled parameter	Acceptable values
Acceptance of raw materials: chemical, physical, microbiological	
Extraneous inclusions	Not allowed
QMAFAnM, CFU/g	No more than $1.0 \cdot 10^3$ CFU/g
Bacteria of the <i>Escherichia coli</i> group (coliforms) in 1 g	Not allowed
Sulfite-reducing clostridia in 0.1 g	Not allowed
<i>S. aureus</i> in 1 g	Not allowed
Blanching: microbiological	
Survival of pathogenic and opportunistic microorganisms	Not allowed
Grinding, cutting: microbiological	
Survival of pathogenic and opportunistic microorganisms	Not allowed
Filling: microbiological, physical	
Survival of pathogenic and opportunistic microorganisms	Not allowed
Extraneous inclusions	Not allowed
Cooking and cooling: microbiological	
Survival of pathogenic and opportunistic microorganisms	Not allowed
Packaging, labeling: microbiological	
Ingestion and development of extraneous microflora	Not allowed
Keeping: microbiological, physical	
Ingestion and development of extraneous microflora	Not allowed
<i>Escherichia coli</i> group bacteria, <i>S. aureus</i> in 1 g	Not allowed
Pathogenic, including salmonella and <i>L. monocytogenes</i> in 25 g	Not allowed
Sulfite-reducing clostridia in 0.1 g	Not allowed
Extraneous inclusions	Not allowed

and pesticides in food products following the implementation of the HACCP system.

Before the implementation of the HACCP system, the levels of Pb, As, Cd, and Hg in the meat pate were slightly higher compared to after the implementation of the system. Specifically, the content of Pb decreased from 0.55 to 0.51 mg/kg, As decreased from 0.12 to 0.07 mg/kg. These results suggest that the implementation of the HACCP system may have contributed to a reduction in heavy metal contamination in the final product (Figure 4). The decrease in levels of Pb, As, Cd, and Hg in the meat pate after implementing the HACCP system suggests that systematic monitoring and control measures can effectively mitigate contamination. This aligns with existing literature that highlights the role of HACCP in managing and reducing heavy metal contamination in food products (Maiberger and Sunmola, 2022; Atambayeva et al., 2022).

In terms of radionuclides, the content of Cs-137 in the meat pate decreased from 7.2 Bq/kg before the implementation of HACCP to 6.8 Bq/kg after. This indicates a slight reduction in radionuclide contamination in the final product (Figure 5). This

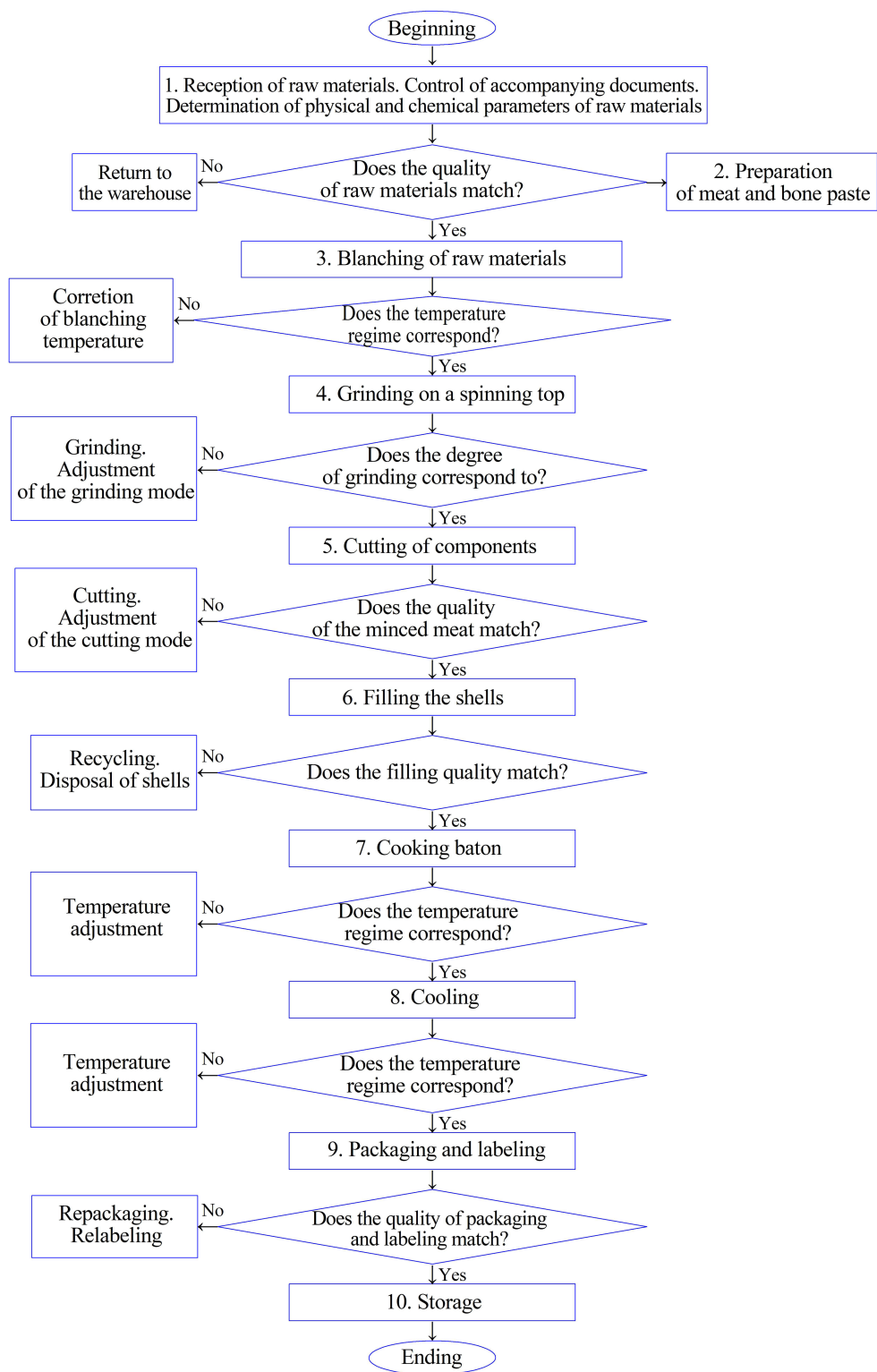


FIGURE 2
Flow chart of the technological process.

finding is supported by Sarap et al. (2024) work on radionuclide behavior in agricultural systems, which emphasizes the need for ongoing monitoring to manage these contaminants effectively.

Regarding pesticide residues, the levels of Hexachlorocyclohexane (α , β , γ isomers) and DDT and its metabolites also showed a decrease after the implementation of the

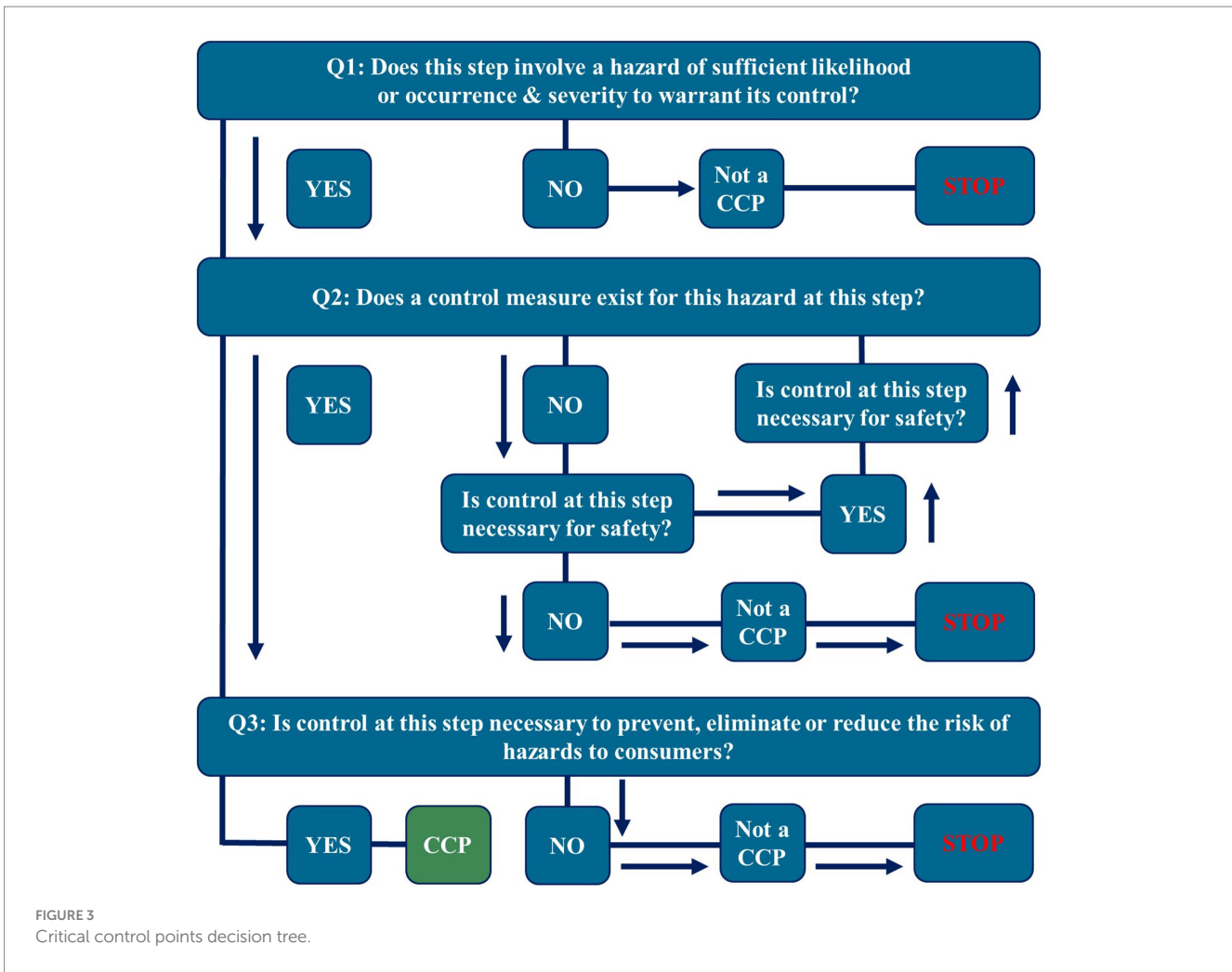


FIGURE 3 Critical control points decision tree.

HACCP system. Specifically, the content of Hexachlorocyclohexane decreased from 0.1 to 0.09 mg/kg, and DDT and its metabolites decreased from 0.1 to 0.08 mg/kg (Figure 5). Lee et al. (2023) have documented the challenges of pesticide contamination in food, and this study provides empirical evidence that HACCP implementation can address these issues effectively.

The study’s findings are consistent with previous research that has demonstrated the effectiveness of HACCP in various settings. Wallace and Mortimore (2016) provided a comprehensive overview of HACCP’s principles and its success in improving food safety across different industries. The results from Semey contribute to this body of knowledge by showing that HACCP can be successfully adapted to regions with significant environmental challenges.

Based on the study’s findings, stakeholders in the food safety sector should prioritize enhanced training to educate professionals about environmental risks and the role of HACCP. They should explore advanced technologies for real-time monitoring and establish robust regulatory frameworks to promote HACCP adoption in environmentally compromised areas.

Future research could explore expanding the scope of HACCP implementation to other food processing sectors in Semey and similar regions. Additionally, ongoing monitoring and evaluation of HACCP’s

long-term impact on reducing environmental contaminants in food products would provide further insights into its sustainability and effectiveness.

In conclusion, the study demonstrates that despite ecological challenges, the HACCP system can significantly improve food safety and quality in Semey’s meat processing industry. By addressing specific local risks and implementing tailored monitoring and control measures, HACCP proves instrumental in safeguarding public health and enhancing food security in environmentally compromised areas.

6 Conclusion

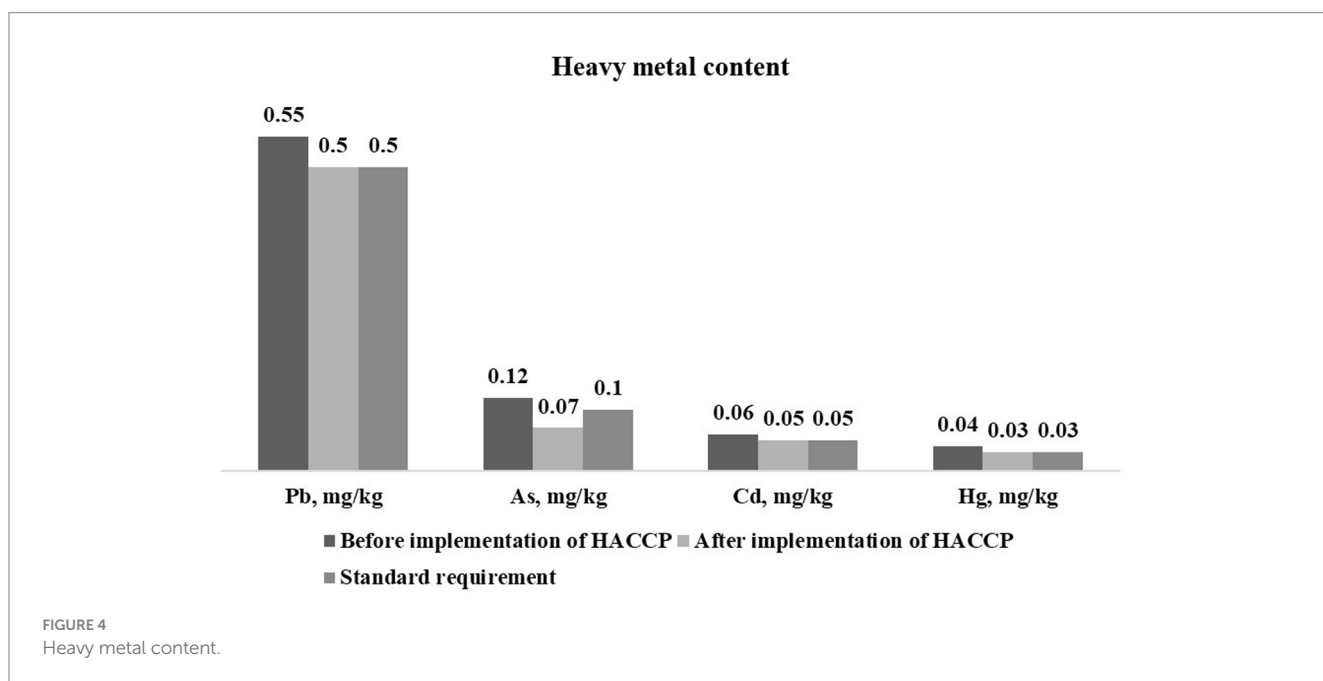
The implementation of the HACCP system at the small-scale meat processing enterprise “Alteev” in Semey, Kazakhstan, led to significant improvements in the safety and quality of the meat pâté “Phirmennyi,” particularly in reducing contaminants such as heavy metals, radionuclides, and pesticides, despite the challenging ecological conditions near the former Semipalatinsk Nuclear Test Site. After HACCP implementation, lead levels were reduced by 7.3% (from 0.55 to 0.51 mg/kg), arsenic decreased by 41.7% (from 0.12 to 0.07 mg/kg), and Cs-137 radionuclides dropped by 5.6%

TABLE 4 CCPs in the production of meat pate with MBP.

CCP No.	Dangerous factors	Critical limit	Monitoring procedure	Corrective actions or preventive measures	Verification procedure	HACCP records
CCP1. Acceptance of raw materials	Microbiological: <i>Escherichia coli</i> group bacteria, QMAFAnM, survival of pathogenic and opportunistic microorganisms	Extraneous inclusions are not allowed; QMAFAnM, CFU*/g, not more than $1.0 \cdot 10^3$ CFU/g; <i>Escherichia coli</i> group bacteria in 1 g is not allowed; sulfite-reducing clostridia in 0.1 g is not allowed; – <i>S. aureus</i> in 1 g is not allowed	Permanent microbiological, physico-chemical quality control of meat raw materials according to State standard 23,042–86, State standard 25,011, State standard 4,288–76, State standard 10444.15–94 State standard 31,747–2012 State standard R 32031–12 State standard 31,659–2012	Compliance with laboratory parameters of testing the quality of meat raw materials	Periodic verification and confirmation of the accuracy of measuring instruments. Checking the records of housing and communal services. Control of personnel competence	Records in the service journal on quality control of meat products. Records confirming the competence of responsible personnel
CCP2. Blanching	Physico-chemical: temperature, exposure time. Microbiological: BGKP, QMAFAnM	QMAFAnM, CFU*/g, not more than $1.0 \cdot 10^3$ CFU/g; <i>Escherichia coli</i> group bacteria in 1 g is not allowed; sulfite-reducing clostridia in 0.1 g is not allowed; – <i>S. aureus</i> in 1 g is not allowed Blanching temperature 105°C for 15–20 min	Constant control of blanching temperature	Equipment adjustment. Re-processing of raw materials	Control of technological modes of blanching. Checking of records in the service journal	Records in the service journal of the blanching process. Records of the verification of measuring instruments. Records confirming the competence of responsible personnel
CCP3. Cooking and cooling	Microbiological: <i>Escherichia coli</i> group bacteria, QMAFAnM, <i>E. coli</i> , Salmonella, <i>L. monocytogenes</i> , <i>S. aureus</i>	QMAFAnM, CFU/g, not more than $1.0 \cdot 10^3$ CFU/g; BGCP (coliforms) in 1 g is not allowed; sulfite-reducing clostridia in 0.1 g is not allowed; – <i>S. aureus</i> in 1 g is not allowed Cooking temperature 80–85°C within 40–80 min Cooling temperature up to $t = 2-6^\circ\text{C}$ in the center of the loaf	Temperature control of cooking and cooling. Technological control of the process	Compliance with temperature conditions. Re-brewing of loaves	Periodic verification and confirmation of the accuracy of measuring instruments. Verification of records in the service journal, confirmation of the correctness of the technological process	Entries in the service journal on the control of the temperature parameters of cooking and cooling. Records confirming the competence of responsible personnel
CCP4. Packaging	Microbiological: <i>Escherichia coli</i> group bacteria, QMAFAnM	QMAFAnM, CFU/g, not more than $1.0 \cdot 10^3$ CFU/g; <i>Escherichia coli</i> group bacteria in 1 g is not allowed; sulfite-reducing clostridia in 0.1 g is not allowed; – <i>S. aureus</i> in 1 g is not allowed	Control of the packaging process	Compliance with packaging requirements	Periodic verification of equipment. Verification of records in housing and communal services, confirmation of the correctness of the technological process	Records confirming the competence of responsible personnel
CCP5. Storage	Physico-chemical: storage temperature, humidity. Microbiological: <i>Escherichia coli</i> group bacteria, QMAFAnM, <i>E. coli</i> , Salmonella, <i>L. monocytogenes</i> , <i>S. aureus</i>	Temperature up to +5°C; air humidity—70%; QMAFAnM, CFU*/g, not more than $1.0 \cdot 10^3$ CFU/g; <i>Escherichia coli</i> group bacteria in 1 g is not allowed; sulfite-reducing clostridia in 0.1 g is not allowed; – <i>S. aureus</i> in 1 g is not allowed	Storage temperature control	Compliance with storage requirements	Periodic verification and confirmation of measuring instruments. Verification of log entries confirmation of the correctness of processing of non-conforming products. Personnel competence testing	Records in the service journal of technological storage parameters. Records confirming the competence of the responsible personnel. Records of internal and external audit results.

TABLE 5 Summary table of the HACCP plan.

CCP/technological process	CCP1. Acceptance of raw materials	CCP2. Blanching	CCP3. Cooking and cooling	CCP4. Packaging	CCP5. Storage
Controlled parameter	<i>Escherichia coli</i> group bacteria	Control of the temperature and time regime of blanching	Temperature control	<i>Escherichia coli</i> group bacteria	<i>Escherichia coli</i> group bacteria
Limit value	Not allowed	Depending on the mode	Not allowed	Not allowed	Not allowed
Monitoring procedure	The method of seeding into a CODE or Kessler environment	Constant temperature	Constant temperature	The method of seeding into a CODE or Kessler environment	The method of seeding into a CODE or Kessler environment
Corrective actions	Proper microbiological control	Adjustment of the line. Re-processing	Compliance with the temperature regime of cooking and cooling	Compliance with the rules of hygiene by personnel, control of the work of personnel, equipment, air disinfection	Proper microbiological control

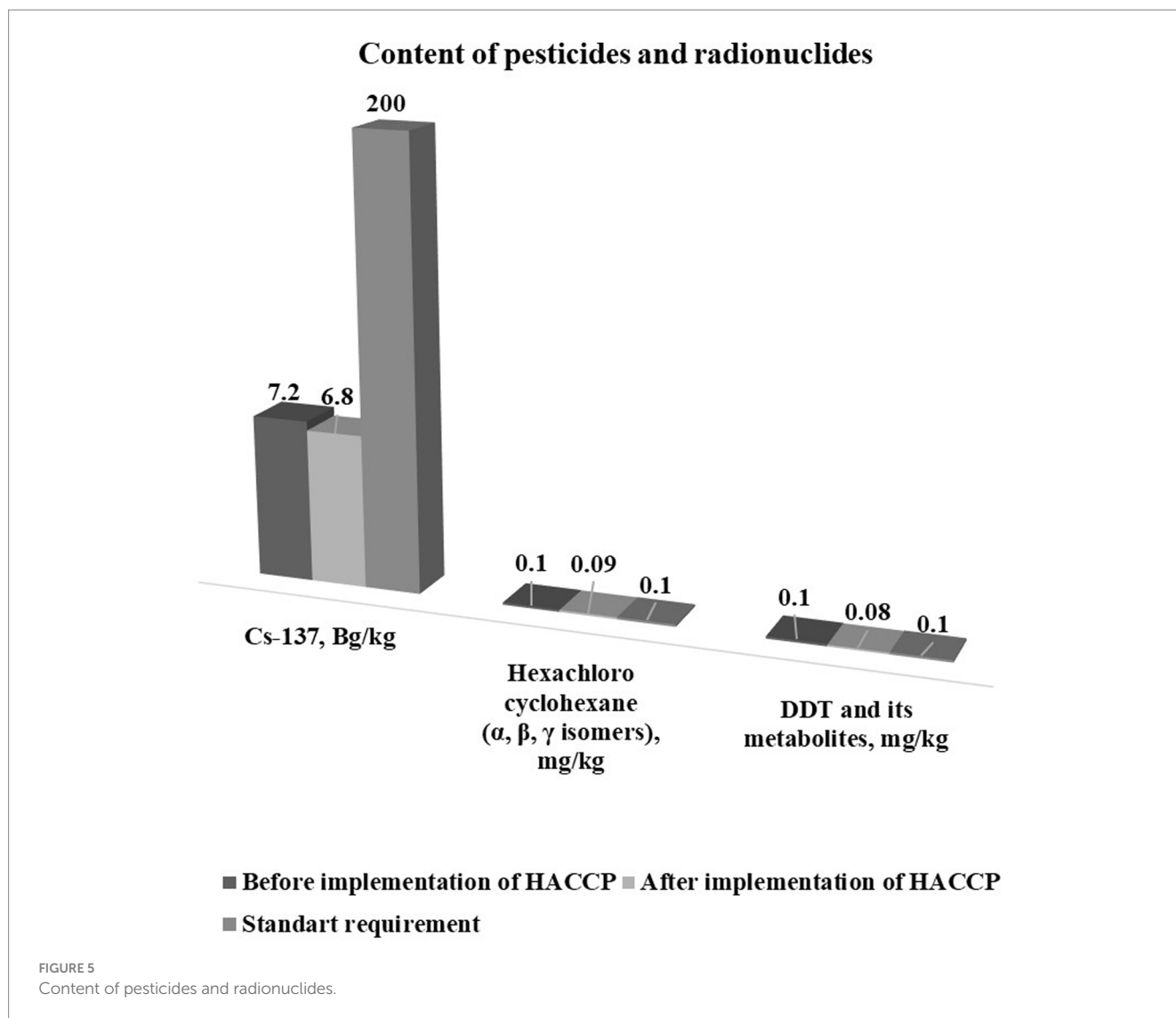


(from 7.2 to 6.8 Bq/kg). These results were compared to regulatory limits set by the Technical Regulations of the Customs Union, showing compliance for arsenic and Cs-137, while lead was near permissible levels. Five critical control points (CCPs) were identified: raw material acceptance, blanching, cooking, cooling, and packaging/storage, each playing a key role in minimizing risks from environmental contaminants. The effectiveness of the HACCP system was validated using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for heavy metals, Scintillation and Semiconductor Gamma Spectrometry for radionuclides, and chromatography-based methods for pesticide residue analysis. Statistical analysis showed a significant correlation between HACCP implementation and contaminant reduction ($p \leq 0.05$). Field trials confirmed the reproducibility of the results, and HACCP outperformed alternative risk management methods like

Good Manufacturing Practices (GMP), further demonstrating its efficacy in this specific environmental context. The findings underscore the urgent need for policymakers and industry stakeholders to prioritize the adoption of HACCP systems in ecologically unfavorable areas, as these systems not only enhance food safety and quality but also offer a pragmatic approach to mitigating the risks associated with environmental contaminants, ensuring public health and compliance with safety regulations.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.



Author contributions

AB: Project administration, Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Methodology, Investigation, Conceptualization. YY: Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. DO: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. BI: Writing – review & editing, Writing – original draft, Visualization, Investigation. AI: Writing – review & editing, Writing – original draft, Supervision, Investigation. SA: Writing – review & editing, Writing – original draft, Investigation. MS: Writing – review & editing, Writing – original draft, Methodology, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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