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Review on Camel Meat: Health Benefits, Chemical Contaminants, Health Risks, and Mitigation Strategies

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Abstract

THIS review highlights the significance of camel meat as a valuable nutritional source while addressing the risks associated with chemical contaminants, including pesticides, veterinary drugs, and heavy metal residues, and their potential effects on human health. With rapid population growth, global meat demand has risen significantly, prompting a shift toward alternative protein sources, including camel meat, due to its high protein content and low levels of fat and cholesterol. These nutritional benefits make camel meat an essential component of human diets, particularly in arid and desert regions. Given the severe health risks posed by chemical contaminants especially heavy metals, pesticides, and veterinary drug residues; global health organizations, international regulatory bodies, and governments are actively working to enhance food safety and protect public health. This review explores the historical development of awareness regarding chemical contamination in camel meat, highlighting advancements in detection technologies and regulatory frameworks. By analyzing recent studies, it identifies key contamination sources, assesses exposure risks, and discusses mitigation strategies. Additionally, case studies are presented to illustrate concerning contamination levels and their implications for public health and food safety. The review concludes by advocating for continued research and enhanced collaboration among stakeholders to mitigate contamination risks and ensure the safety of camel meat within the global food supply chain.

Keywords: Camel meat safety, chemical contaminants, pesticide residue, Public health risks.

Introduction

Camel meat is a crucial part of a balanced diet due to its high protein content, which supports muscle growth, repair, and maintenance, along with essential micronutrients such as iron and zinc, which are vital for red blood cell formation and immune function [1]. Due to population growth and rising meat prices, interest in alternative protein sources, such as camel meat, has increased, particularly in Africa and Asia [2,3,4].

Chemical contamination in camel meat is a significant public health concern, as harmful substances from environmental pollution, agricultural practices, and veterinary drug use can accumulate in the meat, particularly when meat-producing animals, especially camels, graze in areas exposed to industrial activities, pesticides, and contaminated water [5,6]. This exposure poses serious food safety risks, with potential links to chronic diseases, neurological disorders, and cancer [7,8,9].

Advances in detection technologies, such as mass spectrometry and high-performance liquid chromatography, have significantly improved the identification and quantification of chemical contaminants in camel meat, thereby enhancing risk assessment and regulatory control. Over the past few decades, awareness of this issue has increased substantially. Traditionally regarded as a natural and unprocessed food, camel meat was not initially considered a contamination risk [10]. However, the industrialization of agriculture and the widespread use of chemicals in livestock farming have raised serious concerns. Additionally, environmental factors including industrialization, urbanization, and climate change have further exacerbated contamination by

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polluting grazing lands and water sources [11]. Research has consistently detected heavy metals, pesticides, and veterinary drug residues in camel meat, underscoring its potential impact on food safety [12,13]. Furthermore, studies conducted in industrial regions have reported elevated contaminant levels, reinforcing the link between environmental pollution and food safety hazards [14,15,16].

Therefore, this review underscores the critical importance of understanding and mitigating the risks associated with chemical contaminants in camel meat to ensure consumer safety and support sustainable meat production. Effectively addressing these risks requires a comprehensive approach that identifies contaminants, traces their sources and pathways into the food chain, and implements targeted mitigation strategies. Strengthened collaboration among food safety authorities, farmers, and consumers is essential to reducing health risks and ensuring the safe and sustainable production of camel meat.

Health Benefits of Camel Meat

Camel meat is highly valued for its unique texture, rich flavor, and high moisture content, offering a superior nutritional profile compared to other red meats [17,18]. It is an excellent source of Omega-3 fatty acids, essential vitamins (B1, B2, B6, and E), and higher levels of calcium and iron than beef. Additionally, it provides high-quality protein with essential and non-essential amino acids crucial for human nutrition [19]. Bioactive compounds such as coenzyme Q10, carnosine, and glutathione contribute to various health benefits and have been traditionally used to treat ailments like pneumonia and hypertension [4,20].

Compared to other red meats, camel meat has a lower fat content and a higher proportion of polyunsaturated fatty acids, making it a healthier choice for individuals concerned about cardiovascular health. These fatty acids support heart health and help reduce the risk of atherosclerosis [21]. Furthermore, camel meat is rich in essential minerals like iron, zinc, and selenium, which play a key role in immune function and metabolism. Its abundance of bioactive peptides and antioxidants further enhances its health benefits by reducing oxidative stress and inflammation, reinforcing its role as a functional food with significant nutritional advantages [22,23].

Global Economic Value of Camels and Their Products

Camels and their derived products make a noteworthy contribution to the global economy, with annual revenues estimated between $18 and $24 billion. Camel milk, valued for its nutritional and therapeutic properties, dominates the sector with an estimated worth of $10–12 billion. Camel meat follows, generating $4–6 billion annually and playing a key role in enhancing food security in many regions. The trade of live camels, crucial for transport and traditional practices in arid zones, adds approximately $2–3 billion. Furthermore, the leather and wool sectors account for about $1 billion, and camel-related tourism contributes an additional $1 billion each year. The growing field of camel-based pharmaceuticals and nutraceuticals is also emerging, with an estimated value of up to $500 million annually. Collectively, these data highlight the camel's pivotal role in promoting sustainable economic growth, especially in desert and semi-desert environments [Table 1].

Chemical Contaminants and Health Risks

Camel meat is widely consumed in the Middle East and North Africa. Despite its nutritional benefits, camel meat is vulnerable to contamination by chemical residues, including heavy metals, pesticides, and antibiotic residues [24, 25]. These contaminants originate from various environmental sources and pose significant health risks to consumers [26,27]. Identifying the sources of these contaminants, understanding their health effects, and enforcing effective regulatory measures are essential for ensuring food safety and protecting public health [28]. To mitigate these risks, regulatory agencies must establish strict pesticide residue limits and implement rigorous monitoring systems. Ensuring compliance with safety standards is critical to reducing chemical contamination and maintaining the integrity of camel meat within the food supply chain.

Pesticides Residues in Camel Meat

The use of pesticides in agriculture is a critical concern. Pesticides, commonly used to protect crops from pests and diseases, can find their way into livestock, including camels [29]. Organophosphates and carbamates are two classes of pesticides frequently detected in camel meat. These chemicals can disrupt normal nervous system functions, leading to symptoms such as headaches, dizziness, and, in severe cases, respiratory failure [30].

Pesticide residues in camel meat can be categorized based on the type of pesticide and its mode of action. Insecticides, such as organochlorines (OCs) like DDT and Lindane, are persistent organic pollutants that accumulate in animal fat tissues, including those of camels, due to their long environmental half-lives [31,32,33]. Organophosphates (OPs), including Malathion and Chlorpyrifos, degrade faster than OCs but can still leave harmful residues. Pyrethroids, though considered less toxic to humans, may also leave detectable residues with potential long-term effects [34]. The presence of pesticide residues in camel meat raises significant health concerns, as prolonged exposure can lead to acute and chronic effects, including respiratory issues, endocrine disruption, and carcinogenic risks [14].

Various studies have highlighted contamination of camel tissues by different classes of pesticides. For instance, a study in Saudi Arabia identified diazinon, an organophosphate, in both muscle and liver tissues of all examined camels, though the levels were below maximum residue limits, indicating no immediate health risk [15]. Chronic exposure to organophosphates has been linked to conditions such as asthma, endocrine disruption, and cancer [15].

Camels can become contaminated with pesticides through multiple pathways, including environmental exposure from agricultural spraying, ingestion of pesticide-treated feed, direct application of pesticides to control internal and external parasites, and polluted water sources [25].

Pesticide residues in camel meat have been detected across various regions, raising public health concerns. In Saudi Arabia's Al-Qassim region, organochlorine pesticides (OCPs), particularly DDT and its metabolites, were found in 54 out of 200 muscle samples and 55 out of 200 liver samples, with estimated daily intakes for some residues exceeding acceptable limits, indicating potential health risks [10]. Similarly, in Kenya, organochlorine pesticide residues such as α-BHC, β-BHC, γ-BHC, and DDT were detected in beef and camel meat, though most levels were below extraneous residue limits, suggesting the meat was fit for consumption [35]. In Egypt's Sharkia Province, 54.4% of camel carcasses tested positive for DDTs, with contamination levels lower than those in cattle and sheep [33].

Some pesticide metabolites, such as paraoxon (a toxic derivative of parathion) and DDE (a breakdown product of DDT), are even more hazardous than their parent compounds. Research in Saudi Arabia and Jordan has detected DDT and its metabolites in camel meat, highlighting the persistence of these contaminants in the environment. In Jordan, a study analyzed camel milk, meat, and liver samples for organochlorine pesticide (OCP) residues. Findings revealed that 31.7% of milk and 3.3% of meat samples exceeded the maximum residue limits (MRLs) set by the Codex Alimentarius Commission. Notably, 20% of camel milk samples contained DDTs above permissible levels, and 13% had hexachlorocyclohexane (HCH) isomers, with γ-HCH (lindane) concentrations surpassing MRLs. Heptachlor and dieldrin were also detected in milk samples at levels exceeding safety standards. These findings underscore the need for regular monitoring and stricter control measures to ensure consumer safety [36].

In Saudi Arabia, research on 10 camels at the Al-Ahsa abattoir identified seven pesticide residues, including organophosphates (diazinon, profenofos, coumaphos), pyrethroids (cypermethrin, permethrin, lambda-cyhalothrin), and the acaricide amitraz. Diazinon was present in both muscle and liver tissues of all examined camels. Notably, all detected pesticide levels were below maximum residue limits (MRLs), indicating no immediate health risk [15].

A study conducted in Egypt found residues of pesticides and polychlorinated biphenyls (PCBs) in imported meat consumed in Egypt, raising concerns about consumer safety. Long-term exposure to these pesticides has been linked to chronic health conditions, including asthma, endocrine disruption, and cancer [28]. Additionally, research from the United Arab Emirates focused on detecting carbamate pesticide residues in raw and processed camel milk. The study employed advanced analytical techniques to identify 11 different carbamate pesticides. While specific concentrations and health risk assessments were not detailed in the summary, the detection of these residues highlights potential exposure risks for consumers. Continuous monitoring and evaluation of these contaminants are essential to safeguard public health [37].

These findings underscore the need for regular monitoring and stringent regulatory measures to ensure the safety of camel meat for consumers. The persistence of these contaminants in camel meat highlights the necessity for stringent monitoring and regulation of pesticide use to ensure food safety. Regular surveillance and adherence to withdrawal periods post-pesticide application are crucial to mitigate potential health risks associated with consuming contaminated camel meat.

Veterinary drug Residues in Camel Meat

Veterinary drug residues, including antibiotics and antiparasitic agents, are a significant concern in camel farming. These drugs are commonly used to treat and prevent diseases; however, failure to observe proper withdrawal periods can result in residual contamination in meat [34]. Excessive antibiotic use also contributes to antibiotic resistance, a major public health threat. A study in Somalia found that over 30% of camel meat samples contained antibiotic residues exceeding safety limits, highlighting the need for strict regulation and monitoring of veterinary drug use in camel farming [12].

Veterinary drugs, particularly antibiotics and hormones, are widely used in livestock production to promote growth and prevent disease. However, their misuse and overuse can lead to the accumulation of residues in camel meat. The presence of antibiotics in the food supply poses both direct health risks to consumers and contributes to the increasing issue of antibiotic resistance. The Centers for Disease Control and Prevention (CDC) warns that antibiotic-resistant infections can lead to prolonged hospital stays, increased medical costs, and higher mortality rates. A study conducted in Sudan revealed that a significant proportion of camel meat samples contained antibiotic residues, underscoring the need for stricter regulations and enhanced monitoring of veterinary drug use in camel farming [13].

In Saudi Arabia, a study analyzed muscle, kidney, and liver tissues from camels, cattle, and sheep for antibiotic residues using liquid chromatography-tandem mass spectrometry (LC-MS/MS). The results confirmed the presence of various antibiotic residues, including enrofloxacin, ciprofloxacin, and tetracycline derivatives, in camel tissues. While the detected levels remained below the maximum residue limits (MRLs) established by international standards, the study emphasized the necessity of adhering to appropriate withdrawal periods and maintaining rigorous monitoring of antibiotic use in livestock to ensure consumer safety. The researchers concluded that efficient cooking of meat and strict adherence to withdrawal periods for antimicrobial drugs are essential to minimize human exposure to antibiotic residues through meat consumption [38].

In Kenya, a study conducted in Isiolo County examined camel health management practices among pastoralists and their implications for public health. The study found that many pastoralists engaged in self-medication of camels, often without veterinary guidance, leading to the misuse of antibiotics. This practice raises concerns about the potential presence of antibiotic residues in camel meat and the emergence of antibiotic-resistant zoonotic pathogens, which pose significant health risks to consumers. The study highlighted the urgent need for education on prudent veterinary drug use and the establishment of regulatory frameworks to mitigate these risks [39].

Similarly, a cross-sectional study conducted in Mogadishu, Somalia, in 2022 analyzed 100 meat samples—50 from camels and 50 from goats—using the Premi® Test kit to detect antibiotic residues. The findings revealed that 18% of camel meat samples and 8% of goat meat samples contained antibiotic residues. Although the prevalence was higher in camel meat, the difference was not statistically significant. The study emphasized the need for public education on the judicious use of antimicrobial drugs in food-producing animals to preserve therapeutic efficacy and safeguard human health [12].

In Saudi Arabia, a comprehensive review focusing on camel meat hygiene and zoonoses in the Middle East highlighted significant contamination of camel meat with heavy metals and pesticide residues. While the review primarily addressed microbial and chemical safety, it underscored the necessity for stringent regulatory measures and regular monitoring to protect consumer health [25].

These findings reinforce the importance of continuous monitoring, strict adherence to withdrawal periods, and the prudent use of veterinary drugs in camel husbandry. Implementing robust surveillance systems and educating stakeholders about the risks associated with drug residues are crucial steps toward ensuring the safety of camel meat for consumers.

Heavy metals Residues in Camel Meat

Heavy metals such as lead, cadmium, arsenic, and mercury can accumulate in camel tissues due to environmental pollution, contaminated feed, and water sources. Studies have found lead concentrations in camel meat exceeding permissible limits, raising severe health concerns [27]. Exposure to these heavy metals has been linked to neurological damage, developmental issues in children, and chronic diseases. Therefore, monitoring programs are essential to ensure that camel meat remains safe for consumption [40]. Heavy metals often originate from environmental pollution, industrial activities, and agricultural runoff. Once ingested, these metals can accumulate in various organs, leading to severe health complications [41].

Several studies have analyzed trace metal concentrations in camels across different regions. Asli et al. [42] examined liver and muscle samples from 60 camels, finding that liver concentrations of copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), cobalt (Co), and chromium (Cr) were significantly higher than in muscle tissues. Factors such as sex, age, region, and sampling period influenced element concentrations. Notably, all heavy metals except cadmium (Cd) exceeded European Union (EU) standards, indicating potential contamination in camel meat and warranting further investigation. In Mauritania, Ahmed et al. [43] assessed trace metal concentrations in livers, kidneys, and muscles of 25 dromedary camels from butcheries in Nouakchott between February and April 2020. They measured four toxic metals (Hg, As, Cd, and Pb) and found no significant differences in metal concentrations based on age, sex, or diet type; however, significant differences were observed between metals and organs. Mean concentrations were 0.055 mg/kg for As, 0.064 mg/kg for Cd, 0.040 mg/kg for Pb, and 0.027 mg/kg for Hg, with Hg and Pb concentrations highest in the liver, while As and Cd were highest in the kidney. All detected concentrations were below admissible trace metal levels. Additionally, Abdelrahman et al. [44] investigated variations in, Pb, and Cd in the blood and tissues of slaughtered camels from five regions in Saudi Arabia during summer and winter, analyzing samples using inductively coupled plasma mass spectrometry. Their data revealed that Pb and Cd mean values in the liver (0.40 μg/g) were below the EU standard limit for Cd (0.50 μg/g), while Pb contents in meat and liver (1.62 μg/g and 2.57 μg/g, respectively) exceeded EU standards (0.10 and 0.20 μg/g, respectively). The study concluded that region and season influence mineral concentrations in camels, highlighting the need for further research on mineral biological mechanisms under varying environmental conditions.

Several studies have assessed heavy metal concentrations in camel tissues across different regions, highlighting potential health risks associated with their consumption. In 2015, Abdou et al. [5] examined camel tissues from the Banha abattoir in Egypt, finding lead (Pb) levels of 0.81 mg/kg in lungs, 0.66 mg/kg in liver, 0.57 mg/kg in kidneys, and 0.11 mg/kg in muscle tissues; cadmium (Cd) concentrations were highest in kidneys at 1.28 mg/kg, followed by liver at 0.52 mg/kg, lungs at 0.39 mg/kg, and muscles at 0.07 mg/kg, indicating higher heavy metal accumulation in offal compared to muscle meat. A study conducted in Algeria assessed the concentrations of selected heavy metals (Fe, Cu, Zn, Pb, Cd, and Hg) in fresh meat from cattle, sheep, chicken, and camel collected from northern and southern regions of Algeria using atomic absorption spectrophotometry. The findings revealed that iron had the highest concentration across all samples, followed by zinc, copper, lead, cadmium, and mercury. Notably, chicken meat exhibited the highest levels of iron (246.83 μg/g) and lead (8.80 μg/g). In contrast, camel meat generally showed the lowest concentrations of most studied metals, except for lead (3.21 μg/g) and zinc (4.17 μg/g) in the southern region. Samples from the northern area were more contaminated, likely due to increased industrialization and agricultural activities [45].

A 2024 study by AbdAl-Rudha et al. [9] in Najaf, Iraq, reported Pb, Cd, Cu, Ni, and Zn concentrations in cow meat at 0.54, 0.50, 0.33, 0.22, and 1.0 mg/kg, respectively, while camel meat showed lower levels: 0.27, 0.31, 0.26, 0.17, and 0.5 mg/kg, respectively, suggesting environmental contamination and the need for monitoring heavy metal exposure in meat. Additionally, Al-Sultan et al. [46] conducted a comparative study of camel tissues from Egypt and Saudi Arabia, revealing that liver, kidney, and tongue tissues had higher levels of Pb, Cd, As, and Hg compared to muscle tissues, with Egyptian samples exhibiting higher metal residues; notably, a significant percentage of liver, kidney, and tongue samples from Egypt exceeded maximum permissible limits for Cd and As, raising concerns about potential health risks, especially for children.

In a comprehensive analysis of heavy metal concentrations in camels, Meligy et al. [30] examined 225 samples from three breeds (Magaheem, Maghateer, and Wadha) using Atomic Absorption Spectrophotometry, finding that liver tissues exhibited the highest levels of cobalt (Co), chromium (Cr), manganese (Mn), and selenium (Se), with male camels showing notably higher concentrations across all examined tissues. Strong positive correlations between serum and liver concentrations for these metals suggest that serum levels may reflect hepatic metal burdens. The estimated daily intake (EDI) of these metals through camel meat consumption was below tolerable daily intake (TDI) thresholds, indicating minimal risk to consumers. Similarly, Abdelrahman et al. [16] assessed heavy metals in camel tissues from five Saudi Arabian districts, finding that Pb, Cd, and Co concentrations in muscle and liver samples varied by region but remained below international permissible limits, further suggesting minimal risk to consumers. Additionally, Mohamed et al. [25] evaluated trace elements and heavy metals in the serum of 50 imported camels in Aswan, Egypt, using Inductively Coupled Argon Plasma spectrometry, and found that average concentrations were within ranges comparable to previous research on camels from different regions. Essential trace elements like copper (Cu), iron (Fe), Mn, and zinc (Zn) were present in concentrations consistent with normal physiological functions, and heavy metals such as Cd and Pb were minimal, suggesting limited exposure to these toxic elements. Collectively, these studies enhance understanding of trace element and heavy metal status in camels, crucial for ensuring their health and the safety of camel-derived products for consumers.

Detecting Chemical Contaminants in Camel Meat

This section examines the methodologies and objectives of recent studies on chemical contaminants in camel meat. As the global demand for camel meat increases, understanding the potential health risks associated with chemical contamination becomes vital [47]. Researchers have employed various methodologies to evaluate these risks, focusing on analytical techniques for detecting contaminants and developing risk assessment models to evaluate potential health impacts. This comprehensive approach aids in identifying contamination sources associated with camel meat consumption and ensures food safety for consumers [13,48,49].

Recent studies on camel meat contamination have utilized a wide range of analytical techniques to detect various chemical contaminants. These methods are essential for identifying the presence and concentration of harmful substances such as heavy metals, pesticides, and other residues. One of the most commonly used analytical techniques is Atomic Absorption Spectroscopy (AAS), which is particularly effective for detecting heavy metals such as lead, cadmium, arsenic, and mercury in food products. AAS works by measuring the absorption of light by vaporized atoms, allowing for precise quantification of metal concentrations [26,46].

Another method that has gained popularity is Inductively Coupled Plasma Mass Spectrometry (ICP-MS). This technique offers even greater sensitivity and specificity compared to AAS, making it suitable for detecting trace levels of contaminants. Studies highlight the utility of ICP-MS in detecting and quantifying lead levels in camel meat, providing valuable insights into food safety and public health considerations. This underscores the importance of using advanced analytical techniques to ensure accurate detection of contaminants, which is crucial for protecting consumer health [16,50].

Furthermore, chromatographic techniques such as Gas Chromatography Mass Spectroscopy (GC-MS), Liquid Chromatography tandem mass spectrometry (LC-MS/MS) and High-Performance Liquid (HPLC) are widely employed for the analysis of antibiotic and pesticide residues in camel meat. These methods enable researchers to separate and quantify various compounds in complex mixtures, providing valuable insights into the types and levels of pesticides present. Several studies conducted in the Middle East have detected pesticides and antibiotic residues in various meat samples, including camel meat, at concentrations comparable to the maximum residue limits established by the European Union. These findings underscore the need for rigorous testing and continuous monitoring of camel meat products to ensure food safety and regulatory compliance [24,32,36].

Implications of chemical contaminants on public health and food safety

The presence of chemical contaminants in camel meat poses significant public health and food safety risks, particularly as the consumption of camel meat increases in regions like Africa, the Middle East, and Asia. Recent studies have identified heavy metals, pesticide residues, and antibiotic residues as key contaminants in camel meat. Case studies from various regions show instances where contamination levels exceeded safety thresholds, with potential health consequences for vulnerable groups, including pregnant women, infants, and individuals with liver or kidney diseases. These findings emphasize the need for regulatory measures and public awareness campaigns to ensure the safe consumption of camel meat and protect public health.

Epidemiological studies have provided crucial insights into the health implications of chemical contaminants in camel meat. For instance, a study conducted in Egypt found that cadmium content exceeded the established maximum permissible limits in 65% of liver samples, 20% of kidney samples, and 70% of tongue samples. Arsenic residue levels exceeded permissible limits in 50% of liver and kidney samples and 25% of tongue samples. These findings emphasize the necessity for public health interventions aimed at reducing chemical exposure in food. Contaminated camel meat can cause acute symptoms such as nausea, vomiting, dizziness, and organ damage, while long-term exposure is linked to chronic conditions, including cancer, reproductive issues, and nervous system dysfunction [46].

Persistent organic pollutants (POPs) found in contaminated camel meat can bioaccumulate in human tissues, leading to long-term health issues such as endocrine disruption and infertility. Studies indicate that frequent consumption of contaminated meat increases the risk of miscarriages, developmental abnormalities, and reproductive disorders. Additionally, the presence of antibiotic residues contributes to the growing problem of antibiotic resistance, making infections harder to treat. The overuse of antibiotics in livestock facilitates the development of resistant bacterial strains, which, when ingested by humans, result in infections that require stronger or alternative treatments, leading to prolonged hospital stays, increased medical costs, and higher mortality rates [25].

One of the most alarming findings in recent studies is the presence of heavy metals in camel meat. Heavy metals such as lead, cadmium, arsenic, and mercury can accumulate in camel tissues due to environmental pollution, contaminated feed, and water sources. For instance, a study conducted in Mauritania revealed that camel meat samples collected from various markets contained mean concentrations of toxic metals as follows: arsenic (0.055 mg/kg), cadmium (0.064 mg/kg), lead (0.040 mg/kg), and mercury (0.027 mg/kg). Such levels pose severe risks to consumers, particularly vulnerable populations such as children and pregnant women, who are more susceptible to the neurotoxic effects of lead [51].

In addition to heavy metals, pesticide residues represent another significant concern regarding camel meat safety. Pesticides, commonly used to eliminate pests, can have unintended harmful effects on human health when residues remain in food products. A review of studies in the Middle East examined camel meat for pesticide residues and reported alarming results. The review found that high contamination levels were reported in several countries, highlighting critical concerns for food safety. These residues can lead to acute and chronic health effects, including respiratory problems, endocrine disruption, and even carcinogenic effects upon prolonged exposure. These findings highlight the urgent need for regulatory frameworks to monitor and control pesticide usage, particularly in regions where camel meat production is increasing [25].

Another case study from Egypt revealed the implications of antibiotic residues in camel meat. The overuse of antibiotics in livestock farming, including camels, can lead to antibiotic residues in meat, posing a risk to consumer health. The study found that various antibiotic residues, including enrofloxacin, ciprofloxacin, and tetracycline derivatives, were present in muscle, kidney, and liver samples [38]. The presence of antibiotic residues raises concerns not only regarding food safety but also for broader public health issues, as it contributes to the growing problem of antibiotic resistance. This phenomenon can make infections more difficult to treat, leading to increased morbidity and mortality rates [52,53].

Each of these case studies presents compelling evidence of the health risks associated with consuming contaminated camel meat. These risks are not merely theoretical; they have real-world implications for public health. As consumers unknowingly ingest chemical contaminants through camel meat, the potential for adverse health outcomes increases. It is crucial to recognize that these contaminants can cause both acute health issues, such as food poisoning or allergic reactions, and chronic health problems, including developmental delays, organ damage, and an increased risk of cancer [25].

Mitigation strategies to Reduce Camel Meat Contamination

Ensuring the safety and quality of camel meat requires collaborative efforts among governments, health organizations, and the agricultural sector. This collaboration aims to maintain camel meat as a nutritious food option while addressing potential health risks associated with chemical contaminants. A multifaceted strategy involving regulatory oversight, farmer education, and consumer awareness is essential to mitigate these risks. To address the adverse effects of chemical contaminants in camel meat, several mitigation strategies have been proposed:

Implementing Integrated Pest Management (IPM) is crucial for reducing pesticide use in camel farming. IPM combines common-sense practices, such as crop rotation, biological control, and cultural methods, to prevent pest infestations effectively and environmentally sensitively [54].

Adopting a One Health perspective, which integrates human, animal, and environmental health, is vital for ensuring camel meat safety and managing zoonotic risks effectively. Enhancing investment in diagnostic infrastructures, training programs, and planning capabilities is crucial to address these issues at the camel-human interface in the Middle East [25]. This approach emphasizes collaboration among veterinary and public health authorities to enhance food safety measures, improve hygienic practices, and strengthen surveillance systems targeting camel meat [55].

Enhancing hygienic practices during the handling and processing of camel meat is essential to mitigate contamination risks [56]. Studies have assessed the hygienic practices of camel meat handlers and identified bacterial contamination sources in abattoirs and butcheries, underscoring the necessity for proper sanitation protocols to minimize contamination [57,58,59]. Implementing stringent hygiene measures in meat processing facilities and employing cooking techniques that minimize the formation of harmful substances can further reduce health risks associated with camel meat consumption.

Regular monitoring and control of environmental contaminants, such as heavy metals and pesticides, in camel meat are essential. Routine surveillance programs assessing soil, water, and feed for contaminants help identify and mitigate contamination sources, ensuring the safety and quality of camel meat products [16]. Additionally, Proper storage camel meat and regular sanitization of equipment are essential to minimize contamination. Veterinary drugs should be used responsibly, adhering to recommended withdrawal periods [60].

Implementing these strategies requires coordinated efforts from policymakers, industry stakeholders, and public health officials to ensure the safety and quality of camel meat and protect public health.

Conclusion

This review highlights the critical need to address health risks associated with chemical contaminants in camel meat. As discussed above, camel meat serves as an essential nutritional source in regions like the Middle East and North Africa. Renowned for its high protein content coupled with low fat and cholesterol levels, its safety is nevertheless threatened by contaminants like heavy metal, veterinary drugs and pesticide residues, which pose significant health hazards. Chronic exposure to these contaminants can lead to neurological disorders, organ damage, and cancer. Moreover, these substances may interact synergistically, amplifying health risks, which underscores the importance of comprehensive risk assessments that account for multiple contaminants simultaneously. Identifying and mitigating these risks is crucial to ensuring consumer safety and promoting sustainable meat production. A comprehensive approach involving regulatory oversight, farmer education, and consumer awareness is crucial to mitigate these risks. Public health and environmental organizations across the Arab world are actively developing strategies to reduce pesticide use and enhance food safety, ensuring the availability of safe, high-quality camel meat for human consumption.

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Declaration of Conflict of Interest

Authors declare that there is no conflict of interest.

TABLE 1. Estimated Global Economic Contributions of Camels and Their Products.

Category	Estimated Annual Value (USD)	Key Contribution
Camel Milk	$10–12 billion	Nutritional and therapeutic value
Camel Meat	$4–6 billion	Food security and protein source
Live Camel Trade	$2–3 billion	Transport and cultural/traditional uses
Leather and Wool	~$1 billion	Textiles, garments, crafts
Camel-Related Tourism	~$1 billion	Safaris, festivals, cultural tourism
Total Global Economic Value	**$18–24 billion**	Supports sustainable growth in arid regions

Source: *Food and Agriculture Organization* [61].

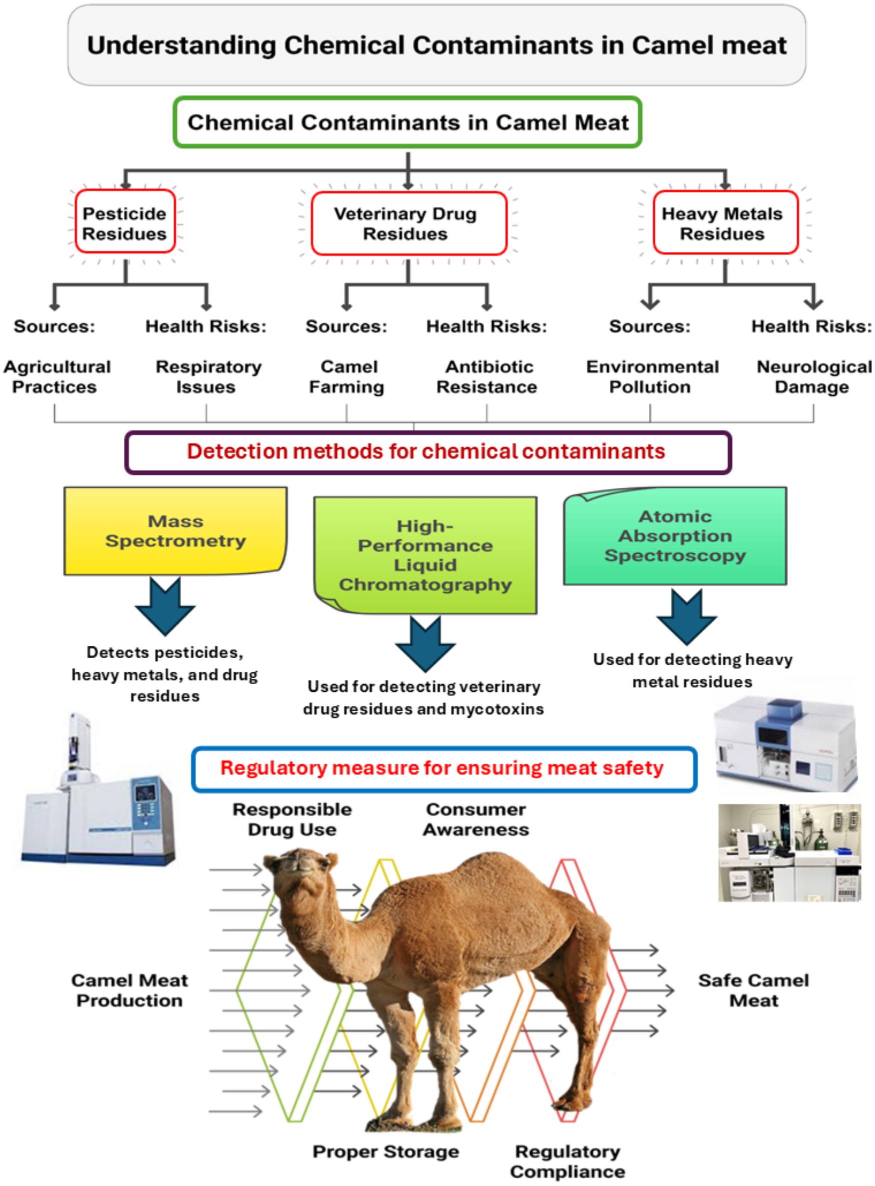

Fig.1. Chemical Contaminants in Camel Meat: Risks, Detection, and Regulatory Measures for Ensuring Food Safety.

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مراجعة حول لحم الإبل: الفوائد الصحية، الملوثات الكيميائية، المخاطر الصحية، واستراتيجيات الحد منها

مها سعيد إبراهيم، عبدالسلام الدايدامونى حافظ ، رشا محمد البيومي وعبد الله فكرى عبدالله محمود*

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الملخص

تُسلّط هذه المراجعة الضوء على أهمية لحم الإبل كمصدر غذائي غني بالقيمة الغذائية، مع التركيز على المخاطر المرتبطة بالملوثات الكيميائية مثل المبيدات الحشرية، الأدوية البيطرية، وبقايا المعادن الثقيلة، وتأثيراتها المحتملة على صحة الإنسان. مع النمو السكاني السريع، ارتفع الطلب العالمي على اللحوم بشكل كبير، مما أدى إلى التوجه نحو مصادر بروتين بديلة، من ضمنها لحم الإبل، نظراً لاحتوائه على نسبة عالية من البروتين ومستويات منخفضة من الدهون والكوليسترول. وتُعد هذه الخصائص الغذائية من العوامل التي تجعل لحم الإبل عنصراً أساسياً في الأنظمة الغذائية، خاصة في المناطق الصحراوية والقاحلة. نظراً للمخاطر الصحية الجسيمة الناتجة عن الملوثات الكيميائية، ولا سيما المعادن الثقيلة، والمبيدات، وبقايا الأدوية البيطرية، تعمل المنظمات الصحية العالمية والهيئات الرقابية الدولية والحكومات بشكل متواصل على تعزيز سلامة الغذاء وحماية الصحة العامة. تستعرض هذه المراجعة التطورات التاريخية في الوعي بالتلوث الكيميائي في لحم الإبل، مع التركيز على التقدم في تقنيات الكشف والأطر التنظيمية. من خلال تحليل دراسات حديثة، تحدد المصادر الرئيسية للتلوث، وتقيم مخاطر التعرض، وتناقش استراتيجيات الحد من التلوث. كما تتضمن المراجعة دراسات حالة توضح مستويات تلوث مقلقة وتأثيراتها على الصحة العامة وسلامة الغذاء. اختتمت المراجعة بالدعوة إلى مواصلة البحث العلمي وتعزيز التعاون بين الجهات المعنية لتقليل مخاطر التلوث وضمان سلامة لحم الإبل ضمن سلسلة الإمداد الغذائي العالمية.

الكلمات الدالة: سلامة لحم الإبل، الملوثات الكيميائية، بقايا المبيدات، المخاطر الصحية.