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Meat Contamination and Food Safety in Animal Production Systems: A Review

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Abstract: The contamination of meat and food safety are also major concerns of animal production systems as meat is a highly nutritious product but also highly susceptible to both biological and chemical contamination throughout the production chain. The given review paper researches the notion of meat contamination and food safety as the primary influencing factors of meat quality and safety as well as the primary microbial and chemical hazards of meat. It also discusses the community health implications of unsafe meat, including foodborne disease, chemical contamination, and antimicrobial resistance as well as strategies used as the main control and prevention measures to reduce the risk of contamination. As the review indicates, meat safety is a matter of a large number of interrelated concerns, including animal health, the environment, hygiene in slaughter areas, processing, storage, transportation, and regulatory policies. All-in-all, the farm-to-fork solution of ensuring meat safety is a holistic concept that should include hygienic control, veterinary control, hazard check, and effective prevention control practices. These steps should be strengthened to increase the quality of meat, protect the health of the population, and provide safer modes of animal production.

Keywords: Meat contamination; Food safety; Animal production systems; Meat quality; Microbial contamination; Chemical contamination; Public health.

Introduction

The food safety and meat contamination has become the topic of focus in animal production systems because meat is one of the most appropriate nutritious foods and, at the same time, it is very vulnerable to biological and chemical hazards of the production chain. The World Health Organization states that unsafe food each year causes approximately 600 million foodborne disease cases and 420,000 deaths worldwide, and this shows that food safety is no longer merely a quality of the food issue, but also a serious issue in the health of the population. Because of the popularity of food of animal origin and the repeated stages of production, slaughter, and processing, transportation, and handling by retailers, the safety of meat products became one of the fundamental issues of the agricultural sciences, veterinary public health, and consumer protection (World Health Organization [WHO], 2024a, 2024b).

Meat safety in an animal production system is determined by factors that start way before the end product gets to consumer. The Food and Agriculture Organization emphasize that food safety and quality management system should be based on the principles of science and risk-taking, whereas the World Organisation for Animal Health provides that veterinary services are the main means to manage the slaughterhouses, traceability, and ante and post mortem inspection of the food to exclude the foodborne risks as much as possible. These perceptions help to support the fact that meat contamination is not a single event at the retail stage, but a mixture of interacting farm-level, environmental, managerial, and processing-related factors at the entire chain of food (Food and

Agriculture Organization of the United Nations [FAO], n.d.; World Organisation for Animal Health [WOAH], n.d.).

The chemical pollution is of the particular concern in the context of meat production, as the environmental pollution, the structure of feed, the waste produced by the animals, and the unbalances of the minerals can all interfere with the hygienic quality of the edible animal products. In this connection, Palani, Al-Obaidy, Palani, and Ahmed (2022) discovered that the alteration in the positive factors and the destructive heavy metals in cow and sheep manure has a human, animal, and environmental connotation. Likewise, Palani, Ahmed, Al-Obaidy, and Palani (2022) examined cooperative and antagonistic relationships between heavy metallic elements in Kurdi sheep with regards to the availability of selenium and zinc supplements, which indicates that mineral interactions in the livestock can be extended to the health and food safety of animals. Moreover, Palani, Hamzah, Hamasalim, et al. (2022) directly examined the concentration of heavy metal in meat tissues and fats, and this is especially significant in the context of the hygienic significance of the control of chemical pollutants of edible animal products. Together, these studies demonstrate that the issue of meat contamination should be considered in a broader context, such as the exposure of the environment, animal physiology, and the safety of products intended to be consumed by humans (Palani, Al-Obaidy, Palani, and Ahmed, 2022; Palani, Hamzah, Hamasalim, et al., 2022).

Therefore, it can be concluded that the paper is a review article in which the authors aim to examine the concept of meat contamination, the main factors that affect the quality and safety of meat, microbial and chemical hazards, the health consequences of unsafe meat on the human body, and the most widely used control and prevention programs, in terms of meat contamination. The subject is especially significant as the safe meat production needs a complex approach that would connect animal health, environmental control, hygienic slaughter, regulatory control, and the well-being of people as a part of the One Health system (FAO, n.d.; WHO, 2024a; WOAH, n.d.).

Methodology

The preparation of this review article was based on a structured literature search method due to the necessity to gather and combine the required evidence on meat contamination and food safety in animal production systems. The review process was formalised in accordance with the overall postulates of transparent review reporting as offered in the PRISMA 2020 statement that is actively employed to promote the clarity of literature identification, screening, and selection during review studies (Page et al., 2021a, 2021b).

The relevant literature was identified with the help of the major scientific databases, namely PubMed, Scopus, and Google Scholar, as well as selected official sources of the international organizations related to the food safety and animal health. The main source was PubMed because it is a free database which allows to search and retrieve literature and biomedical and life sciences and now has more than 40 million citation and abstracts (National Center for Biotechnology Information [NCBI], n.d.).

The search strategy was based on the combinations of the following keywords; meat contamination, food safety, meat quality, microbial contamination of meat, chemical contamination of meat, meat foodborne pathogens and animal production systems. The relevance of the search results was enhanced with the help of Boolean operators: AND and OR, and reference lists of the articles that were selected were also scanned with the aim of revealing other helpful studies. This kind of explicit search and selection is in line with the up to date review guidance presented in Cochrane Handbook and PRISMA 2020 documents (Cochrane Collaboration, 2025; Page et al., 2021a).

The inclusion criteria encompassed the peer-reviewed journal articles, review articles as well as official reports that are directly connected with meat contamination, food safety, meat-borne pathogens, chemical hazards and the risks of food of animal origin to the general health. Recent

and English language publications were preferred to offer up to date scientific coverage. After screening titles and abstracts, the full-text analysis of potentially relevant sources was done to eliminate duplicate records and studies that were not directly related to the objectives of the review (Page et al., 2021a, 2021b).

Finally, the selected articles were organized in theme according to the major lines of the review idea including the concept of meat contamination, factors affecting meat quality and safety, microbial contamination, chemical contamination, impact on the population, and control. Since this article is a narrative review, but not a quantitative meta-analysis, evidence synthesis was performed by synthesis to provide a clear and coherent overview of the topic (Cochrane Collaboration, 2025).

Food Safety and Meat Contamination Idea.

Contamination of meat is a concept that is employed to refer to the existence of biological, chemical or physical hazards in meat that can result in diminished quality or an unhealthy state to humans. The given article by the World Health Organization proves that the question of food safety is directly connected not only to its appearance but also to hazard control, that is why the unsafe food can harbor the harmful bacteria, viruses, parasites, or even chemical substances which can cause more than 200 diseases (World Health Organization [WHO], 2024).

Food safety in connection with meat production, thus, is considered as production, handling, processing, transportation, and storage of meat under hygienic environment that prevents or minimizes contamination. According to Codex Code of Hygienic Practice of Meat, hygienic control of meat is not a trivial task and the hygienic control should not be confined to only production of live animals, but also include slaughter, processing and distribution. This shows that the concept of meat safety is not limited to the final product, but also to the entire production system that involves farm to consumer (Codex Alimentarius Commission, 2005).

Microbial spoilage is more narrow in definition than meat contamination. It consists of microbiological (bacteria of pathogenic type), chemical (the presence of drug and heavy metals) and physical (introduced foreign objects) contamination during working or processing. Hazards are also considered to be a biological, chemical and physical agent, which could lead to illness or injury, unless it is controlled properly, and identifying the hazards is one of the significant steps in the management of meat safety (FAO, 2005; WHO, 2024).

A distinction exists between the quality of meat and meat safety. Meat may be of satisfactory color, feel and look and be unsafe with dangerous contaminants. According to FAO meat handling, pre-slaughter treatment, hygienic dressing, evisceration, refrigeration and transportation of meat all affect the end result of meat and this implies that good and safe meat is achieved when it is well handled during the processing (Food and Agriculture Organization of the United Nations [FAO], 1991).

In general, meat contamination and food safety concept can be considered an advanced integration of efforts that should provide meat with healthiness, cleanliness, and suitability to be consumed by a person. This is why the idea of meat safety belongs to the most significant considerations in the animal production system, veterinary population health, and food hygiene, when the control measures should be implemented to the hazards at every point of the chain, and not at its final point only (Codex Alimentarius Commission, 2005; WHO, 2024).

impacting Factors of Meat Quality and safety.

The quality and safety of the meat is determined by the combination of the pre-slaughter factors, slaughter factors, and post-slaughter factors. They not only determine the sensory characteristics of meat, such as color, tenderness, juiciness and shelf life, but also the hygienic worth and even the suitability of meat to human consumption. The international meat hygiene standards have required that safe meat production does not rely on the mitigation measures at the last stage but

throughout the entire meat chain (Codex Alimentarius Commission, 2005; World Organisation for Animal Health [WOAH], n.d.).

Ante-slaughter condition constitutes species of animals, breed, age, sex, nutritional history, health conditions, exposure to the environment, transportation, and pre-slaughter stress. One of the recent scoping reviews of cattle has stated that the pre-slaughter management factors can make a considerable impact on the ultimate outcome of meat quality, and the FAO guidelines have also noted that preslaughter management and slaughter procedures have a strong influence on the ultimate meat status (Sullivan et al., 2022; Food and Agriculture Organization of the United Nations [FAO], 2004). The stress in the transportation or lairage is of specific significance since it can affect the muscle metabolism and, consequently, the postslaughter meat quality (Sullivan et al., 2022).

Among other factors that should be taken into consideration in the context of meat safety, animal mineral balance and environmental contamination should be mentioned. The research by Palani, Ahmed, Al-Obaidy and Palani (2022) indicated high health impacts of mutual and antagonistic relationship between heavy metallic elements in the Kurdi sheep, and mineral imbalance in livestock may affect the health and hygiene of food intake. In the same way, heavy metal has been used in the monitoring of meat tissues and fats directly associated with measuring the safety of meat (Palani, Hamzah, Hamasalim, Mohammed, and Palani, 2022).

During slaughter, stunning, bleeding, skinning and evisceration is necessary because contamination may be transmitted directly on the carcass where the processes are not handled well. According to the FAO meat inspection guidelines, inspection schemes are expected to be applied to preserve health of animals and wholesomeness and absence of disease risk in meat, according to the European Food Safety Authority [EFSA] n.d., the purpose of meat inspection is to prevent and detect any disease risk and chemical contamination in meat, which is a health hazard to the population.

The post slaughter state also has an impact on quality and safety of meat. They are; chilling of carcass, carcass cutting, carcass packaging, storage temperature, transportation condition and pre consumption time. In a recent study of beef quality, it was found that slaughtering conditions, aging period, and other post-slaughter have interacted in terms of their effects on the quality of eating, and risk-based meat-safety literature asserts that modern systems must prevent the effects of the most relevant meat-borne hazards with preventive and evidence-based interventions regardless of acceptable slaughtering practices (Pogorzelski et al., 202

Overall, there exists a series of biological, environmental, managerial, and hygienic factors of the quality and safety of meat. Thus, to enhance the safety of meat, animal health, and preslaughterary, mineral balance, hygienic slaughter, official inspection, and proper handling of the entire production chain after slaughtering should be considered (WOAH, n.d.; Codex Alimentarius Commission, 2005).

Meat Contamination by Microbes.

Among the greatest threats to the safety of meat, microbial contamination should be mentioned since the moisture level of meat, abundance of nutrients, and the relatively neutral pH of meat create favorable conditions under which microorganisms survive and reproduce. Meat chain contamination may be done at various points in the chain that incorporates: animal rearing, animal transportation, slaughtering, dressing of carcass, processing, storage and retailing. According to the international meat hygiene standards, control should be implemented at the line of production, and not on end products tested (Codex Alimentarius Commission, 2005).

Salmonella, pathogenic Escherichia coli, Listeria monocytogenes and Campylobacter can be considered as the main microbial hazards of meat. According to the literature analysis, the organisms are considered the most important meat-carrying zoonotic bacterial pathogens (Ali and Alsayeqh, 2022). The World Health Organization also reports that the key causes of

Campylobacter foodborne infections in general, and enterohaemorrhagic E. coli is typically caused by undercooked meat (World Health Organization [WHO], 2020, 2024).

The source of the microbial contamination can be the animal itself, particularly behind, feathers, skin or gastrointestinal tract and could be the contaminated knives, equipment, hands of workers, water, and surfaces of the slaughterhouse. The Codex Code of Hygienic Practice in Meat states that animals to be slaughtered must be clean and the environment under which they are kept be such that the risk of contamination by food-borne pathogens is minimized which implies that the contamination risk begins before such pathogens begin to attack the carcass itself (Codex Alimentarius Commission, 2005).

The Listeria monocytogenes would particularly need to be given more emphasis because it can contaminate the processed ready to eat meat products and also continue posing a risk to chilled foods. A multistate listeriosis outbreak was reported by the U.S. Centers for Disease Control and Prevention that was associated with delis-sliced meats, and as of January 31, 2025, the outbreak consisted of 61 reported cases. This portrays the continued risk of post-processing pollution to the health of the communities in the food distribution facilities (Centers for Disease Control and Prevention [CDC], 2025a, 2025b).

The other critical problem is the fact that certain microorganisms are able to survive and develop at refrigeration conditions. That is the reason why refrigeration cannot be referred to as a total solution but to the list of controls which should be supported by hygienic slaughtering, sanitation, and avoidance of cross-contamination. In total, microbial contamination of meat is a farm-to-fork issue, which is supposed to be addressed through a complex of the following measures: healthy animals, sanitary slaughter, sanitary facilities and equipment, temperature, and safe handling (Codex Alimentarius Commission, 2005; Ali and Alsayeqh, 2022).

Meat Chemical Contamination.

The issue of chemical contamination of meat is one of the largest food safety challenges since dangerous chemicals can be found in the edible tissues despite the meat looking normal in terms of color, texture, and smell. The predominant chemical hazards of animal production regimes consist of the heavy metals, the residues of veterinary medicines, pesticides residues and compounds, which are harmful and occur during the high-temperature cooking or processing. These pollutants may be acquired through feeds, water, soil, environmental pollution or therapeutic treatment or technological processing environment. (Khalifa et al., 2024; Jia et al., 2024).

The heavy metals constitute one of the gravest chemical contaminants and these having been in the feed, water and the environment around them, may get into the meat and cause health hazards after several years of exposure. Your given sources also reveal this concern. Palani, Ahmed, Al-Obaidy, and Palani (2022) discussed the importance of interactions between heavy metallic components and the state of Kurdi sheep, whereas Palani, Al-Obaidy, Palani, and Ahmed (2022) associated beneficial and harmful heavy metals in cow and sheep manure with the health of people, animals, and the environment. Besides, Palani, Hamzah, Hamasalim, et al. (2022) directly evaluated the heavy metal content of meat tissues and fats, which suggests that the monitoring of metallic residues in edible animal products can be used.

Another chemical risk in meat is the presence of veterinary drug residues. Recent review evidence has demonstrated that veterinary medicines can be left in food animal products as pharmacologically active residues and that pharmacologically active residues can be causal in antimicrobial resistance, hypersensitivity reactions, a carcinogenic risk and other negative health outcomes in the case of control system failure. That is why the withdrawal inspection, residue inspection, and regulatory compliance are also mandatory items of meat safety programs (Khalifa et al., 2024).

The pesticide residues should not be left out also under the case of meat safety as they may find their way into the animal based foods indirectly through contaminated feed water or water or even

through exposure to the environment. As Jia, Shi, and Xu (2024) noted, the issue of pesticide residues in food of animal origin remains a large analysis and food safety issue, and that chemical meat safety must be incorporated into the whole production system, and not simply at the slaughter or retail stage.

Other chemical hazards are also not introduced when slaughtering, but they are generated during cooking and processing. Heterocyclic aromatic amines may be generated during the high temperature cooking of protein rich foods like meat, and have been reported in the contemporary review literature as being robust mutagens and carcinogens that are associated with high practice of cancer. This expands the meaning of chemical contamination to include not only the dangers related to residues, but also the dangers connected to the process (Oz et al., 2023).

Altogether, the meat chemical pollution issue has a variety of sides including the contact with the environment, the overabundance of minerals, the misuse of veterinary drugs, the pesticide transfer, and the way of chemical formation during processing. As a result, to have it under control, residues, safe feed, water management, good veterinary control, safer processing and cooking of meat need to be managed jointly (Khalifa et al., 2024; Jia et al., 2024; Oz et al., 2023).

Health Impact of Unsafe Meat.

The role of unsafe meat in the health of the whole population is immense as it can be considered to be a source of biological and chemical threats not only to people but in some instances to the whole community. According to the findings of the World Health Organization, the problem of food safety is not a minor international one since it is the leading cause of 600 million incidences of foodborne diseases and 420,000 deaths per year (World Health Organization [WHO], 2024a, 2024b).

One of the most important effects of unsafe meat in relation to the health of the population is foodborne infection by pathogenic microorganisms. The most important zoonotic threats of the meat-consumption are said to be Salmonella, pathogenic Escherichia coli, Listeria monocytogenes, and Campylobacter. The pathogens can result in diarrhea, fever, vomiting, septicemia, kidney complications, miscarriage, and death in severe cases, especially in children, older adults, pregnant women, and immunocompromised people (Ali and Alsayeqh, 2022; WHO, 2024a).

This is also crucial to the hazardous meat in the long-term as far as the chemical exposure is concerned. The heavy metals, veterinary drug residues, pesticide residues and toxic compounds formed during processing or cooking are cumulative in meat and present chronic health risks which are long-term during repeated exposure over a period of time. They may include not only acute food poisoning but also toxic, allergic, carcinogenic, and antimicrobial resistance-related effects, in other words, the health effect of unsafe meat is a complex concept (Khalifa et al., 2024; Palani, Al-Obaidy, Palani, and Ahmed, 2022; Palani, Hamzah, Hamasalim, et al

Another serious health problem among the population is antimicrobial resistance. The WHO has identified antimicrobial resistance as one of the biggest global threats to human health and development and this indicates that the most significant contributors to pathogen resistance are the misuse and overuse of antimicrobials in human beings, animals and plants. When applied to the sphere of meat production, it implies that unsafe meat can be the cause of not only infection but also curing more severe, more expensive to manage infections (WHO, 2023).

The public health importance of unsafe meat is also represented by surveillance data. According to the estimates of the source of foodborne illnesses that have been provided by U.S. Centers of Disease Control and Prevention 22 percent of foodborne illnesses and 29 percent of foodborne deaths in the United States were caused by meat and poultry. The given statistics are peculiar to the U.S. attribution estimates, but also help to demonstrate that contaminated meat products are expensive (Centers for Disease Control and Prevention [CDC], 2025).

On the whole, health outcomes of unsafe meat are acute food poisoning, chronic chemical exposure, antimicrobial resistance, and common health and economic outcomes in the population. Hence, enhancing the safety of meat is a huge step in protecting the quality of the food, disease prevention, consumer protection, and safe food production systems (WHO, 2024a; CDC, 2025).

Control and Prevention Measures.

To manage meat contamination, a multi-faceted approach should be implemented, which involves the management of the farm and further to slaughter, processing, transportation, storage, and final handling. According to Codex, meat hygiene programs are to be founded on a risk-based principle and that meat must be safe and appropriate to human consumption that is prevention is better than cure and end-product inspection.

The farm level of prevention is based on good animal husbandry, safe food and water, disease surveillance and veterinary control. Veterinary services according to WOAH help in the realization of food safety objectives and reduction of threats to animal and human health through the execution of activities in the farms and processing places like slaughterhouses. It shows that the meat safety begins with healthy animals and controlled production setting prior to slaughter being carried out (World Organisation for Animal Health [WOAH], n.d.).

In slaughter and carcass dressing hygienic control is essential as contamination may be directly introduced to the meat surface like the poorly handled meat, unsanitary equipment or improper sanitation. The Codex Code of Hygienic Practice in Meat lays stress on the use of preventive and remedial measures, veterinary examination and official meat hygiene as the primary aspects of meat hygienic systems. Good handling of the carcass and clean facilities is thus a significant measure that can be adopted in order to minimize biological and physical risks occurred in meat (Codex Alimentarius Commission, 2005).

Safe food handling after slaughtering and temperature control is another factor that should be handled. The WHO Five Keys to Safer Food framework advances five fundamental preventive steps, which include: maintain hygiene, maintain raw and cooked food apart, cook, maintain food and use of water and raw materials clean. WHO also details that a person should not leave his or her cooked food at room temperature and leave it more than two hours but refrigerate the perishable food immediately and cook meat and poultry. The following recommendations can be directly implemented in the process of microbial growth and prevention of cross-contamination of meat products (World Health Organization [WHO], 2006).

Official inspection and regulatory monitoring also play a great role in prevention systems. The veterinary services as per WOAH guidelines are concerned in the assurance of food of animal origin to be safe and can also be utilized to perform ante-mortem and post-mortem inspection to determine health of animals and wholesomeness of animal products. This, in turn, implies that it should be prevented by compliance on the part of the producers, and powerful official controls, traceability and effective veterinary supervision along the meat chain (WOAH, n.d.).

Generally, meat safety prevention can only be achieved by a concerted effort on the whole chain, which involves healthy production of animals, hygienic slaughtering, hygiene, cold-chain, consumer food handling, and regulatory monitoring. Combined, they will mitigate the risks of contamination and enhance human health protection in the animal production systems (Codex Alimentarius Commission, 2005; WHO, 2006; WOAH, n.d.).

Problems and Future Forecasts.

The food safety and meat contamination are complex and evolving factors because the modern food systems are being industrialized, globalized, and more exposed to biological and chemical hazards. The World Health Organization states that the issue of food safety management is complex due to population increase, changes in the food production, environmental pollution, food trade and travel globalization, and the advent of new technologies. It means that the previous approach to inspection will no longer be possible to make sure that the meat is safe but a more

versatile and comprehensive system of risk-control is required instead (World Health Organization [WHO], 2024).

Among the main concerns is the fact that the meat safety should be considered not only of the final product, but also of the entire production chain. According to the WHO, food safety standards in animal production are also meant to control the risks that are involved between the farm level to the primary processing and Codex standards that are imposed on consumption. This assures that successful future meat safety systems should be intertwined, aligned and founded on a real farm-to-fork approach (World Organisation for Animal Health [WOAH], n.d.).

The other menace is the antimicrobial resistance. According to WHO, the antimicrobial resistance is one of the most significant health-related problems of the modern world as the resistant microorganisms complicate or even prevent the prevention of the disease exposing the people to the threat of the disease spread, severe illness, and disability and even death. When applied to the situation with meat production, it translates to the fact that the judicious use of antimicrobials, the monitoring of antimicrobial-resistant pathogens, and the One Health collaboration between the animal health, human health, and environmental sectors will assume even greater significance in the food safety practices in the future (WHO, 2023).

Environmental and climatic forces are also increasing concerns on the future of meat safety. FAO emphasizes the fact that climate change is defining the direct implications on food systems and has already been attributed to the current and future food safety fears. The temperature variations, extreme weather patterns, and ecosystem changes may change the patterns of contamination, microbial activity, and exposure sites of animal production systems. Consequently, the policies of meat safety in the future will need to consider the principle of climate resilience and environmental monitoring besides the traditional hygiene and inspection measures (Food and Agriculture Organization of the United Nations [FAO], 2025a, 2025b).

The development of meat safety in the future will be premised on the expansion of the capacity of risk analysis, surveillance, traceability, and other collaboration of the veterinary services, food control authorities, producers, and the public health institutions. WHO has still indicated that it has to pay attention to the problem of food safety throughout an entire food chain according to the One Health Joint Plan of Action that helps to promote more integrated control actions in the future. In this way, the future outlook in the area of meat safety should be enhanced laboratory capacity, hygienic monitoring, digital solutions, and more preventive control with the help of the science (WHO, 2024; WOAH, n.d.).

Overall, meat safety in the future lies in the shift of fragmented control measures to comprehensive and preventive systems that would address microbial hazards, chemical contamination, antimicrobial resistance, and environmental transformation. This course of action is needed to safeguard the well-being of the populace and boost consumer confidence and assist in establishing more secure and more sustainable production systems of animals (WHO, 2024; FAO, 2025b; WOAH, n.d.).

Conclusion

In conclusion, meat contamination and the food safety issue is one of the critical issues in the animal production systems as meat can be exposed to biological and chemical hazards at different stages of production, slaughtering, processing, storage and distribution. These risks may lower the quality of meat and put the health of consumers at risk, as well as lead to some broader health issues in the society, including foodborne diseases and antimicrobial resistance. Thus, to secure meat safety, farm-to-fork approach is to be adopted and it must be founded on hygienic, veterinary audit, hazard monitoring, handling and regulation. These must be enhanced to enhance the quality of meat produced, safeguard human health and develop safer and more sustainable animal production systems.

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