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# CORIANDER AS A NATURAL ANTIMICROBIAL FOR MEAT PRODUCTS: A ONE HEALTH PERSPECTIVE REVIEW

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***Abstract***
*The demand for safe, high-quality meat products drives the need for effective antimicrobial solutions to combat bacterial contamination, a significant health and economic concern. Synthetic preservatives face increasing scrutiny, leading to interest in natural alternatives such as coriander (Coriandrum sativum L.). Known for its culinary and medicinal uses, coriander essential oils, particularly linalool and pinene, exhibit strong antimicrobial properties against a wide range of pathogens. This review examines the phytochemical composition and antimicrobial mechanisms of coriander, and its practical applications in meat preservation through a One Health perspective, which addresses the interconnectedness of human, animal, and environmental health. Coriander offers unique benefits such as a milder flavor and cost-effectiveness. Despite challenges, including variability in antimicrobial efficacy and sensory impacts, its safety profile and regulatory status support its use. Future research should optimize extraction methods, explore synergies with other preservatives, and evaluate long-term safety and efficacy. Coriander is a viable natural solution for improving food safety and quality in the meat industry, aligning with One Health objectives by promoting sustainable practices and reducing health risks across the food production continuum.*

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## Introduction

The quest for safe and high-quality meat products has never been more crucial, especially in an era where the global food supply chain faces unprecedented challenges. Bacterial contamination in meat products is a persistent and alarming issue, with pathogens such as *Salmonella* species, *Escherichia coli*, and *Listeria monocytogenes* frequently implicated in severe foodborne illnesses [1]. These microorganisms can infiltrate meat at various points of the production process, from slaughter and processing to packaging and storage, driven by lapses in hygiene practices, mishandling, and inadequate refrigeration [2]. The consequences are profound with significant health risks to consumers and substantial economic losses to the meat industry [3].

In light of these challenges, the search for effective antimicrobial agents has taken on heightened urgency. Traditional synthetic preservatives, while effective, are increasingly scrutinized for their potential health risks and environmental impact [4]. This has spurred a growing interest in natural antimicrobial agents, which offer a safer and more sustainable alternative. Natural antimicrobials, derived from plants, herbs, and other biological sources, are valued for their ability to inhibit microbial growth without adverse effects on human health or the environment [5].

Among the array of natural antimicrobials, coriander (*Coriandrum sativum L.*) stands out as a particularly promising candidate. Known for its culinary versatility and medicinal properties, coriander has been used for centuries in various cultures [6]. Recent scientific investigations have begun to uncover its potent antimicrobial properties, revealing its potential as a natural preservative in meat products [7,8,9]. Coriander essential oils and bioactive compounds exhibit a broad spectrum of activity against a range of pathogenic bacteria, positioning it as a viable solution to enhance food safety and quality [10].

Furthermore, from a One Health perspective, the use of natural antimicrobials such as coriander not only addresses food safety but also promotes environmental sustainability [11]. By reducing the reliance on synthetic preservatives and embracing natural alternatives, we can minimize the ecological footprint of meat production, decreasing chemical residues and pollution. This holistic approach ensures that our efforts to safeguard public health are in harmony with the need to protect and preserve our environment for future generations.

This review delves into the multifaceted role of coriander, exploring its phytochemical composition, antimicrobial mechanisms, and practical applications in meat preservation. By examining the evidence and advancements in this field, we aim to highlight how coriander can contribute to mitigating bacterial contamination in meat products, thereby enhancing public health and consumer confidence. Additionally, we will explore how the use of coriander aligns with the One Health approach by addressing the interconnected impacts on human health, animal health, and environmental sustainability.

**Objects and methods**

The methodology for this review involved a systematic and interdisciplinary literature search. The process was designed to encompass various dimensions of antimicrobial efficacy, meat safety, and holistic health impacts, integrating insights from fields such as microbiology, food science, and public health.

The advanced search methodology used to conduct the study consisted of two stages. The initial stage of the literature search involved identifying and gathering relevant studies to address the objectives of the review. This was achieved through an extensive search using predefined keywords and phrases related to antimicrobial properties of coriander and meat contamination. The key terms included "plant-based preservation, essential oils, foodborne pathogens, food safety, and phytochemicals". The search was conducted in multiple databases to ensure a broad and inclusive collection of relevant literature such as PubMed, Scopus, Google Scholar, ScienceDirect, and Web of Science. These databases were selected for their comprehensive coverage of scientific articles, reviews, and book chapters related to microbiology, food safety, and public health. The second stage involved a meticulous selection process. It began with screening the titles and abstracts of the collected studies to identify those that were most pertinent to the focus of the review. Publications were evaluated based on their relevance to antimicrobial effects of coriander, its application in meat safety, and the integration of a One Health perspective.

Inclusion criteria were as follows:

1. Peer-reviewed articles and reviews published between 2005 and 2024.
2. Studies that investigated the antimicrobial properties of coriander or its extracts in meat products.
3. Research articles addressing the application of natural antimicrobials from a One Health perspective.
4. Papers with clear experimental data or case studies related to effectiveness of coriander in meat preservation.

Exclusion criteria were as follows:

1. Articles not related to coriander or natural antimicrobials in the context of meat preservation.
2. Publications that lack experimental data or are purely theoretical without practical application.

Data sources and geographic information:

The data sources included primary research studies, review articles, and meta-analyses. Geographic information was considered to include a diverse range of studies from different regions to ensure comprehensive coverage. The literature reviewed included research from North America, Europe, Asia, and Africa, reflecting global perspectives on the use of coriander as an antimicrobial agent in meat products.

Research subjects and analysis techniques:

The research subjects focused on various types of meat products including beef, poultry, and fish. Studies were analyzed for their methodologies in assessing the antimicrobial efficacy of coriander, such as the use of *in vitro* tests, sensory evaluations, and shelf-life studies. Data were synthesized to highlight common findings and discrepancies in effectiveness of coriander across different meat types and conditions.

Analysis techniques involved qualitative synthesis and comparative analysis of the studies reviewed. Key factors assessed included the concentration of coriander extracts used, methods of application (e. g., direct application, infusion, etc.), and effectiveness against specific microbial contaminants. Statistical analysis techniques reported in the studies were also evaluated to determine the robustness of the findings.

**Phytochemical composition of coriander**

Coriander is renowned not only for its culinary applications but also for its rich phytochemical profile, which underpins its potential as a natural antimicrobial agent [12]. The primary active compounds in coriander are essential oils and various phytochemicals, each contributing to its biological activities [13]. The essential oils of coriander, predominantly composed of linalool (approximately 60–70%) and pinene, are of significant interest due to their potent antimicrobial properties [14]. Linalool, a monoterpene alcohol, is known for its ability to disrupt microbial cell membranes, thereby exhibiting broad-spectrum antibacterial and antifungal activities [15]. Additionally, the essential oil contains other compounds such as camphor, borneol, and geranyl acetate, which collectively enhance its antimicrobial efficacy [16]. In terms of phytochemical composition, coriander seeds also contain various bioactive compounds including flavonoids, phenolic acids, and terpenoids [17]. These compounds contribute to the antioxidant, anti-inflammatory, and antimicrobial properties of coriander [18]. For instance, the presence of quercetin and kaempferol in coriander seeds has been associated with its ability to scavenge free radicals and inhibit the growth of pathogenic microorganisms [19].

The extraction of essential oils and phytochemicals from coriander is achieved through several methods, each affecting the yield and composition of the extract [20]. Steam distillation is the most common technique used to obtain coriander essential oil [21]. This method involves passing steam through coriander seeds, causing the essential oil to evaporate and subsequently condense into a liquid form [22]. Alternatively, solvent extraction and cold pressing are employed to obtain extracts and oils, respectively [23]. Solvent extraction uses organic solvents, such as ethanol or hexane, to dissolve the essential oils, which are then separated from the solvent [24]. Cold pressing involves mechanically pressing the seeds to extract the oil without the use of heat, preserving its sensitive compounds [25]. Overall, the diverse array of active compounds in coriander, coupled with the various extraction methods employed, underscores its potential as a valuable natural antimicrobial agent [26]. This phytochemical richness makes coriander a compelling prospect for further exploration and application in food safety and preservation.

**Antimicrobial properties of coriander**

Coriander exhibits significant antimicrobial properties, making it a valuable option for enhancing food safety. The essential oils and phytochemicals derived from coriander demonstrate various mechanisms of action against bacterial pathogens, contributing to their efficacy as natural antimicrobial agents [27]. One of the primary mechanisms through which coriander exerts its antimicrobial effects is the disruption of bacterial cell membranes [28]. Linalool, the main component of coriander essential oil, interacts with the lipid bilayer of bacterial membranes, causing increased permeability and leading to cell leakage and death [29]. This mechanism is effective against a broad spectrum of bacteria, including both Gram-positive and Gram-negative strains [30]. Additionally, other compounds in coriander essential oil, such as pinene and camphor, also contribute to membrane disruption and subsequent microbial inhibition [31].

Coriander has been extensively studied for its antimicrobial properties through various *in vitro* experiments, demonstrating its effectiveness against a wide range of bacterial pathogens. Essential oil and extracts of coriander have shown substantial antimicrobial activity, which has been verified through different methodologies. Talebi et al. [7] conducted a study to assess the antimicrobial activity of coriander essential oil using agar diffusion technique. Their results revealed significant bacterial growth inhibitory properties against both Gram-positive (*S. aureus)* and Gram-negative (*P. aeruginosa* and *E. coli*) bacteria at 100% concentration of essential oil. Teshale et al. [32] performed a comprehensive *in vitro* evaluation using the disc diffusion method, finding that coriander oil (15 μL/disc) demonstrated the antibacterial activity against *E. coli*, *P. aeruginosa*, and *Salmonella* typhi (*S.* typhi), with inhibition zone diameters of 25 mm, 10 mm, and 18 mm, respectively. At this concentration, coriander oil exhibited bactericidal effects against *S.* Typhi and bacteriostatic effects against *E. coli*. In addition, Zare-Shehneh et al. [33] utilized a MIC assay to show that coriander essential oil exhibited antimicrobial activity against Gram-negative bacteria, with minimum inhibitory concentrations (MIC) of 71.55 μg/mL for *K. pneumoniae* and 86.4 μg/mL for *P. aeruginosa*, as well as against Gram-positive bacteria, with a MIC of 35.2 μg/mL for *S. aureus*. This is consistent with findings by Nanasombat and Lohasupthawee [34], who demonstrated the inhibitory effect of coriander EO against 25 bacterial strains including 20 serotypes of *Salmonella* and five other enterobacteria species: *Citrobacter freundii*, *Enterobacter aerogenes*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Serratia marcescens*. The results showed a minimum inhibitory concentration (MIC) of 4.2 μL/mL for most bacterial strains. However, *Salmonella enterica* serotype Rissen was resistant to *Coriandrum sativum* essential oil, with a MIC greater than 62.5 μL/mL. In another investigation conducted by Elkady et al. [9], using 1%–2% coriander oil reduced the *E. coli* count in camel meat by 24% and 65%, respectively, without affecting the sensory characteristics. These *in vitro* studies collectively underscore the robust antimicrobial properties of coriander. They reveal its potential as an effective natural preservative capable of combating a diverse spectrum of bacterial pathogens, supporting its application in food safety and preservation.

**Application of coriander in meat products**

Coriander can be incorporated into meat products through various methods to harness its antimicrobial properties. One common approach is the direct addition of coriander essential oil or ground coriander seeds during the preparation and processing of meat products. Essential oil can be emulsified and evenly distributed in meat matrices, whereas ground seeds can be mixed into meat batters or coatings [35]. Another innovative method involves using coriander extracts as a marinade for meats, allowing the bioactive compounds to permeate meat and exert their antimicrobial effects [36]. Additionally, coriander can be integrated into packaging materials or edible films that encase meat products, providing a sustained release of antimicrobial agents during storage [37].

Vacuum packaging or modified atmosphere packaging (MAP) combined with coriander essential oil or extracts can significantly extend the shelf life of meat by inhibiting the growth of spoilage microorganisms and pathogens [38]. Edible coatings enriched with coriander compounds can be applied to the surface of meat products, creating a barrier that slows down microbial growth and oxidation processes [39]. Moreover, coriander extracts can be used in combination with other natural preservatives such as lactic acid bacteria or plant-derived antimicrobials to create synergistic effects, enhancing the overall preservation efficacy [40].

The effectiveness of coriander as a natural antimicrobial agent in real-world applications has been demonstrated in several studies. For instance, research has shown that coriander essential oil exhibits potent antibacterial activity against some Gram-positive and Gram-negative bacteria (*Salmonella* Typhimurium, *Listeria monocytogenes*, *Staphylococcus aureus*, *Serratia grimesii*, *Enterobacter agglomerans*, *Yersinia enterocolitica*, and *Bacillus cereus*) [41]. Also, the antimicrobial activity of coriander against potential spoilage bacteria, including *K. pneumoniae*, *Bacillus megaterium*, *P. aeruginosa*, *S. aureus*, *E. coli*, *Enterobacter cloacae,* and *Enterococcus faecalis*, has been documented [42]. In practical applications, meat products treated with coriander extracts or essential oils have exhibited reduced microbial counts and extended shelf life compared to untreated controls [9,43,44]. Consumer acceptability studies also indicate that coriander-treated meat products maintain desirable sensory qualities, with no significant adverse effects on taste or texture [9,45,46]. These findings underscore the potential of coriander as an effective and natural solution for enhancing the microbial safety and quality of meat products. By integrating coriander into meat products through these methods and preservation techniques, the meat industry can leverage its natural antimicrobial properties to mitigate bacterial contamination, improve food safety, and potentially reduce the reliance on synthetic preservatives.

**Comparative analysis with other natural antimicrobials**

Compared to other natural preservatives such as garlic, thyme, rosemary, and oregano, coriander offers unique benefits and similar effectiveness [47]. Coriander essential oil demonstrates broad-spectrum antimicrobial activity against foodborne pathogens including *Salmonella* species, *Listeria monocytogenes*, and *Escherichia coli*, comparable to garlic and thyme [48]. Its milder aroma and flavor make it preferable for preserving the sensory qualities of meat products [49]. Active compounds of coriander, such as linalool and geraniol, are effective at low concentrations, making it a cost-effective option [13]. Combining coriander with other antimicrobials, for example oregano or thyme essential oils, enhances its effectiveness due to synergistic interactions [50]. Additionally, pairing coriander with organic acids such as citric or lactic acid improves antimicrobial efficacy and meat quality during extended storage [51]. This strategic use of coriander and other natural preservatives offers a promising approach to enhancing microbial safety and extending shelf life while maintaining desirable sensory attributes.

**Impact on sensory and nutritional qualities of meat**

Incorporating coriander into meat products can significantly influence their sensory attributes, including taste, aroma, and texture. Coriander essential oil and ground seeds impart a distinct flavor profile characterized by citrusy, nutty, and slightly spicy notes. This can enhance the overall palatability of meat, making it more appealing to consumers [52]. Studies have shown that moderate levels of coriander addition are generally well-received, as the mild and pleasant aroma does not overpower the natural taste of meat [53,54]. Moreover, volatile compounds of coriander can help mask any undesirable odors that might develop during storage [55]. However, excessive use of coriander might lead to an overpowering flavor that could be undesirable for some consumers. In terms of texture, coriander does not significantly alter meat physical properties, ensuring that a product remains tender and juicy [56]. In addition, the use of coriander in marinades and coatings can also contribute to a more appealing and consistent texture by promoting even moisture distribution [51]. Furthermore, adding coriander to meat products can enhance their nutritional profile. Coriander seeds and leaves are rich in essential nutrients, including vitamins A, C, and K, as well as minerals such as potassium, calcium, and magnesium [57] These nutrients can fortify meat, contributing to a healthier final product. Additionally, coriander contains dietary fiber and antioxidants, which can offer health benefits such as improved digestion and reduced oxidative stress [58]. The antimicrobial compounds in coriander, primarily linalool and geraniol, not only help in preservation but also have potential health benefits, including anti-inflammatory and anti-carcinogenic properties [59]. Therefore, the inclusion of coriander can boost the functional value of meat products, aligning with the growing consumer demand for healthier food options. By incorporating coriander, meat producers can create products that are not only safer and longer-lasting but also offer enhanced sensory and nutritional qualities. This makes coriander a multifaceted ingredient that can meet both preservation and consumer satisfaction goals in the meat industry.

**Safety and regulatory aspects**

Toxicological studies and safety evaluations of coriander are essential to ensure its safe use as an antimicrobial agent in meat products. Various studies have demonstrated that coriander and its essential oils are generally safe for human consumption at the concentrations typically used in food preservation [55]. Acute and chronic toxicity studies on animals have shown that coriander essential oil has a high safety margin, with no significant adverse effects observed at doses considerably higher than those used in food applications [41]. Additionally, the main bioactive compounds of coriander, such as linalool and geraniol, have been evaluated for genotoxicity and carcinogenicity, with results indicating no mutagenic or carcinogenic potential [60,61]. These findings support the conclusion that coriander is a safe natural additive for enhancing the microbial safety of meat products.

The regulatory status of coriander as a food additive varies across different regions but is generally favorable due to its long history of safe use in culinary applications [62]. In the United States, coriander and its essential oil are classified as Generally Recognized As Safe (GRAS) by the Food and Drug Administration (FDA), meaning they can be safely used in foods within certain limits without requiring pre-market approval [63]. Similarly, the European Food Safety Authority (EFSA) has evaluated coriander and deemed it safe for use as a flavoring agent in various food products [64]. Despite these approvals, it is important for food manufacturers to adhere to regulatory requirements and guidelines when incorporating coriander into meat products. This includes complying with labeling regulations, ensuring that the levels of coriander used do not exceed permissible limits, and conducting regular safety assessments to monitor any potential adverse effects. By following these regulatory frameworks, the meat industry can confidently utilize coriander as a natural antimicrobial agent, enhancing food safety while maintaining compliance with food safety standards.

### Integrating One Health principles in the use of coriander for controlling bacterial contamination in meat products

The One Health framework advocates for a comprehensive approach to managing health risks by considering the interdependencies between human, animal, and environmental health [65]. Coriander as a natural antimicrobial in meat products can significantly enhance food safety, directly impacting public health. Meat products contaminated with pathogenic bacteria pose a serious risk to human health, often leading to foodborne illnesses that can strain healthcare systems [66]. By utilizing antimicrobial properties of coriander, we can reduce the prevalence of bacterial contamination in meat, thereby lowering the incidence of foodborne diseases. This approach not only protects consumers but also aligns with One Health objective of mitigating risks at the human-animal-environment interface. Antimicrobial resistance (AMR) is a critical concern in both human and animal health, driven by the overuse and misuse of antibiotics in livestock production [67]. One Health emphasizes the importance of addressing AMR through integrated strategies. The use of coriander as a natural antimicrobial in meat products presents a sustainable alternative to conventional antibiotics, thereby reducing the selective pressure that drives AMR [68]. By incorporating coriander into meat processing, we can help decrease the reliance on synthetic antimicrobials, ultimately contributing to the preservation of antibiotic efficacy. This aligns with One Health goal of combating AMR by fostering practices that minimize the spread of resistant bacteria across the human-animal-environment continuum.

The One Health approach also highlights the importance of sustainable practices in maintaining ecosystem health [69]. Coriander, as a natural antimicrobial, supports sustainability in meat production by reducing the environmental burden associated with synthetic chemicals and antibiotics. The cultivation of coriander itself is associated with minimal environmental impact compared to synthetic alternatives [70]. Furthermore, integrating coriander into meat processing aligns with the principles of sustainable agriculture, which aim to enhance biodiversity, reduce chemical runoff, and promote soil health [71]. By utilizing coriander, which can be grown with relatively low inputs and minimal impact on the surrounding ecosystem, we contribute to more sustainable and environmentally friendly food production systems. This practice not only supports the One Health objective of protecting environmental health but also ensures that food production methods remain resilient and adaptable to future challenges.

One Health emphasizes the need for collaborative efforts across different sectors to address complex health issues effectively [72]. The incorporation of coriander as a natural antimicrobial in meat processing exemplifies how interdisciplinary approaches can lead to significant improvements in food safety. Collaboration between agricultural scientists, food technologists, public health experts, and environmentalists is crucial for maximizing the benefits of coriander in controlling bacterial contamination. Such interdisciplinary cooperation can facilitate the development of best practices for coriander application, ensuring that its antimicrobial properties are utilized effectively while also considering its impact on the environment and overall food safety. By fostering cross-sector partnerships, we can advance One Health goals, create more robust food safety systems, and promote a holistic approach to managing health risks at the human-animal-environment interface.

Integrating coriander into meat processing also provides an opportunity to enhance public health education and policy within the One Health framework. Educating consumers, producers, and policymakers about the benefits of natural antimicrobials like coriander can drive more informed decisions regarding food safety practices and regulatory policies. Promoting the use of coriander as a viable alternative to synthetic antimicrobials can support policy initiatives aimed at reducing antibiotic use in agriculture and improving overall food safety standards. Additionally, raising awareness about the One Health implications of natural antimicrobial use can help align public health strategies with sustainable and environmentally conscious practices, further advancing the objectives of the One Health approach.

### Challenges and limitations

While coriander shows promise as a natural antimicrobial agent for meat products, several potential drawbacks and limitations must be considered. One of the primary limitations is the variability in the antimicrobial efficacy of coriander essential oil and extracts, which can be influenced by factors such as the geographical origin of the coriander, the method of extraction, and storage conditions [52]. This variability can lead to inconsistent results in microbial inhibition. Additionally, while coriander has a relatively mild flavor, its strong, distinct aroma might not be universally accepted by all consumers, potentially affecting the sensory qualities of meat products [55]. Furthermore, the effectiveness of coriander as an antimicrobial agent is often concentration-dependent, and higher concentrations required for significant microbial inhibition may not be feasible due to cost constraints and potential sensory impacts [73]. Implementing coriander as a natural antimicrobial agent in large-scale meat processing faces several challenges. Standardizing coriander extracts or essential oils for consistent antimicrobial activity requires rigorous quality control, which can be resource-intensive. Integrating coriander into existing workflows may necessitate modifications to equipment and processes, increasing operational costs [74]. Ensuring the stability and efficacy of antimicrobial compounds of coriander throughout the meat product shelf life is another concern, as factors such as temperature, humidity, and light can degrade the bioactive compounds [75]. Additionally, while generally safe, coriander can cause allergic reactions or sensitivities in some individuals, necessitating clear labeling and consumer education [76]. Overall, while coriander has significant potential as a natural antimicrobial agent for meat products, these challenges must be carefully managed for effective and safe large-scale application.

**Future prospects and research directions**

The use of natural antimicrobials in food preservation is a rapidly growing field, driven by increasing consumer demand for clean-label products and the need to reduce reliance on synthetic preservatives. Emerging trends in this area include the exploration of plant-based extracts, essential oils, and bioactive compounds with antimicrobial properties. Researchers are focusing on identifying new sources of natural antimicrobials and understanding their mechanisms of action. Additionally, there is a trend towards developing multifunctional natural preservatives that not only inhibit microbial growth but also enhance the sensory and nutritional qualities of food products. Technological advancements, such as nanoencapsulation and microencapsulation, are being applied to natural antimicrobials to improve their stability, controlled release, and efficacy. These technologies protect the bioactive compounds from degradation and ensure their sustained antimicrobial activity over the product shelf life.

Furthermore, the combination of natural antimicrobials with other preservation methods, such as high-pressure processing and pulsed electric fields, is being explored to enhance food safety and extend shelf life. Several areas warrant further research and development to optimize the use of coriander as a natural antimicrobial in meat products. One key area is the standardization of coriander extracts and essential oils. This involves developing methods to ensure consistent quality and antimicrobial efficacy across different batches. Research should focus on identifying the optimal extraction techniques and conditions that maximize the yield and activity of the bioactive compounds in coriander.

Another critical area is the investigation of the synergistic effects of coriander with other natural antimicrobials and preservation methods. Understanding how coriander interacts with other compounds can help in formulating more effective antimicrobial systems. Studies should explore the optimal combinations and concentrations that provide the best antimicrobial activity without compromising the sensory qualities of meat. Further research is also needed to evaluate the long-term safety and efficacy of coriander in various meat products under different storage conditions. This includes studying the stability of antimicrobial compounds of coriander and their interactions with meat components over time. Additionally, research should address the potential allergenicity and consumer acceptance of coriander-treated meat products.

Lastly, advancements in biotechnology and genetic engineering offer opportunities to enhance the antimicrobial properties of coriander. Genetic modifications could be explored to increase the production of bioactive compounds in coriander plants, potentially leading to more potent antimicrobial agents.

**Conclusion**

Coriander (*Coriandrum sativum L.*) is a promising natural antimicrobial for meat preservation due to its rich phytochemical composition, particularly linalool, flavonoids, and phenolic acids. These compounds effectively combat Gram-positive and Gram-negative bacteria, enhancing food safety and extending shelf life without compromising sensory qualities. Its use supports the One Health approach by promoting human health, sustainable agriculture, and environmental protection. However, challenges like antimicrobial variability, extract standardization, and consumer acceptance need addressing. Future research should focus on optimizing extraction, exploring synergies with other preservatives, and enhancing efficacy through technologies like nanoencapsulation.

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