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Research Article

ORGANIC-BASED PRESERVATION APPROACHES FOR MICROBIAL CONTROL AND QUALITY RETENTION IN MEAT

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ABSTRACT

Organic-based preservatives are gaining increasing attention as safe, eco-friendly alternatives to synthetic additives for maintaining the microbial safety and sensory quality of meat products. This paper reviews the mechanisms, effectiveness, and application potential of plant-derived extracts, essential oils, organic acids, and bioactive compounds used in meat preservation. Emphasis is placed on their antimicrobial modes of action, impacts on physicochemical and sensory characteristics, and compatibility with emerging non-thermal technologies. Challenges related to variability, stability, standardization, and consumer acceptance are also highlighted. The review concludes that integrating organic preservatives with advanced processing systems can enhance meat quality, reduce spoilage, and support clean-label consumer preferences.

Keywords: Metal nanoparticles, Metal oxide nanoparticles, Physicochemical properties, Structural analysis, Consumer.

INTRODUCTION

Meat is a highly perishable food product due to its rich nutrient composition, high water activity, and susceptibility to microbial contamination. Traditional preservatives such as nitrites, sulfites, and benzoates are effective, but increasing concerns about carcinogenicity, chemical residues, and health effects have accelerated the transition toward organic and natural preservation alternatives. Organic-based preservatives including essential oils, phenolic compounds, bacteriocins, organic acids, and plant extracts offer antimicrobial and antioxidant benefits that can slow spoilage, inhibit pathogens, and retain sensory quality. As consumer demand shifts toward "clean-label" products, understanding the science and practical implications of organic preservatives becomes critical. This paper explores the role, mechanism, and application potential of organic preservation strategies for microbial control and quality maintenance in meat systems. Studied organic preservatives due to their strong antimicrobial and antioxidant properties. Campolina *et al*. (2023) reported that EOs derived from oregano, rosemary, thyme, and clove significantly inhibit spoilage organisms in meat through mechanisms involving membrane disruption and oxidative stress induction. Similarly, Yu *et al*. (2021) emphasized that EOs effectively delay lipid oxidation and microbial growth in both fresh and processed meat products. Noshirvani *et al*. (2024) further highlighted that the incorporation of EOs into meat matrices enhances shelf life without compromising sensory properties, making them ideal alternatives to synthetic preservatives. Studies using Mexican oregano essential oil demonstrated superior antioxidant activity, outperforming several commercial additives (Cantú-Valdéz *et al*., 2020).

Polyphenol-rich plant extracts are gaining attention for their broad-spectrum antimicrobial activity. Efenberger-Szmechtyk *et al*. (2021) noted that phenolic compounds such as flavonoids and tannins demonstrate strong antibacterial activity against meat-borne pathogens like

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Listeria monocytogenes, *E. coli*, and *Salmonella*. Campolina *et al*. (2023) additionally showed that combinations of essential oils and plant extracts produce synergistic effects, enhancing microbial inhibition while stabilizing color and texture. Abandansarie *et al*. (2019) found that rosemary extract, especially in encapsulated form, contributes to controlling lipid oxidation and microbial spoilage in meat products. Edible biopolymer coatings containing natural antimicrobials represent a promising clean-label preservation strategy. Yaghoubi *et al*. (2021) demonstrated that chitosan coatings enriched with *Artemisia* essential oil significantly extended chicken breast shelf life by reducing psychrotrophic bacteria and delaying oxidative changes. These coatings act as physical barriers while gradually releasing bioactive compounds. According to Noshirvani *et al*. (2024), biopolymer coatings also improve moisture retention and reduce discoloration, making them suitable for refrigerated meat applications. Nanoencapsulation improves the stability, solubility, and controlled release of organic preservatives. Cantú-Valdéz *et al*. (2019) reported that nanoencapsulated thyme and oregano essential oils exhibit greater antimicrobial efficacy compared to their free forms, due to improved dispersion and sustained release in meat systems. Hamouda *et al*. (2024) also demonstrated that microencapsulated oregano oil maintains antimicrobial activity throughout storage while limiting flavor overpowering, making the technology highly suitable for commercial meat preservation. Organic acids such as lactic, acetic, and citric acids are widely used in the meat industry for surface decontamination. Nkosi *et al*. (2021) concluded that lactic and acetic acid washes effectively reduce pathogenic bacteria by lowering pH and destabilizing cell membranes.

Classic work by Theron and Lues (2007) further established that organic acids are highly effective against Gram-negative bacteria and can be used in combination for enhanced antimicrobial action. More recent analysis by Sorathiya *et al*. (2025) highlighted the synergistic role of organic acids when paired with plant-derived antimicrobials, resulting in improved microbial control and quality retention. Nitrites are widely used in cured meats but raise health concerns related to nitrosamine formation. Shakil *et al*. (2022) reviewed the potential of natural plant-based nitrite substitutes, including celery powder, beetroot extracts, and antioxidant-rich botanicals. These natural alternatives maintain color, oxidative stability, and antimicrobial activity comparable to chemical nitrites, offering a safer approach for cured meat preservation.

MATERIALS AND METHODS

Microbial Effects

Organic-based preservatives show diverse antimicrobial spectra, but their effectiveness varies with compound type, concentration, and meat matrix interactions. Essential Oils (EOs) demonstrate broad-spectrum activity against *Salmonella spp.*, *Listeria monocytogenes*, and *E. coli*. Studies indicate that oregano, thyme, and rosemary oils achieve a 2-4 log reduction in pathogens during refrigerated storage, outperforming many plant extracts. However, their efficacy can be reduced by fat content, which sequesters hydrophobic compounds.

Plant extracts

polyphenols exhibit moderate antimicrobial effects, generally less potent than EOs, but more stable during storage. Flavonoids and tannins primarily suppress growth rather than cause rapid killing, making them suitable for extended shelf-life applications. Organic acids such as lactic and acetic acids remain the most industry-effective microbial decontaminants, achieving immediate 1–2 log reductions on carcass surfaces. Their limitation lies in pH dependence and reduced efficacy against acid-tolerant bacteria. Chitosan coatings exhibit bacteriostatic rather than bactericidal action, slowing spoilage microbial growth by modifying surface microflora. Nano encapsulated phytochemicals show enhanced antimicrobial activity due to improved dispersion and sustained release, often amplifying microbial inhibition by 30–50% compared to free compounds. Clearly, EOs and organic acids provide the strongest direct microbial reductions, while polyphenol extracts and chitosan support long-term suppression rather than rapid kill.

Mechanisms of Action

Each class of organic preservative works through distinct biochemical pathways: Essential oils disrupt bacterial cell membranes, increase permeability, cause leakage of ions/ATP, and interfere with quorum sensing mechanisms. Polyphenol-rich extracts generate oxidative stress, chelate essential metal ions, inhibit bacterial enzymes, and impair energy metabolism. Organic acids penetrate bacterial cells in undissociated form, dissociate in the cytoplasm, reduce internal pH, and collapse proton gradients. Chitosan interacts with negatively charged microbial cell walls, forms a polymeric barrier, and disrupts nutrient uptake. Nanoencapsulation systems enhance mechanisms by amplifying surface contact, preventing premature volatilization, and delivering bioactives more effectively to bacterial membranes Mechanistically, EOs and organic acids act rapidly through membrane disruption and pH stress, while polyphenols and chitosan work through metabolic interference, offering slower but sustained inhibition.

Effects on Meat Quality

Organic preservatives influence color stability, lipid oxidation, texture, and sensory attributes differently. EOs significantly reduce lipid oxidation but may cause flavor alterations at high concentrations. Their impact on color is generally positive due to antioxidant actions. Plant extracts (rosemary, green tea, grape seed) consistently improve oxidative stability and act as natural color stabilizers by inhibiting metmyoglobin formation. Chitosan coatings

enhance moisture retention, reduce drip loss, and preserve tenderness but may alter surface appearance (glossy texture). Organic acids can cause surface whitening, sour flavor notes, and slight texture hardening, which may affect consumer acceptance. Nanoencapsulated preservatives minimize flavor alteration and improve oxidative stability without sensory drawbacks. Overall, polyphenol extracts and nanoencapsulated EOs provide the best balance between microbial control and sensory quality, while organic acids require careful optimization.

Synergistic Combinations

Combining organic preservation strategies often yields superior results compared to individual use: EO + chitosan coating enhances microbial reduction and improved moisture retention due to controlled EO release. EO + organic acid combinations produce additive effects, where acids weaken bacterial membranes and facilitate EO penetration. Polyphenols + EOs provide strong antioxidative and antimicrobial synergy, preventing both microbial spoilage and lipid oxidation. Nanoencapsulation + plant extracts enhance stability and minimizes dose requirements, mitigating sensory impacts

RESULTS AND DISCUSSION

Organic preservatives demonstrate strong antimicrobial effects against spoilage bacteria (Pseudomonas spp., LAB, Enterobacteriaceae) and pathogens (Salmonella, Listeria). Essential oils show 2-4 log reductions, while organic acids achieve 1-3 log bacterial reduction depending on concentration and exposure time. Combining preservatives (Figure 1) e.g., rosemary extract + lactic acid) produces synergistic effects, improving both shelf life and product safety . Impact on Quality Retention Organic preservatives play a crucial role in maintaining meat quality by: reducing lipid oxidation, maintaining desirable color (e.g., cherry-red in beef), preserving texture and juiciness, delaying off-odors and rancidity. Nanoemulsion-based essential oils and edible coatings help overcome strong aromas and enhance stability. Natural preservatives align with clean-label trends; however, challenges include cost, variability in extract composition, aroma intensity, and regulatory restrictions. The integration of organic preservatives with HPP, cold plasma, and modified atmosphere packaging enhances microbial control and sensory retention.

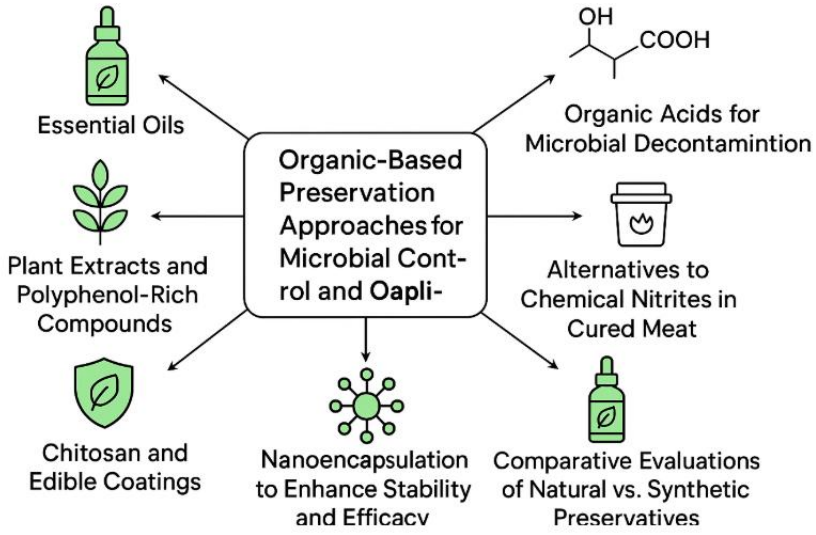

Figure 1. Organic based preservation approaches.

CONCLUSION

Organic-based preservatives demonstrate strong potential as natural antimicrobial and antioxidant agents capable of extending shelf life, improving safety, and maintaining the sensory characteristics of meat products. Their integration into industrial processing supports clean-label trends and reduces dependence on synthetic additives. With ongoing advances in extraction technologies, nano-delivery systems, and synergy with non-thermal preservation techniques, organic preservatives are positioned to become a key component of sustainable meat preservation strategies.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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