

## INNOVATIVE APPROACHES TO ENHANCING MEAT PRODUCT INTEGRITY WITH NATURAL ANTIOXIDANTS AND ENCAPSULATION

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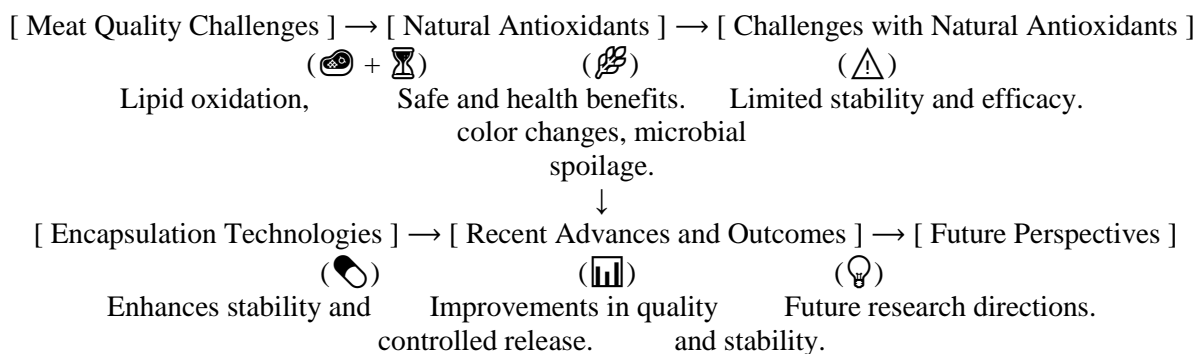
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*The quality and stability of meat products are crucial for consumer acceptance and safety. Lipid oxidation, color changes, and microbial spoilage are primary factors affecting meat quality, leading to a reduction in shelf life and nutritional value. Natural antioxidants have emerged as promising alternatives to synthetic antioxidants due to their safety and health benefits. However, their application is limited by their stability and efficacy under various processing and storage conditions. Encapsulation techniques have been developed to enhance the stability and controlled release of natural antioxidants in meat products. This review provides an overview of the latest advancements in the use of natural antioxidants and encapsulation technologies to improve meat product quality and stability. Recent studies, their outcomes, and future perspectives are discussed.*

**Keywords: Meat Quality, Shelf life, Natural Antioxidants, Encapsulation.**



### Graphical Presentation

#### ТАБИҒИ АНТИОКСИДАНТТАР МЕН ИНКАПСУЛЯЦИЯ АРҚЫЛЫ ЕТ ӨНІМДЕРІНІҢ ТҰРАҚТЫЛЫҒЫН АРТТЫРУ ӘДІСТЕРІ

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*Ет өнімдерінің сапасы мен тұрақтылығы тұтынушының өнімді таңдауы және өнімнің қауіпсіздігі үшін өте маңызды. Липидтердің тотығуы, өнім түсінің өзгеруі және микробтық бұзылуы ет сапасына әсер ететін негізгі факторлар болып табылады, бұлардың нәтижесінде өнімнің сақтау мерзімі қысқарады және тағамдық құндылығы төмендейді. Табиғи антиоксиданттар олардың қауіпсіздігі мен денсаулыққа пайдасы арқасында синтетикалық антиоксиданттарға перспективалы балама ретінде қарастырылып жатыр. Дегенмен, олардың пайдаланылуы әртүрлі өңдеу және сақтау жағдайларында тұрақтылығы мен тиімділігімен шектеледі. Ет өнімдерінде табиғи антиоксиданттардың тұрақтылығы мен бақыланып шығарылуын жақсарту үшін әртүрлі инкапсуляция әдістері бар. Бұл шолу ет өнімдерінің сапасы мен тұрақтылығын жақсарту үшін табиғи антиоксиданттарды және инкапсуляция технологияларын*

қолданудағы соңғы жетістіктерге шолу жасайды. Соңғы зерттеулер, оның нәтижелері және болашақ перспективалары талқыланды.

Негізгі сөзер: Ет сапасы, сақтау мерзімі, табиғи антиоксиданттар, инкапсуляция

## ИННОВАЦИОННЫЕ ПОДХОДЫ К ПОВЫШЕНИЮ ЦЕЛОСТНОСТИ МЯСНЫХ ПРОДУКТОВ С ПОМОЩЬЮ НАТУРАЛЬНЫХ АНТИОКСИДАНТОВ И ИНКАПСУЛЯЦИИ

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*Качество и стабильность мясных продуктов имеют решающее значение при выборе потребителем продукта и безопасности самого продукта. Окисление липидов, изменение цвета и микробная порча являются основными факторами, влияющими на качество мяса, что приводит к сокращению срока хранения и снижению пищевой ценности. Природные антиоксиданты стали перспективной альтернативой синтетическим антиоксидантам благодаря своей безопасности и пользе для здоровья. Однако их применение ограничено их стабильностью и эффективностью при различных условиях обработки и хранения. Для повышения стабильности и контролируемого высвобождения в мясных продуктах натуральных антиоксидантов были разработаны методы различные инкапсуляции. В данном обзоре представлен обзор последних достижений в области использования натуральных антиоксидантов и технологий инкапсулирования для улучшения качества и стабильности мясных продуктов. Обсуждаются последние исследования, их результаты и перспективы на будущее.*

**Ключевые слова:** Качество мяса, срок хранения, природные антиоксиданты, инкапсуляция

### **Introduction**

Meat products are an essential part of the human diet, providing high-quality proteins, essential vitamins, and minerals. However, the quality and stability of meat products are susceptible to deterioration due to lipid oxidation, microbial growth, and other biochemical processes. These changes can result in off-flavors, discoloration, and a reduction in nutritional value, ultimately leading to a shorter shelf life and lower consumer acceptance [1, 2]. To mitigate these issues, antioxidants are commonly used in meat processing. Traditionally, synthetic antioxidants like butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) have been employed due to their effectiveness. However, concerns about their potential health risks have driven the food industry to explore natural antioxidants as safer alternatives [3]. Natural antioxidants, such as phenolic compounds, vitamins, and essential oils, not only inhibit lipid oxidation but also offer additional health benefits, including anti-inflammatory and anti-carcinogenic properties [4, 5]. Despite these advantages, natural antioxidants often exhibit lower stability and efficacy under varying processing and storage conditions. To address these

challenges, encapsulation technologies have been developed. Encapsulation can protect antioxidants from environmental factors, enhance their stability, and allow for controlled release during meat processing and storage [6, 7]. This review explores the latest advancements in the application of natural antioxidants and encapsulation techniques in meat products, focusing on their impact on quality and stability.

### **2. Natural Antioxidants in Meat Products**

#### **2.1 Types of Natural Antioxidants**

Natural antioxidants are derived from various sources, including plants, fruits, herbs, and spices. The most common types of natural antioxidants used in meat products include phenolic compounds, vitamins (e.g., vitamin E and C), carotenoids, and essential oils [8,9]. Phenolic compounds, such as flavonoids and phenolic acids, are known for their strong antioxidant activity, which is primarily due to their ability to donate hydrogen atoms or electrons to free radicals, thus neutralizing them [10, 11]. Essential oils, extracted from plants like rosemary, oregano, and thyme, have been widely studied for their antioxidant and antimicrobial properties. These oils are rich in bioactive compounds like carvacrol, thymol, and ros-

marinic acid, which contribute to their effectiveness in preserving meat quality [12, 13].

### **2.2 Mechanisms of Action**

The primary mechanism by which natural antioxidants preserve meat quality is through the inhibition of lipid oxidation. Lipid oxidation is a chain reaction that begins with the formation of free radicals, leading to the degradation of unsaturated fatty acids and the production of off-flavors and rancid odors [14, 15]. Natural antioxidants interrupt this chain reaction by donating hydrogen atoms to free radicals, stabilizing them, and preventing further oxidation [16, 17]. In addition to their antioxidant activity, some natural compounds possess antimicrobial properties, which can inhibit the growth of spoilage microorganisms and pathogens in meat products. This dual functionality enhances the overall stability and safety of meat products [18, 19].

### **2.3 Recent Studies and Findings**

Recent studies have demonstrated the effectiveness of natural antioxidants in improving the shelf life and quality of meat products [23]. For example, researchers reported that the incorporation of pomegranate peel extract in minced beef patties significantly reduced lipid oxidation and microbial growth during storage [20, 21]. Similarly, the use of rosemary and oregano essential oils in sausage formulations has been shown to improve color stability and sensory properties [24, 25]. However, the efficacy of natural antioxidants can be influenced by several factors, including the concentration used, the type of meat product, and the processing and storage conditions [26]. Therefore, optimizing the application of natural antioxidants is essential to maximize their benefits.

### **2.4 Advantages and Limitations**

The primary advantage of natural antioxidants is their safety and potential health benefits. Unlike synthetic antioxidants, which have been linked to adverse health effects, natural antioxidants are generally recognized as safe (GRAS) and may offer additional nutritional benefits [27-29]. Moreover, the use of natural antioxidants aligns with consumer preferences for clean-label products, which are free from artificial additives [30, 31]. However, the application of natural antioxidants is not without challenges. Many natural compounds are sensitive to heat, light, and oxygen, leading to degradation during processing and

storage. Additionally, the strong flavors and aromas of some natural antioxidants can negatively impact the sensory attributes of meat products, necessitating careful formulation [32, 33].

## **3. Encapsulation Techniques for Antioxidants**

### **3.1 Overview of Encapsulation Methods**

Encapsulation involves the incorporation of active ingredients, such as antioxidants, within a carrier material to protect them from environmental factors and control their release [31]. Various encapsulation techniques have been developed, including spray drying, freeze-drying, coacervation, and liposome formation [34-36]. These methods differ in their principles, encapsulation efficiency, and applicability to different types of antioxidants and meat products.

Spray drying is one of the most commonly used methods for encapsulating natural antioxidants due to its scalability and cost-effectiveness. In this process, an antioxidant solution is sprayed into a hot chamber, where the solvent evaporates, leaving behind microcapsules containing the antioxidant [37, 38]. Liposomes, which are spherical vesicles composed of phospholipid bilayers, have also gained popularity for encapsulating hydrophilic and lipophilic antioxidants. Liposomes can protect antioxidants from oxidation and allow for controlled release during meat processing [39, 40].

### **3.2 Impact of Encapsulation on Antioxidant Stability and Release**

Encapsulation enhances the stability of natural antioxidants by shielding them from environmental factors such as light, heat, and oxygen, which can cause degradation. For example, encapsulating vitamin E in liposomes has been shown to improve its stability and extend its shelf life in meat products [41, 42]. Additionally, encapsulation allows for the controlled release of antioxidants during meat processing and storage, ensuring that the antioxidant activity is sustained over time [43, 44]. The effectiveness of encapsulation depends on the encapsulation method, the properties of the carrier material, and the type of antioxidant. Recent studies have demonstrated that encapsulating essential oils in chitosan nanoparticles enhances their antioxidant and antimicrobial activity in meat products, leading to improved shelf life and quality [45].

Table 1. Common Natural Antioxidants Used in Meat Products

Antioxidant	Source	Mechanism of Action	Meat Application	References
Phenolic Compounds	Plants (e.g., rosemary, green tea)	Scavenge free radicals, chelate metal ions	Sausages, ground beef	Shah et al. (2021); Alirezalu et al. (2021)
Essential Oils	Herbs (e.g., thyme, oregano)	Antimicrobial activity, inhibit lipid oxidation	Poultry, beef	Rao et al. (2022); Saeed et al. (2022)
Tocopherols (Vitamin E)	Vegetables oils, nuts	Inhibit lipid peroxidation	Processed meats	Bolumar et al. (2021)
Ascorbic Acid (Vitamin C)	Fruits, vegetables	Reduce nitrite in cured meats, regenerate tocopherols	Cured meats, sausages	Jiang et al. (2021); Zhao et al. (2020)
Carotenoids	Carrots, tomatoes	Scavenge singlet oxygen, quench free radicals	Raw and cooked meats	Gómez et al. (2021)

Table 2. Comparative Efficacy of Encapsulated vs. Non-Encapsulated Antioxidants in Meat Products

Antioxidant	Form	Lipid Oxidation Inhibition	Color Stability	Sensory Quality	References
Green Tea Extract	Non-encapsulated	Moderate	Low	Slightly bitter flavor	Zhao et al. (2020)
Green Tea Extract	Encapsulated (e.g., liposomes)	High	High	Improved flavor profile	Wang et al. (2022)
Rosemary Extract	Non-encapsulated	Moderate	Moderate	Acceptable aroma	Gómez et al. (2021)
Rosemary Extract	Encapsulated (e.g., nanoemulsion)	High	High	Enhanced sensory attributes	Chen et al. (2023)

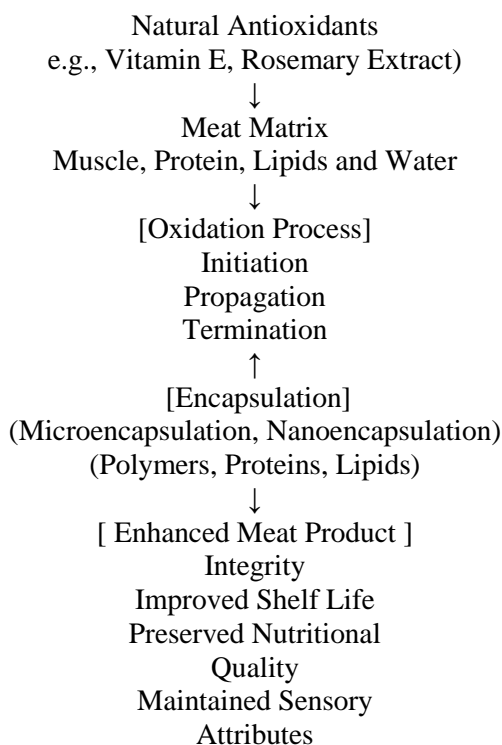


Diagram: Enhancing Meat Product Integrity with Natural Antioxidants and Encapsulation

### 3.3 Recent Advances in Encapsulation Technology

Recent advancements in nanotechnology have led to the development of novel encapsulation techniques that offer higher encapsulation efficiency and better control over the release of antioxidants. Nanocapsules, nanoemulsions, and solid lipid nanoparticles are among the innovative carriers being explored for encapsulating natural antioxidants [41, 42]. These nanoscale carriers provide a larger surface area, allowing for better interaction with meat components and improved antioxidant efficacy. For instance, the encapsulation of curcumin in solid lipid nanoparticles has been shown to enhance its antioxidant activity and protect against lipid oxidation in meat products [13, 14]. Similarly, nanoemulsions containing essential oils have demonstrated improved stability and controlled release, making them suitable for application in meat processing [18, 19].

### 3.4 Case Studies: Encapsulation of Specific Antioxidants in Meat Products

Several studies have focused on the encapsulation of specific natural antioxidants and their application in meat products. For example, encapsulating green tea polyphenols in alginate beads has been found to improve the antioxidant stability and sensory properties of pork sausages [20]. Another study reported that the encapsulation of rosemary extract in chitosan nanoparticles enhanced its antioxidant and antimicrobial activity in ground beef, leading to a significant reduction in lipid oxidation and microbial growth [7, 8]. These case studies highlight the potential of encapsulation technology to enhance the effectiveness of natural antioxidants in meat products. However, further research is needed to optimize the encapsulation process and explore new carrier materials that can improve the stability and release of antioxidants.

## 4. Impact on Meat Quality and Stability

### 4.1 Effects on Lipid Oxidation, Color Stability, and Sensory Properties

The incorporation of encapsulated natural antioxidants in meat products has been shown to have a positive impact on lipid oxidation, color stability, and sensory properties. Lipid oxidation is a major cause of quality deterioration in meat products, leading to the formation of off-flavors and rancid odors. Encapsulated antioxidants can effectively inhibit lipid oxidation, thereby extending the shelf life of meat products [19, 20]. Color stability is another critical factor influencing consumer acceptance of meat products. The oxidation of myoglobin, the pigment responsible for the red

color of meat, leads to discoloration and a loss of visual appeal. Encapsulated antioxidants, such as vitamin C and rosemary extract, have been found to improve color stability by preventing the oxidation of myoglobin [3]. Sensory properties, including flavor, aroma, and texture, are key determinants of consumer preference. Encapsulation can help preserve the sensory attributes of meat products by protecting the antioxidant compounds from degradation and controlling their release during cooking and storage. For example, encapsulated essential oils have been shown to enhance the flavor profile of sausages while maintaining their antioxidant and antimicrobial activity [11].

### 4.2 Comparative Studies of Encapsulated vs. Non-Encapsulated Antioxidants

Comparative studies have demonstrated the superiority of encapsulated antioxidants over non-encapsulated ones in maintaining meat quality and stability. For instance, a study comparing the effects of encapsulated and non-encapsulated green tea extract on ground beef found that the encapsulated form provided better protection against lipid oxidation and microbial growth [10,11]. Similarly, encapsulated rosemary extract was found to be more effective than its non-encapsulated counterpart in preserving the color and sensory properties of pork sausages [43]. These findings suggest that encapsulation not only enhances the stability and efficacy of natural antioxidants but also provides additional benefits in terms of controlled release and improved sensory attributes. However, the choice of encapsulation method and carrier material should be carefully considered based on the specific application and desired outcomes.

## 5. Future Perspectives and Challenges

The application of natural antioxidants and encapsulation technologies in meat products holds great promise for improving quality and stability. However, several challenges remain, including the need for further research on the long-term stability of encapsulated antioxidants, the development of cost-effective and scalable encapsulation methods, and the evaluation of consumer acceptance of encapsulated products. Future research should focus on exploring new natural antioxidants with enhanced efficacy, optimizing encapsulation techniques to improve stability and release properties, and conducting comprehensive studies on the safety and sensory impact of encapsulated antioxidants in meat products. Additionally, the development of clean-label formulations that meet consumer demands for natural and sustainable products will be crucial for the successful adoption of these technologies in the meat industry.

## 6. Conclusion

The use of natural antioxidants and encapsulation technologies offers a promising approach to enhancing meat product quality and stability. Natural antioxidants, such as phenolic compounds and essential oils, provide effective protection against lipid oxidation and microbial spoilage, while encapsulation enhances their stability and controlled release. Recent advancements in encapsulation technology, particularly in nanotechnology, have further improved the efficacy of natural antioxidants in meat products. While challenges remain, continued research and innovation in this field will contribute to the development of safer, more sustainable, and high-quality meat products.

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