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Application of Nanotechnology to Enhance Microbial Safety and Sensory Quality of Chilled Meat Products

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Abstract

This research aimed to evaluate the effectiveness of nanotechnology in improving the microbial integrity and sensory qualities (taste, smell, texture, and appearance) of refrigerated meat products, while examining their impact on shelf life and food safety. Nano-coated biomaterials were prepared using high-energy ultrasound, and their encapsulation efficiency, particle size, and zeta potential were evaluated. Steak samples were then prepared and divided into four treatment groups: a control group, a group treated with the free active compound (without nano-encapsulation), and two groups treated with nano-encapsulated materials at low and high concentrations. All samples were stored at 4°C for three weeks. The free-form treatment represented direct application of the active ingredient without nano-packaging, whereas the nano-treated groups received the active compound within a nanocoating system designed to enhance stability and controlled release on the product surface. The parameters studied included total viable bacterial count, lactic acid bacteria, coliform bacteria, *Staphylococcus aureus*, pH, reactants with thiobarbituric acid, water retention capacity, color fastness, and sensory evaluation of appearance, odor, texture, flavor, and overall acceptability. The study results showed inhibition of microbial growth ($P < 0.05$) in the nano- coated groups compared to the control and free groups. Furthermore, the plant extracts exhibited better sensory acceptance and the bitterness was eliminated using nanotechnology. A balanced improvement in microbial safety, sensory quality, and chemical and physical stability was observed in the high-dose group. In conclusion, meat products can be preserved in a clean manner using plant-based bioactive materials coated with nanotechnology.

Keywords: sensory, microbial safety, chilled meat and nanotechnology

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Introduction

As a result of the increasing global demand for meat products by consumers, this sector faces major challenges related to microbial safety and fat oxidation in these products. Although there are natural and artificial preservatives for meat, consumers reject and do not want them because they reduce the quality of the product. For thisreason, there must be new mechanisms for preserving meat products that rely on nano-coating technology. Meat and its products are important for humans due to their high nutritional value, being rich in proteins and vitamins and easily absorbed. On the other hand, processed meat products are susceptible to oxidative and microbial spoilage, which significantly affects their shelf life and negatively impacts consumer safety and acceptance. These challenges have prompted researchers to exert their utmost efforts to develop effective mechanisms for improving and preserving meat and maintaining its quality during refrigerated storage [1]. Microbial contamination is one of the most prominent challenges facing meat technology. The highwater content and high pH of meat make it an ideal environment for the growth of bacteria such as *Salmonella*, *Staphylococcus aureus*, lactic acid bacteria, and pathogenic and enteric bacteria [2]. Due to their antioxidant and antimicrobial properties, plant-derived bioactive compounds, such as rosemary (Rosmarinus officinalis) and green tea (Camellia sinensis) extracts, have received considerable attention for their apparent effectiveness in inhibiting lipid oxidation and microbial growth in various types of meat as major preservatives [3]. Nano-coating technology for meat has emerged as a way to reduce the negative sensory effects of meat while preserving natural preservatives. The mechanism relies on incorporating bioactive compounds into nanocarriers, which improves their stability, solubility, and controlled release within food [4]. These compounds can be prepared for use in food using biopolymers and surfactants. Antioxidant and antimicrobial activity is higher in plant extracts coated with nanoparticles compared to their uncoated counterparts [5][6]. Given several considerations, this research paper was designed to find a nano-coating strategy for chilled beef meat containing an extract of rosemary and green tea, and to evaluate its effectiveness as a natural preservative.

Materials and methods

Experimental Design

This research paper was conducted to evaluate the biologically active properties of nano-encapsulated plant compounds on the microbial safety, physicochemical properties, and sensory evaluation of refrigerated beef. The study samples (40 samples) were randomly and equally assigned to four groups as follows:

- Control Group (G0): Contained beef without additives.
- Group 1 (G1): Contained beef with added unencapsulated (free) plant extracts.
- Group 2 (G2): Contained beef with added (0.75%) nano-encapsulated plant extracts.
- Group 3 (G3): Contained beef with added (1.5%) nano-encapsulated plant extracts.

The beef portions were stored at 4 ± 1°C and analyzed at weeks 0, 1, 2, and 3 of storage [7].

Raw Materials

Fresh beef cuts were purchased from a local butcher shop in Basra Governorate, Iraq, a few hours after the animal were slaughtered. The meat was ground after the fat and connective tissue had been removed using a meat grinder with a 3 mm diameter disc. Rosemary (Rosmarinus officinalis) and green tea (Camellia sinensis) were purchased from a herb market in the governorate. Plant materials were cleaned, dried, and sterilized prior to use to ensure the removal of contaminants and maintain sample safety and stability during the experimental procedures. Analytical reagents and chemicals were purchased from Sigma-Aldrich (USA).

Preparation of Bioactive Plant Extracts Phenol Extract from Rosemary

Rosemary leaves were thoroughly washed with distilled water, air-dried under shade at room temperature, ground into a fine powder, and stored at 4°C until further analysis and nano-encapsulation procedures. The powdered samples were sterilized using appropriate sterilization procedures before extraction. Extraction was carried out by mixing a known weight of plant powder with the selected solvent at a specified ratio, followed by continuous stirring/shaking for a defined extraction period. The extract was then filtered, concentrated using a rotary evaporator under reduced pressure, were air-dried and then ground into a fine powder. 70% (v/v) ethanol was used in a 1:10 (w/v) ratio between the solid and solvent for extraction. The mixture was magnetically agitated for one day at room temperature using a rotary evaporator, followed by filtering and evaporating the solvent under low pressure. The concentrated extract was stored at -20°C until later use [3].

Green tea catechin extract

Green tea leaves were extracted using hot water (80°C for 30 minutes) filtered then freeze –dried the extract. The freeze-dried extract was used to obtain a powder rich in catechins [8].

Nanoencapsulation of Bioactive Compounds

A 1:1 (w/w) mixture of rosemary and green tea extracts was collected and dispersed in an aqueous medium containing 2% whey protein isolate as a food-grade encapsulating agent. 0.75% whey protein was used as an emulsifier. Using a high- speed mixer, the mixture was homogenized (10,000 rpm for 5 minutes). Following homogenization, a sonicator was used for 10 minutes at 400 W. The particle size, polydispersity index, and zeta potential of the resulting nanoemulsion were characterized using dynamic light scattering [4]. Using spectroscopy, the encapsulation efficiency (%) was calculated by quantifying the unencapsulated phenolic compounds.

Preparing the beef patties

Ground beef was mixed with the salt (1.5%) to ensure uniform distribution with the ground beef thoroughly and divided equally into four experimental groups. The respective treatments were added to each group according to the experimental design, and samples were manually mixed for 5 min under standardized conditions to achieve homogenous incorporation of additives. Patties weighing 100 g each were then formed and placed individually in sterile polyethylene trays. The trays were covered with breathable plastic lids/perforated polyethylene film to allow limited air exchange while preventing external contamination. All samples were stored under refrigerated conditions at 4 ± 1°C for the designated storage period, and analyses were performed at predetermined intervals [9].

Microbiological Analysis

Meat samples and all laboratory instruments were treated under sterile conditions to minimize external contamination. 10 g of each sample was taken and homogenized with 90 ml of sterile peptone water using a sterile homogenizer to obtain the initial dilution (10^{-1}), and then sequential decimal dilutions were performed using sterile peptone water. The dilutions suitable for microbial assay were then implanted as follows: Total count of live bacteria on Plate Count Agar medium with incubation at 37°C for 48 hours, lactic acid bacteria on MRS Agar medium incubated at 30°C for 72 h under anaerobic conditions, Colon bacteria on Violet Red Bile Agar medium incubated at 37°C for 24 hours, and *Staphylococcus aureus* bacteria on Baird–Parker Agar medium at 37°C for 48 hours. The results were expressed in log units of colony per gram (log CFU/g) according to the standard methods adopted [10] [11].

Physical and Chemical Analyses pH Measurement

This was performed by directly inserting the electrode into the homogenized meat samples using a calibrated digital thermometer [12].

Liquid Oxidation: This was performed using the thiobarbituric acid assay with reactants [13].

Water Retention: This was performed using a centrifuge [14].

Color Measurement: Color parameters (L*, a*, b*) were measured using a Minolta colorimeter according to CIE laboratory standards.

Sensory Evaluation

Sensory assessment sessions of cooked meat samples were conducted using a 9-point Hedoni to assess cooked cuts of meat in terms of appearance, aroma, texture, flavor, and overall acceptability by a trained panel of 12 members [15]. The scale's scores have been interpreted as follows: 1 = not acceptable at all, 2 = not highly acceptable, 3 = unacceptable, 4 = slightly acceptable, 5 = moderately acceptable, 6 = acceptable, 7 = well acceptable, 8 = very acceptable, 9 = very highly acceptable.

Statistical Analysis

Using SPSS 26 software, the study data were statistically analyzed. A two-way analysis of variance (ANOVA) was performed. Means were compared using Tukey's test with a statistical significance level of $P < 0.05$ [16].

Results

Total Live Bacterial Count (TVC)

Table 1 shows that beef meat samples from the group treated with nano-coated biologically active ingredients (G2 and G3) exhibited low microbial counts compared to the control group and the group treated with the free extract. However, a significant increase ($P < 0.05$) in the total live bacterial count was observed in all treatments.

Table 1: Total viable count of beef patties during refrigerated storage (log CFU/g) (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	2.34±0.06ᵃ	4.01±0.09ᵃ	5.87±0.13ᵃ	8.10±0.16ᵃ
G1	2.31±0.05ᵃ	3.65±0.07ᵇ	5.10±0.10ᵇ	7.24±0.12ᵇ
G2	2.29±0.04ᵃ	3.01±0.08ᶜ	4.31±0.09ᶜ	6.37±0.11ᶜ
G3	2.27±0.03ᵃ	2.74±0.06ᵈ	3.85±0.07ᵈ	5.71±0.08ᵈ

Small letters referred to significant difference among groups at (p≤0.05).

Lactic acid bacteria

In the nanocoated G3 group, the growth of lactic acid bacteria was significantly delayed during refrigerated storage (Table, 2), which may indicate improved microbial stability and a slowdown in spoilage. It is likely that this reduction in bacterial proliferation has contributed to maintaining the quality of the meat and prolonging the shelf life of the product throughout the storage period.

Table 2: Count of Lactic acid bacteria (log CFU/g) (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	1.84±0.04ᵃ	3.34±0.08ᵃ	4.87±0.11ᵃ	6.00±0.14ᵃ
G1	1.82±0.03ᵃ	3.00±0.06ᵇ	4.24±0.10ᵇ	5.30±0.12ᵇ
G2	1.79±0.04ᵃ	2.51±0.05ᶜ	3.61±0.07ᶜ	4.47±0.09ᶜ
G3	1.77±0.04ᵃ	2.24±0.04ᵈ	3.17±0.06ᵈ	4.00±0.08ᵈ

Small letters referred to significant difference among groups at (p≤0.05).

Bacteria of Coliforms and *Staphylococcus aureus*

Group G3 in table (3&4) show an antimicrobial effect, as coliform bacteria and *Staphylococcus aureus* were inhibited.

Table 3: Counts of Coliform bacteria (log CFU/g) (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	1.11±0.02[a]	2.74±0.06[a]	3.94±0.09[a]	4.61±0.11[a]
G1	1.09±0.02[a]	2.31±0.05[b]	3.33±0.08[b]	4.00±0.10[b]
G2	1.07±0.01[a]	1.85±0.04[c]	2.60±0.06[c]	3.01±0.07[c]
G3	1.03±0.01[a]	1.44±0.03[d]	2.16±0.05[d]	2.54±0.06[d]

Small letters referred to significant difference among groups at ($p \leq 0.05$).

Table 4: Counts of *Staphylococcus aureus* bacteria (log CFU/g) (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	1.03±0.02[a]	2.54±0.05[a]	3.71±0.08[a]	4.44±0.10[a]
G1	1.01±0.02[a]	2.11±0.04[b]	3.10±0.07[b]	3.77±0.09[b]
G2	1.00±0.01[a]	1.67±0.02[c]	2.45±0.05[c]	3.03±0.07[c]
G3	1.00±0.01[a]	1.34±0.02[d]	2.01±0.04[d]	2.47±0.06[d]

Small letters referred to significant difference among groups at ($p \leq 0.05$).

pH Values

The results of the Table (5) showed a clear decrease in pH values in the nanocoated treatments, indicating inhibition of microbial growth and slowing down the biochemical changes associated with spoilage during the storage period, which contributed to maintaining product quality for longer. pH values are closely related to bacterial growth and metabolic activity, as a lower pH value creates a more acidic environment that may limit the growth of many of the damaged microorganisms, while relatively high values help increase bacterial activity and accelerate degradation and damage. The growth of some bacteria, especially lactic acid bacteria, may lead to the production of organic acids and lower pH during storage, which is reflected in the chemical and sensory qualities of the product.

Table5: pH Values (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	4.51±0.00^{a}	4.78±0.01^{a}	5.04±0.02^{a}	5.31±0.03^{a}
G1	4.50±0.00^{a}	4.70±0.01^{b}	5.00±0.02^{b}	5.10±0.02^{b}
G2	4.49±0.00^{a}	4.61±0.00^{c}	4.74±0.01^{c}	4.87±0.02^{c}
G3	4.48±0.00^{a}	4.57±0.00^{d}	4.67±0.01^{d}	4.78±0.01^{d}

Small letters referred to significant difference among groups at ($p \le 0.05$).

Oxidation of Lipid

The results of the Table (6) show a decrease in lipid oxidation values in the nanocoated treatments compared to the control treatment, due to the ability of the active materials used, especially compounds with antioxidant activity, to inhibit the formation of free radicals and reduce oxidation reactions during storage. Nano-packaging also contributed to enhancing the stability of these compounds and improving their efficiency in protecting lipids from oxidative degradation, which helped to maintain the quality of the product and its sensory qualities.

Table 6: Oxidation of Lipid values (mg MDA/kg sample) (mean ± SD)

Groups	Day 0	Week 1	Week 2	Week3
G0	0.26±0.00^{a}	0.70±0.01^{a}	1.15±0.02^{a}	1.62±0.03^{a}
G1	0.25±0.00^{a}	0.56±0.00^{b}	0.89±0.01^{b}	1.18±0.03^{b}
G2	0.24±0.00^{a}	0.40±0.00^{c}	0.57±0.01^{c}	0.86±0.01^{c}
G3	0.23±0.00^{a}	0.33±0.00^{d}	0.53±0.00^{d}	0.69±0.01^{d}

Small letters referred to significant difference among groups at ($p \le 0.05$).

Sensory Traits

The table (7) results show a significant improvement and clear sensory acceptance in flavor and overall palatability for the groups coated with nanotechnology.

Table 7: Sensory Scores on week3 (mean ± SD)

Groups	Appearance	Odor	Texture	Flavor	Overall Acceptability
G0	3.1 ± 0.4^{a}	2.7 ± 0.4^{a}	3.4 ± 0.3^{a}	2.5 ± 0.4^{a}	2.7 ± 0.3^{a}
G1	4.5 ± 0.3^{b}	4.1 ± 0.3^{b}	4.7 ± 0.4^{b}	4.0 ± 0.3^{b}	4.2 ± 0.4^{b}
G2	5.7 ± 0.2^{c}	5.4 ± 0.2^{c}	5.8 ± 0.3^{c}	5.6 ± 0.2^{c}	5.7 ± 0.3^{c}
G3	6.4 ± 0.1^{d}	6.2 ± 0.2^{d}	6.5 ± 0.2^{d}	6.3 ± 0.2^{d}	6.4 ± 0.2^{d}

Small letters referred to significant difference among groups at ($p\leq0.05$).

Water-Holding Capacity

Table 8 shows that water-holding capacity increased significantly ($p \leq 0.05$) in all nano-coated groups compared with the control group. The highest value was recorded in G3 (57.6 ± 0.7%), while the lowest was observed in G0 (47.3 ± 1.1%), indicating that nano-coating improved water retention during storage.

Table 8: Water-Holding Capacity on week3 (%) (mean ± SD)

Groups	Water-Holding Capacity
G0	47.3 ± 1.1^{a}
G1	50.7 ± 1.0^{b}
G2	54.8 ± 0.8^{c}
G3	57.6 ± 0.7^{d}

Small letters referred to significant difference among groups at ($p\leq0.05$).

Discussion

The results in this study showed that using rosemary and the catechins found in green tea, along with their phenolic compounds, improved functional performance when used in nano-coating compared to using them in their free form. This reflects the positive effect of using nano-coating on meat preservation. One of the most significant challenges affecting the storage of fresh meat products is microbial proliferation. The results of the research paper showed a clear decrease in microbial growth ($P < 0.05$) in the high-dose group (T3) treated with bioactive materials coated with nanotechnology, while a gradual increase in bacterial growth of *Staphylococcus aureus*, live bacteria, coliform bacteria, and lactic acid bacteria occurred in the other groups during the refrigerated storage process. The results of this study were consistent with the results of previous studies conducted by [12] [2]. The improvement in reducing bacterial growth when using nano-encapsulation technology may be attributed to the fact that the encapsulation increased the surface area to volume of the biologically active compounds, and thus the nano-system enabled those compounds to penetrate microbial cells and thus increased their antimicrobial activity [17]. The decrease in microbial growth in groups G2 and G3 in the third week of storage may be due to the fact that nano-encapsulation provided protection to the biologically active materials from being affected by any harmful external environmental factor, thus allowing them to be released in a controlled manner, as stated by [18].

One of the biggest challenges to the quality of meat products and leading to their deterioration is fat oxidation, as it affects the flavor and leads to rancidity. The treatments in which the nano-coating process was used showed distinctive oxidative stability compared to the rest of the groups that were exposed to a clear fat oxidation process. The improvement and oxidative stability in the group coated with nanotechnology may be due to the high concentrations of phenolic terpenes in rosemary and green tea extracts, which work to degrade metals and scavenge free radicals within the meat structure, giving it strong protection against oxidation [19]. The delayed oxidation process may also be due to the isolated whey protein, which binds to oxidized metal ions and thus delays the oxidation process [8].

Fat oxidation is one of the main challenges that affect the quality of meat products, as it leads to deterioration of taste and the formation of fermented substances. Phenolic compounds and whey protein can contribute to reducing this problem through their antioxidant properties [20]. Phenolic compounds, which are abundant in fruits and vegetables, are active antioxidants. They eliminate free radicals and oxidative substances, which contributes to the stability of fat in meat and reduces its damage, the phenolic compounds react with lipids and contribute to the formation of stable complexes, which impedes the process of oxidation and prolongs the life of the product [21]. Phenolic compounds are able to bind metal ions such as iron and copper, which catalyze oxidation reactions, reducing the availability of these metals to promote oxidation [22].

Whey protein is an effective emulsifier, as it helps stabilize emulsifiers in meat products. By forming a stable matrix around fat droplets, it reduces the available surface area for oxidation [23]. Whey protein contains bioactive peptides that exhibit antioxidant activity, which contributes to the increased antioxidant capacity of the product. Whey protein can form a protective layer around fatty acids, reducing their exposure to oxygen and slowing down fat oxidation [24].

One of the common issues in meat product storage is the increase in pH due to protein breakdown and microbial metabolism. The study results showed a clear decrease in pH in the nano-coated groups compared to the control and free groups. These results are consistent with the decrease in microbial activity and support the strong antimicrobial effect [25].

The water holding capacity of meat products is an important technological feature that directly affects the quality of meat, as it is related to the tenderness, texture and juiciness of the meat, and the reduction of loss during cooking and storage. This property reflects the ability of muscle proteins to retain water within muscle tissue and prevent it from coming out when exposed to pressure or heat. Studies have shown that nanocoated or reinforced treatments have a higher water retention capacity than conventional treatments, due to the role of Nanoparticles in improving the stability of protein structure and reducing the degradation of proteins during storage, which contributes to maintaining the structural cohesion of muscle fibers and reducing fluid loss [14].

Packaging or nanoemulsions also help to form a protective layer around the meat components, which limits oxidative damage and moisture loss caused by chemical and microbial changes during storage. The increase in water retention capacity can also be attributed to the interaction between muscle proteins and the nanoemulsion, as the nanoparticles strengthen the bonds between water molecules and muscle proteins, resulting in increased water stability within muscle tissue and reduced shrinkage and loss of juice during cooking [6].

In addition, the reduction of lipid and protein oxidation in nanocoefficients indirectly contributes to the preservation of the integrity of cell membranes and protein structure, helping to reduce fluid leakage and improve the sensory qualities of the final product, such as tenderness, juiciness, and overall consumer acceptance.

The sensory quality of meat products is one of the most important factors that determine the degree of consumer acceptance of the product, as it is directly related to the qualities of appearance, smell, flavor, texture and juiciness. It is known that the use of natural preservatives extracted from plants, despite their antioxidant and antimicrobial benefits, may affect the sensory properties of meat due to their presence of phenolic compounds or volatile oils with a strong taste or smell that may lead to the appearance of a bitter or pungent taste when used in high concentrations [20]. Clearly in the non-nanoencapsulation group (G1), where a decrease in sensory receptivity and the appearance of a bitter taste was observed compared to nanocoated treatments.

In contrast, the nano-coated high-dose array showed a marked improvement in sensory qualities, due to the ability of the carrier nanoparticles to encapsulate the active compounds and partially isolate them from taste receptors, reducing the immediate sensation of unwanted taste and reducing the volatilization of pungent odor compounds [26]. Nano-packaging systems also facilitate the gradual release of biocompounds, which contributes to improving flavor balance and maintaining acceptable sensory qualities during storage [27].

In addition, the reduction of lipid and protein oxidation in the nanocoefficients played an important role in improving flavor and odor, as oxidation products are one of the main causes of the appearance of unwanted flavors in stored meats [28]. Inhibition of microbial growth also contributed to reducing the formation of compounds associated with meat spoilage, which reflected positively on general sensory acceptance [4] [29]. Studies confirm that flavor and odor characteristics are among the most influential factors in consumer evaluation and overall acceptance scores of meat products [3].

Conclusion

This study showed that the use of the hybrid nano-encapsulation system, consisting of rosemary extract and green tea, greatly enhanced oxidative stability, microbial integrity, oxidative stability, and sensory acceptability, compared to both the control group and the free (unencapsulated) group.

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تطبيق تقنية النانو لتعزيز سلامة الميكروبات وجودة المعايير الحسية في منتجات اللحوم المبردة.

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الملخص

هدفت هذه الدراسة إلى تقييم فعالية تقنية النانو في تحسين سلامة الميكروبات والخصائص الحسية (الطعم، الرائحة، الطراوة، العصيرية والقبول العام) لمنتجات اللحوم المبردة، مع دراسة تأثيرها على عمر الصلاحية وسلامة الغذاء. تم تحضير المواد الحيوية المغلفة بالنانوية باستخدام الموجات فوق الصوتية عالية الطاقة، وتم تقييم كفاءة تغليفها، وحجم الجسيمات، وإمكانات زيتا. ثم تم تحضير عينات شرائح اللحم وتقسيمها إلى أربع مجموعات: مجموعة ضابطة، مجموعة عولجت بالمركب النشط الحر (بدون تغليف نانوي)، ومجموعتان عولجت بمواد مغلفة بالنانوية بتركيزات منخفضة وعالية. تم تخزين جميع العينات عند 4°C لمدة ثلاثة أسابيع. مثلت المعالجة الحرة التطبيق المباشر للمكون النشط دون تغليف نانو، بينما تلقت المجموعات المعالجة بالنانوية المركب النشط ضمن نظام طلاء نانوي مصمم لتعزيز الاستقرار والإطلاق المتحكم به على سطح المنتج. شملت المعايير التي تمت دراستها العدد الكلي البكتيريا الحية، وبكتيريا حامض اللاكتيك، وبكتيريا القولون، *والمكورات العنقودية الذهبية*، ودرجة الحموضة، والمتفاعلات مع حمض الثيوباربيتوريك، وقدرة الاحتفاظ بالماء، وثبات اللون، وتقييم الحواس للمظهر، والرائحة، والطراوة، والنكهة، والقبول العام. أظهرت نتائج الدراسة تثبيط نمو الميكروبات ($P < 0.05$) في المجموعات المغطاة بالنانوية مقارنة بالمجموعات الضابطة والحرارة. علاوة على ذلك، أظهرت مستخلصات النباتات قبولا حسيا أفضل وتم القضاء على الطعم المر باستخدام تقنية النانو. لوحظ تحسن متوازن في سلامة الميكروبات، وجودة المعايير الحسية، والاستقرار الكيميائي والفيزيائي في مجموعة الجرعات العالية. الاستنتاج، يمكن حفظ منتجات اللحوم بطريقة نظيفة باستخدام مواد نباتية نشطة حيويا مغطاة بتقنية النانو.

الكلمات المفتاحية: الخصائص الحسية، والسلامة الميكروبية، واللحوم المبردة، وتقنية النانو