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Impact of Various Herbal Essential Oil Nanoemulsions on the Freshness and Shelf Life of Minced Meat

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Abstract

NANO-EMULSIONS derived from essential oils have emerged as a promising approach to improving the preservation of meat products by utilizing their antimicrobial and antioxidant properties. Therefore, the current study was planned to evaluate the impact of ginger (GNE), thyme (TNE) and lemongrass (LNE) essential oil-based nanoemulsions (NEs) on the sensory, bacteriological and chemical criteria of minced meat shelf life and keeping quality by the concentrations of 1.0 and 2.0% for each during refrigeration. Results revealed that the different investigated treatments showed potent potential enhancement ability in the keeping quality and acceptability of the treated minced meat samples; especially with higher concentrations. Organoleptic, bacteriological and chemical evaluations showed superiority of lemongrass NEs over ginger and thyme NEs; where, the treated samples with LNE-treated samples kept their acceptability scores up to twelve and eighteen days of storage. Moreover, the mean total bacterial count (TBC), pH, total volatile basic nitrogen (TVBN) and thiobarbituric acid (TBA) were 3.3 and 3.7, 5.65 and 5.72, 18.9 and 19.4, 0.75 and 0.84 at the 12th day for LNE 1.0% and 18th day for LNE 2.0%; from which, it appeared that the action of the used materials depends basically on the concentration of the additive and time of storage. After all, the used NEs showed a potent preservative effect on the treated minced meat samples represented by significant ($P \leq 0.05$) extension in the sensory acceptability, reduction in the bacterial counts, and retardation in the chemical indices of freshness raising up; so, it permits recommendation for its use safely in minced meat preservation.

Keywords: Food preservation, Minced meat, Nanoemulsion.

Introduction

Beef is an important nutritional resource and is a key component of many diets globally. Its rich nutrient profile and high-quality protein content make it a valuable option for diverse populations [1].

The application of herbal oil-based nanoemulsions in meat products has garnered attention due to their potential to enhance freshness and extend shelf life [2]. Nanoemulsions, which are stable mixtures of oil and water stabilized by surfactants, can encapsulate bioactive compounds from essential oils, allowing for improved delivery and efficacy [3]. These nanoemulsions possess antimicrobial and antioxidant properties that can significantly impact the chemical criteria of meat freshness, such as pH, color stability, and lipid oxidation levels. By utilizing these properties, the food industry aims to reduce spoilage and enhance the sensory qualities of meat products [2].

One of the primary benefits of incorporating herbal oil-based nanoemulsions into meat is their ability to inhibit microbial growth. Studies have shown that essential oils like ginger, thyme and lemongrass exhibit strong antimicrobial effects against common pathogens such as *E. coli* and *S. aureus* [3]. For instance, a study demonstrated that lemongrass essential oil nanoemulsion effectively preserved the microbial quality of beef burger during refrigerated storage, highlighting its potential as a natural preservative. By reducing microbial load, these nanoemulsions not only improve safety but also contribute to maintaining the meat's organoleptic properties [4].

In addition to their antimicrobial properties, herbal oil-based nanoemulsions play a crucial role in

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preventing lipid oxidation, a major factor affecting meat quality and shelf life. Lipid oxidation leads to rancidity, off-flavors, and discoloration in meat products. Research indicates that nanoemulsions containing essential oils can significantly lower malonaldehyde levels—a marker of lipid oxidation—compared to untreated controls. For example, ginger and thyme essential oil nanoemulsions have been shown to maintain low levels of thiobarbituric acid reactive substances (TBARS), thereby preserving the freshness and flavor profile of minced meat over extended storage periods [5, 6].

The impact of herbal oil-based nanoemulsions on the pH and color stability of meat is also noteworthy. Maintaining an optimal pH is essential for preserving the quality of meat during storage. Studies have reported that treated samples with essential oil nanoemulsions exhibited more stable pH levels compared to untreated controls. Furthermore, these treatments have been associated with reduced metmyoglobin formation—a compound linked to discoloration in meat—thereby enhancing visual appeal and consumer acceptance. The ability to stabilize both pH and color contributes significantly to the overall quality perception of meat products [7].

Sensory attributes such as taste and aroma are critical in determining consumer preferences for meat products. Herbal oil-based nanoemulsions can improve flavor profiles by minimizing undesirable odors while enhancing desirable ones. For instance, thyme oil nanoemulsion has been reported to eliminate unpleasant odors in food products while improving texture. The encapsulation process allows for a controlled release of flavor compounds, which can enhance the overall eating experience without compromising the product's integrity [8].

As the food industry continues to explore sustainable preservation methods, herbal oil-based nanoemulsions represent a significant advancement in extending the shelf life and freshness of meat products [2]. Because the main goal of nanotechnology application research in the food industry is to extend the shelf life of meat products, in addition to the preference of using natural plant extracts as safe additives, the current study aimed to investigate the antibacterial effects of the previously mentioned nanoemulsions against foodborne *S. aureus* and *E. coli,* isolated from minced meat samples in Qalubiya governorate.

Material and Methods

Collection and preparation of samples

Three-hundred and eighty-five grams of fresh beef were purchased from a high-quality butcher in Benha city. Meat was minced and prepared in Animal Health Research Institute – Benha lab. Samples were divided into seven equal groups in the form of thin films, followed by addition of nanoemulsions by direct addition and left for 30 minutes, after which the experiment zero time was recorded.

Preparation and characterization of essential oil based nanoemulsion

Ginger, thyme and lemon grass nanoemulsions were prepared in the unit of nanomaterials, Animal Health Research Institute (AHRI), with a concentration of 20%, which was prepared according to [9] by using tween-80 as surfactant. The prepared nanoemulsions were kept in dark bottle in refrigerator (4oc) until the usage. Nano-droplet size was determined in animal health research institute.

Experimental grouping [4]

385 grams of minced beef were equally divided into seven groups as follow:

G1: Control positive untreated minced beef

G2: 55 g minced beef + 1.0% ginger nanoemulsion (GNE).

G3: 55 g minced beef + 2.0% ginger nanoemulsion (GNE).

G4: 55 g minced beef + 1.0% thyme nanoemulsion (TNE).

G5: 55 g minced beef + 2.0% thyme nanoemulsion (TNE).

G6: 55 g minced beef + 1.0% lemon grass nanoemulsion (LNE).

G7: 55 g minced beef + 2.0% lemon grass nanoemulsion (LNE).

Bacteriological examinations

After preparation of serial dilutions according to 6887-2 [10], Control and treated meat mince were examined for their overall sensory acceptability, total bacterial counts (TBC), pH, total volatile basic nitrogen (TVBN), and thiobarbituric acid (TBA) according to Mörlein [11], ISO 4833-1 [12], EOS: 63-11 [13], 63-9 [14] and 63-10 [15], respectively. Examinations were repeated every three days of refrigeration in triplicate manner.

Statistical Analysis

The obtained data was statistically treated by two-way ANOVA using SPSS software for Windows (Version 16) for more than three comparable groups in relation to the time of stage and the type of treatment as two factors of the experiment. On the other hand, independent T test statistical test was used between two comparable groups. Duncan's post hoc analysis was used to analyze the data, with a p-value of 0.05 being regarded statistically significant.

Results

Characterization of the used nanometrials

Nanoemulsions droplet size was determined by Microtrac® size analyzer, results revealed that the droplet size was 17.94, 139.5 and 49.3 nm for ginger, thyme and lemon grass NEs, respectively.

Effect of the used NEs on the sensory quality of minced beef

Fig. (1), revealed that all of the treated minced beef samples had a significant elongation in the sensory acceptability characters in comparison with the control group which showed signs of unacceptability since the 6^{th} day of storage. Although all of the used NEs had an enhancement effect on the sensory quality of the treated minced beef samples, lemongrass NEs gave significant higher acceptability scores up to the 18th day of storage for 2.0% conc., followed by ginger and thyme NEs, respectively.

Regarding to the bacteriological profile of the treated samples, Table (1) revealed significant bactericidal effect of the applied treatments appeared as significant reductions in the bacterial mean counts (log10 CFU/g) in relation to the control group; whereas, lemongrass NEs treated samples revealed the highest reductions, especially in higher concentration (2.0%), followed by ginger and thyme NEs. While, thyme NEs showed bacteriostatic effect appeared as significant retardations in the bacterial counts along the experimental time.

Regarding the chemical indicators of keeping quality, Tables (2, 3 and 4) showed that the treatment with different oil-based NEs had a significant favorable effect on the keeping quality of the treated minced samples appeared as staying of pH, TVBN and TBA values within the permissible limits up to 12th day of chilled storage for G2, G4 and G6; whereas still acceptable up to 15th day of storage for G5. Additionally, treated samples with ginger and lemongrass NEs revealed acceptability up to eighteen days of storage. On the other hand, control samples exceeded the permissible limits after the 6th day of storage.

Discussion

Meat products play a crucial role in human nutrition and have been a fundamental part of diets around the globe for centuries. They are an outstanding source of complete proteins and fats, supplying all the essential amino acids and fatty acids needed for muscle growth, repair, and overall well-being. Additionally, meat—especially red meat—is abundant in B vitamins, including B12, as well as iron and zinc, which are vital for nerve function and the production of red blood cells [16].

The use of herbal oils as meat preservatives has gained significant attention in recent years due to their natural antimicrobial and antioxidant properties. Essential oils, derived from various plants, contain bioactive compounds that can inhibit the growth of spoilage microorganisms and pathogens, thus enhancing the safety and shelf life of meat products. For instance, oils such as thyme, oregano, and clove have demonstrated effectiveness against a range of bacteria and fungi. These natural preservatives not only help in extending the shelf life of meat but also contribute to maintaining its sensory qualities, such as flavor and aroma, which are crucial for consumer acceptance [17].

Incorporating essential oils into meat products can be achieved through various methods, including direct application or incorporation into edible coatings. However, the volatility and strong flavors of some essential oils, such as of citrus origin, can limit their practical use in food applications [18]. To overcome these challenges, researchers have turned to nanoemulsion technology that involves the dispersion of essential oils in a carrier medium at the nanoscale level, which enhances their stability, bioavailability, and allows for a more controlled release of the active compounds, improving their effectiveness as preservatives while minimizing any adverse effects on the sensory attributes of the meat [19].

The role of essential oil nanoemulsions in extending the shelf life of meat products is particularly noteworthy. Studies have shown that these nanoemulsions can significantly reduce microbial load and lipid oxidation in meat during storage [3]. For example, ginger and lemongrass essential oil nanoemulsions have been found to maintain lower levels of malonaldehyde—a marker for lipid oxidation—compared to untreated controls. This reduction in oxidative rancidity not only preserves the quality of the meat but also enhances its nutritional value by preventing the degradation of essential fatty acids [4, 5].

Regarding with the present study, the obtained results recorded significant ($P \leq 0.05$) extension in the treated minced meat shelf life with improved bacteriological quality and chemical indices, especially with higher concentrations, that may be attributed to the potential antimicrobial and antioxidant effects that help keeping the acceptability criteria within range for longer time [20].

The current recorded results came in line with those of Noori *et al.* [5], Bhat and Bhat [21] and Bakheet *et al.* [4] who recorded significant reductions in the treated foodborne bacterial counts post-treatment with ginger, thyme and lemongrass essential oil based nanoemulsions with concentrations ranged from 0.5% to 5.0% without adverse affecting the sensory characters of the treated meat samples.

The tested NEs have demonstrated significant antibacterial and antioxidant effects. Their potency may be attributed to its nanoscale size, which enhances the bioavailability and stability of its active compounds. This sustained release enhances the antibacterial activity over time, effectively disrupting microbial cell membranes and leading to cell lysis [22].

The mechanism of action involves the penetration of gingerol of ginger; thymol and carvacrol of thyme; citral of lemongrass and other active components into the phospholipid bilayer of bacterial membranes, increasing permeability and causing leakage of cellular contents, which ultimately results in microbial death [5, 6, 23].

Although, the present results indicated that ginger and thyme NEs also possess antibacterial properties, though they are generally less potent than lemongrass; which was previously recorded by Gago *et al.* [24] who concluded superiority of the used LNE over the other examined oils; which may be attributed to the nanosize of the used emulsions, bioavailability of the active components of each essential oil and the extent of microbial sensitivity to the used material [25].

Furthermore, all of the used NEs had a preservative potential appeared through extension of the overall sensory acceptability of the treated samples in relation to the control samples; and retardation in the pH, TVBN and TBA raising up through the storage time; which came in line with the recorded results by Höferl *et al.* [26] and Bakheet *et al.* [4] who attributed their results to the noticed antibacterial and antioxidant effects of the used essential oils that was maximized in to nanoemulsion form.

Ginger and thyme essential oil nanoemulsions have been noted for its ability to lower the pH of minced meat over time, which is beneficial as a lower pH can inhibit bacterial growth. Additionally, these oils have been shown to reduce TVBN levels, which are indicative of protein degradation and spoilage. By suppressing the formation of TVBN, ginger nanoemulsion helps maintain the quality and freshness of the meat during storage. Furthermore, its antioxidant properties contribute to lower TBA values, indicating reduced lipid oxidation and rancidity in the meat [27].

Lemongrass essential oil nanoemulsion has shown remarkable efficacy in enhancing the shelf life of minced meat as well. Research indicates that lemongrass oil can significantly lower both pH and TVBN levels during storage. The presence of citral in lemongrass contributes to its antimicrobial action, effectively controlling microbial populations that lead to spoilage. Moreover, lemongrass nanoemulsion has demonstrated strong antioxidant activity, resulting in lower TBA values compared to untreated samples. This combination of effects makes lemongrass a valuable addition to meat preservation strategies [28].

Conclusion

Overall, the application of ginger, thyme, and lemongrass essential oil nanoemulsions has shown promising results in improving the preservation of minced meat. Their ability to lower pH levels, reduce TVN concentrations, and inhibit lipid oxidation as indicated by TBA values underscores their potential as natural preservatives in the food industry. Continued research into optimizing these formulations could lead to broader applications in meat preservation, promoting safer and more sustainable food practices.

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Declaration of Conflict of Interest

The authors declare that there is no conflict of interest.

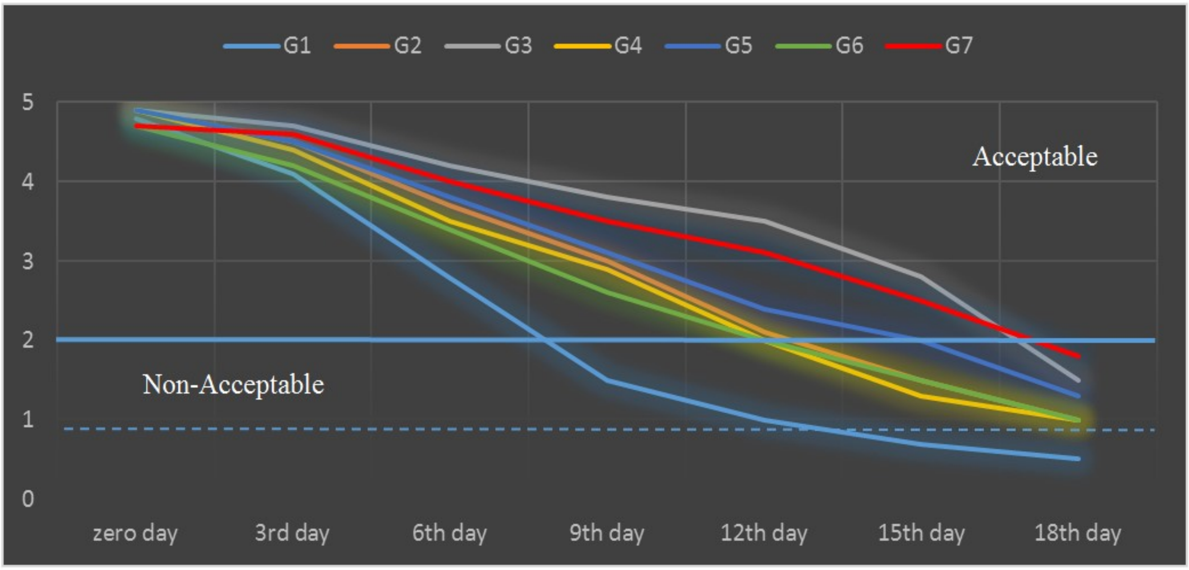

Fig. 1. Sensory profile of the examined minced beef groups during cold storage (4±1°C).
According to this figure, if the final quality score is 2, the sample's quality is marginally acceptable. If this score is less than 2, the sample is unacceptable. If this score is less than 1, the sample is apparently spoiled.

TABLE 1. Mean of aerobic plate count (APC) (log_{10}) of the examined groups during storage at 4±1°C

Day	G1	G2	G3	G4	G5	G6	G7
Zero day	$4.5^{aC} \pm 0.2$	$4.4^{aA} \pm 0.1$	$4.3^{abA} \pm 0.1$	$4.5^{aB} \pm 0.1$	$4.5^{aA} \pm 0.1$	$4.4^{aA} \pm 0.1$	$4.2^{bA} \pm 0.1$
3rd day	$5.8^{aB} \pm 0.6$	$4.2^{bcB} \pm 0.2$	$4.0^{cB} \pm 0.2$	$4.3^{bC} \pm 0.1$	$4.1^{cB} \pm 0.1$	$4.1^{cB} \pm 0.2$	$3.6^{dB} \pm 0.2$
6th day	$6.4^{aA} \pm 0.4$	$3.8^{cC} \pm 0.1$	$3.6^{dC} \pm 0.1$	$4.0^{bD} \pm 0.3$	$3.8^{cC} \pm 0.3$	$3.6^{dC} \pm 0.1$	$3.2^{eD} \pm 0.1$
9th day	xx	$3.5^{bD} \pm 0.3$	$3.2^{cD} \pm 0.3$	$4.5^{aB} \pm 0.3$	$3.4^{bD} \pm 0.3$	$3.4^{bD} \pm 0.3$	$3.0^{dE} \pm 0.5$
12th day	xx	$3.6^{bD} \pm 0.2$	$3.0^{dE} \pm 0.5$	$5.6^{aA} \pm 0.5$	$3.5^{bD} \pm 0.4$	$3.3^{cE} \pm 0.2$	$3.4^{bC} \pm 0.3$
15th day	xx	xx	$3.2^{cF} \pm 0.4$	xx	$4.2^{aB} \pm 0.1$	xx	$3.6^{bB} \pm 0.4$
18th day	xx	xx	$3.4^{*G} \pm 0.3$	xx	xx	xx	$3.7^{*B} \pm 0.5$
Overall means	5.5±0.6	3.9±0.2	3.5±0.2	4.6±0.3	3.9±0.2	3.8±0.2	3.5±0.1

Results were presented as mean± SE
Abcde Different superscript letters within the same row means statistical significant difference ($P \leq 0.05$).
ABCDE Different superscript letters within the same column means statistical significant difference ($P \leq 0.05$)
*Superscript star means significant difference ($P \leq 0.05$).
xx: Means out of examination because of physically spoilage

TABLE 2. Mean values of pH of control and treated groups during storage at 4±1°C.

Day	G1	G2	G3	G4	G5	G6	G7
Zero day	$5.36^{aD} \pm 0.1$	$5.35^{aE} \pm 0.1$	$5.34^{abF} \pm 0.1$	$5.35^{aE} \pm 0.1$	$5.33^{bD} \pm 0.1$	$5.33^{bD} \pm 0.1$	$5.32^{cF} \pm 0.1$
3rd day	$5.58^{aC} \pm 0.2$	$5.37^{bD} \pm 0.2$	$5.36^{bcF} \pm 0.8$	$5.37^{bD} \pm 0.2$	$5.35^{cD} \pm 0.8$	$5.35^{cD} \pm 0.2$	$5.33^{dE} \pm 0.8$
6th day	$5.72^{aB} \pm 0.4$	$5.48^{cC} \pm 0.1$	$5.42^{eE} \pm 0.5$	$5.50^{bC} \pm 0.1$	$5.46^{dC} \pm 0.5$	$5.38^{fC} \pm 0.1$	$5.36^{gE} \pm 0.5$
9th day	$5.84^{aA} \pm 0.3$	$5.65^{cB} \pm 0.3$	$5.60^{eD} \pm 0.6$	$5.69^{bB} \pm 0.3$	$5.63^{dB} \pm 0.6$	$5.49^{fB} \pm 0.3$	$5.47^{gD} \pm 0.6$
12th day	xx	$5.72^{bA} \pm 0.2$	$5.64^{dC} \pm 0.4$	$5.75^{aA} \pm 0.2$	$5.68^{cB} \pm 0.4$	$5.65^{dA} \pm 0.2$	$5.62^{eC} \pm 0.4$
15th day	xx	xx	$5.70^{bB} \pm 0.4$	xx	$5.78^{aA} \pm 0.4$	xx	$5.68^{cB} \pm 0.4$
18th day	xx	xx	$5.76^{*A} \pm 0.4$	xx	xx	xx	$5.72^{*A} \pm 0.4$
Overall means	5.6±0.1	5.5±0.1	5.5±0.1	5.5±0.1	5.5±0.1	5.4±0.1	5.5±0.1

Results were presented as mean± SE
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TABLE 3. Mean values of TVB-N (mg/100 g) of control and treated groups during storage at 4±1°C.

Day	G1	G2	G3	G4	G5	G6	G7
Zero day	10.5 ± 0.1^{aA}	10.5 ± 0.1^{aE}	10.5 ± 0.1^{aG}	10.5 ± 0.1^{aE}	10.5 ± 0.1^{aF}	10.5 ± 0.1^{aE}	10.5 ± 0.1^{aG}
3rd day	14.1 ± 0.2^{aA}	12.9 ± 0.1^{bD}	11.4 ± 0.2^{fF}	12.7 ± 0.1^{cD}	11.8 ± 0.2^{eE}	12.3 ± 0.2^{dD}	11.2 ± 0.11^{gF}
6th day	16.7 ± 0.1^{aA}	14.7 ± 0.1^{cC}	13.2 ± 0.2^{fE}	15.0 ± 0.2^{bC}	13.7 ± 0.1^{eD}	14.2 ± 0.1^{dC}	13.1 ± 0.14^{gE}
9th day	20.2 ± 0.2^{aA}	17.5 ± 0.2^{bB}	15.6 ± 0.11^{eD}	17.5 ± 0.1^{bB}	16.2 ± 0.1^{dC}	17.1 ± 0.2^{cB}	15.0 ± 0.2^{fD}
12th day	xx	19.3 ± 0.2^{aA}	17.2 ± 0.4^{dC}	19.5 ± 0.2^{aA}	17.6 ± 0.4^{cB}	18.9 ± 0.2^{bA}	$16.8^{e}\pm0.4^{eC}$
15th day	xx	xx	19.1 ± 0.4^{bB}	xx	19.6 ± 0.4^{aA}	xx	18.6 ± 0.4^{cB}
18th day	xx	xx	$19.8\pm0.4^{*A}$	xx	xx	xx	$19.4\pm0.4^{*A}$
Overall means	15.4±2.0	33.9±17.8	15.3±1.4	15.0±1.6	14.9±1.4	14.6±1.5	14.9±1.3

Results were presented as mean± SE
^{abcde} Different superscript letters within the same row means statistical significant difference ($P\leq0.05$).
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TABLE 4. Mean values of TBA (mg MDA/kg) of control and treated groups during storage at 4±1oC.

Day	G1	G2	G3	G4	G5	G6	G7
Zero day	0.41 ± 0.01^{aD}	0.41 ± 0.01^{aE}	0.41 ± 0.01^{aG}	0.41 ± 0.01^{aE}	0.41 ± 0.01^{aF}	0.41 ± 0.01^{aE}	0.41 ± 0.01^{aG}
3rd day	0.58 ± 0.01^{aC}	0.48 ± 0.01^{bD}	0.45 ± 0.01^{cF}	0.46 ± 0.01^{cD}	0.44 ± 0.01^{dE}	0.44 ± 0.01^{dD}	0.43 ± 0.01^{dF}
6th day	0.74 ± 0.01^{aB}	0.56 ± 0.04^{bC}	0.51 ± 0.03^{dE}	0.58 ± 0.01^{bC}	0.54 ± 0.01^{cD}	0.52 ± 0.04^{dC}	0.47 ± 0.03^{eE}
9th day	0.95 ± 0.02^{aA}	0.68 ± 0.01^{bcB}	0.60 ± 0.01^{dD}	0.71 ± 0.01^{bB}	0.67 ± 0.02^{bcC}	0.64 ± 0.01^{cB}	0.54 ± 0.01^{eD}
12th day	xx	0.81 ± 0.02^{bA}	0.72 ± 0.02^{cdC}	0.86 ± 0.02^{aA}	0.73 ± 0.02^{cdB}	0.75 ± 0.2^{cA}	0.68 ± 0.4^{dC}
15th day	xx	xx	0.79 ± 0.01^{bB}	xx	0.85 ± 0.01^{aA}	xx	0.73 ± 0.4^{cB}
18th day	xx	xx	$0.86\pm0.03^{*A}$	xx	xx	xx	$0.84\pm0.4^{*A}$
Overall means	0.6±0.1	0.6±0.1	0.6±0.1	0.6±0.1	0.6±0.1	0.55±0.1	0.58±0.1

Results were presented as mean± SE
^{abcde} Different superscript letters within the same row means statistical significant difference ($P\leq0.05$).
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التأثير المضاد للبكتيريا لبعض المستحلبات النانوية المستخلصة من الأعشاب ضد بعض البكتيريا المنتقلة عبر الغذاء

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الملخص

برزت المستحلبات النانوية المشتقة من الزيوت العطرية كطريقة حفظ واعدة لتحسين جودة وسلامة منتجات اللحوم من خلال الاستفادة من خصائصها المضادة للميكروبات ومضادات الأكسدة. لذلك، تم إجراء الدراسة الحالية لتقييم تأثير المستحلبات النانوية المشتقة من الزيوت العطرية لنبات الزنجبيل والزعتر وعشبة الليمون على المعايير الحسية والبكتريولوجية والكيميائية والعمر التخزيني للحوم المفرومة بتركيزات 1.0 و 2.0٪ لكل منهما أثناء الحفظ بالتبريد. كشفت النتائج أن المعالجات المختلفة محل الدراسة استطاعت تحقيق فروق معنوية من حيث قدرتها على تحسين الخصائص الحسية والجودة البكتريولوجية وإطالة العمر التخزيني لمجموعات اللحوم المفرومة مقارنة بالمجموعة الضابطة؛ وخاصة مع التركيزات الأعلى (2.0%). أظهرت التقييمات الحسية والبكتريولوجية والكيميائية تفوق مستحلبات عشبة الليمون على مستحلبات الزنجبيل والزعتر؛ حيث حافظت العينات المعالجة بمستحلب عشبة الليمون (1.0 و 2.0%) على درجات قبولها الظاهري حتى اثني عشر وثمانية عشر يومًا من التخزين، على التوالي. علاوة على ذلك، كان متوسط العد الكلي للبكتريا الهوائية (لو$_{10}$ خلية/جرام)، ودرجة الحموضة، ومركبات النيتروجين المتطاير (مجم/100جم) وحمض الثيوباربيتيوريك (مجم مالونالدهيد/كجم) تساوي 3.7 و 5.72 و 19.4 و 0.84 في اليوم الثامن عشر من تخزين العينات المعالجة بمستحلب زيت عشبة الليمون (2.0%)، على التوالي؛ ومن هنا، ظهر أن تأثير المواد المستخدمة يعتمد بشكل أساسي على تركيز المادة المضافة ووقت التخزين. أظهرت مجموعة المستحلبات النانوية المستخدمة تأثيرًا قويًا كمواد حافظة في عينات اللحم المفروم المُعالجة من حيث إطالة فترة القبول الحسي، وانخفاض في عدد البكتريا، وتأخر في ارتفاع المؤشرات الكيميائية؛ لذلك، يمكن التوصية باستخدامها بأمان في حفظ اللحم المفروم.

الكلمات الدالة: ميكروبات التسمم الغذائي، سلامة الغذاء، المواد النانومترية.