

RESEARCH ARTICLE

Inhibitory Effects of Quercetin-containing Nanoliposomes Against *Listeria Monocytogenes* and the Expression of Virulence Genes *actA* and *hlyA*

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ABSTRACT

Objective(s): Liposomes are nanostructures which can be used for encapsulation and delivery of bioactive agents. *Listeria monocytogenes* is an important foodborne pathogen with increasing prevalence of antibiotic resistance. Because of the increasing rate of drug-resistance, quercetin, a flavonoid, tend to be a promising new treatment option against some infectious disease considering its antioxidant, free radical scavenging, and antimicrobial properties. The aim of this study was to investigate the inhibitory effects of quercetin-containing nanoliposomes against *L. monocytogenes* growth and expression of virulence genes *actA* and *hlyA* in this pathogen.

Methods: Nanoliposomes were synthesized by thin-layer hydration method. Particle size and zeta potential were evaluated by DLS morphology by TEM. The degree of quercetin entrapment was assessed by spectrophotometry. Antimicrobial effects was evaluated by microdilution method and Real-Time PCR was used to study the gene expression in the studied pathogen.

Results: Quercetin-containing nanoliposomes with an average size of 324 nm and a zeta potential of -88 mV were synthesized and the rate of quercetin entrapment in nanoliposomes was reported to be 92.5%. Culture-based studies in Mueller Hinton agar highlighted the detectable inhibitory effect of quercetin and quercetin-containing nanoliposomes against *L. monocytogenes*. Using the 96-well microplate method, the MIC and MBC of quercetin-containing nanoliposomes were reported to be 812.7 mg/ml, and the MIC and MBC of free quercetin were reported to be 625.15 mg/ml. Additionally, a considerable decrease of expression of the biofilm-associated genes; *hlyA* and *actA*, was observed in the treated samples compared to the control group.

Conclusions: Quercetin-containing nanoliposomes have detectable antibacterial properties against *Listeria monocytogenes* when compared to free quercetin.

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INTRODUCTION

Contaminated food can result in foodborne infections, so, incidence of such illnesses tend to be a significant public health issue. *Listeria monocytogenes*, an important foodborne pathogen,

belong to a genus of gram-positive facultative aerobic bacteria which are bacilli that occur singly or in short chains. *Listeria* species sometimes form coccoids and may be confused with streptococci. Some cells, especially in old cultures, lose their ability to retain their Gram staining and may

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be mistaken for *Haemophilus*[1]. These bacteria produce acid from sugar fermentation but do not produce gas. They also do not form spores or capsules. Members of this genus usually grow well in most common bacteriological media under aerobic or anaerobic conditions. Colonies are small (1–2 mm after 24 h at 37°C) and smooth, and appear blue-gray when examined with oblique light on nutrient agar. These organisms are motile at 20–25°C by 1–5 peritrichous flagella. The optimum growth temperature is between 30–37°C, but they can also multiply at refrigerated temperatures (4°C) and such a psychrotolerance is very important from a food contamination point of view. *Listeria* species are catalase-positive but oxidase-negative [2], although catalase-negative strains have been also reported[3; 4]. *Listeria* species have been isolated from soil, water, plants, feces, rotting vegetables, meat, seafood, dairy products, and asymptomatic human and animal carriers. Their natural habitat of these bacteria is decaying plant material, where they live as saprophytes. The widespread presence of *Listeria* in the environment could be a factor in its presence in food production environments and the food chain. In addition, the ability of this bacterium to grow at refrigerated temperatures increases the risk of food contamination. All *Listeria* genomes sequenced to date are circular chromosomes with a size of 2.7 to 3 megabases (Mb). Approximately 89% of the sequence of the various *Listeria* genomes is coding, and 62.5% of it performs specific functions [5].

Quercetin was first isolated and identified in 1936. The flavonoid quercetin is derived from the amino acid phenylalanine. Quercetin is found in fruits and vegetables and is one of the most common dietary flavonols in Western countries. According to the US Department of Health and Human Services, the average daily intake of quercetin in humans is about 25 mg. Quercetin has been reported to have a wide range of biological effects, including antioxidant, anticancer, anti-inflammatory, antidiabetic, and antimicrobial activities [6]. Antimicrobial effects of quercetin against foodborne pathogens including *Staphylococcus aureus* [7], *Escherichia coli* [8], and *Pseudomonas aeruginosa* [9] has been studied.

From a food hygiene perspective, the presence of a non-pathogenic species such as *L. innocua* in food can indicate the potential for co-contamination of the given food sample with *L. monocytogenes*. However, epidemiological studies have shown

that only *L. monocytogenes* and only serovars 1/2a, 1/2b and 4b are responsible for 90% of foodborne outbreaks caused by *L. monocytogenes*[10]. In fact, 1/2a, 1/2b and 4b have been responsible for 95% of human cases, with 4b alone being associated with most outbreaks. It has been shown that 17% of sporadic listeriosis cases could be related to the consumption of food from deli outlets [11].

The field of nanotechnology has grown in the last two decades and nanoscale particles or nanoparticles have emerged with wide applications in drug delivery, diagnostics, cosmetics and several biological and non-biological fields. Many products containing nanoparticles are currently used in various applications such as: food science, cosmetics and pharmaceuticals. Nanoliposomes and solid nanoparticles have many clinical applications that depend on various parameters such as: physical and chemical properties, drug release. Nanoliposomes are lipid-based, composed of phospholipid bilayers and are one of the most common drug delivery systems with several FDA-approved formulations in use and many others in clinical or preclinical trials [12]. Nanomaterials have attracted the attention of many researchers in recent decades due to their potential role in improving public health. In fact, research on nanoparticles has led to the development of various medical and pharmaceutical devices such as drug carriers and biosensors. Nanomaterials are specific size-dependent structures, these materials have been investigated in the diagnosis, prevention and treatment of various diseases in recent years [13]. Recent researches have shown that defined nanoparticle formulations can interfere with bacterial growth, aggregation and biofilm formation, which leads to a reduction in the pathogenicity of a large number of bacteria that cause disease via biofilm formation [14]. Nanoliposomes are nanometric versions of liposomes and are one of the most practical encapsulation and controlled release systems [15]. In recent years, significant progress has been made in the study of liposomes as vesicles for the delivery of therapeutic agents. It can be said that liposomes have undeniable advantages, including improving the efficacy and therapeutic index of drugs and their stability by encapsulation [13]. Nanoliposomes allow the loading of drugs into their core and shell, the main components of liposomes are phospholipids and cholesterol, which are natural biological compounds [16]. Comparative studies have confirmed that the used

and approved nanoliposomal drugs have practically very low side effects [13].

The aim of this study is to prepare, characterize and enhance the antimicrobial activity of quercetin-containing nanoliposomes on *L. monocytogenes*.

MATERIALS AND METHODS

L. monocytogenes strain ATCC 7644 was obtained from the Microbial Strain Collection Center. After preparation according to the company's instructions, it was inoculated in Tryptic Soy Broth (TSB) medium and incubated at 37°C for 24 hours. Then, a linear sub-culture was performed on the Oxford agar medium. This medium was incubated at 35°C for 24-48 hours to test the purity of the strain, phenotypically.

In order to prepare nanoliposomes containing quercetin, 0.2 grams of quercetin was dissolved in 2 ml of 96% filter sterilized ethanol in a 50 ml beaker on a heater stirrer (50 °C, 400 rpm, 2 hour). In a separate 50 ml beaker, one gram of lecithin was dissolved in 2 ml of glycerol on a heater stirrer (50 °C, 400 rpm, 2 hours).

Nanoliposomes size and zeta potential analysis

Nanoliposome size and zeta potential analyses were performed using a dynamic light scattering (DLS) system. To examine the size of quercetin nanoliposomes, one milliliter of the prepared quercetin-containing nanoliposomes was diluted in a ratio of one to ten with distilled water. Then, a sufficient amount of the diluted sample was poured into a transparent four-sided cuvette for nanoliposome size and zeta potential analysis.

Transmission electron Microscopy of Nanoliposomes

Morphology and size of the quercetin-containing nanoliposomes was assessed using transmission electron microscopy (TEM). 20 µL of quercetin-containing nanoliposomes was placed on a carbon film coated on a 300 mesh copper grid (EMS) for two minutes, the excess liquid was absorbed with filter paper, then negatively stained with 2% uranyl acetate for one minute, and finally allowed to air dry. Then, it was examined on a Zeiss EM10C transmission electron microscope operating at an accelerating voltage of 100 kV.

Standard curve and spectrophotometry for quercetin

A CE7250 spectrophotometer was used to prepare a standard curve based on serial concentrations and examine the absorption

behavior of quercetin at various wavelengths and determination of $\lambda_{\max}$. Hence, 0.4 gram of quercetin was dissolved in 10 ml of 96% ethanol. To blank the device, appropriate amount of ethanol was used. As the next step, a sufficient amount of the sample with the initial concentration was tested. Then, serial dilution was performed sequentially until the concentration at which the peak diagram of the device began to be completed. From that concentration, we performed dilution up to 6 points to draw the absorption curve. Then, at the final wavelength, when the peak diagram was completely drawn by the device, that wavelength was set as the $\lambda_{\max}$ of quercetin. This step was repeated three times.

Measurement of intra nanoliposome entrapped quercetin

Amicon rapid ultrafiltration method was used to examine the amount of quercetin entrapped in nanoliposomes. A 3 kDa Amicon centrifuge filter vial was prepared and washed with 10 ml of distilled water. Then, 10 ml of the quercetin-containing nanoliposome sample was filtered with the Amicon filter centrifugation (10,000 rpm, 60 minutes, 4°C). After centrifugation, the centrifuged solution was assessed for any quercetin based on the absorption analysis by spectrophotometer.

Differential scanning calorimetry (DSC)

DSC analysis was used to investigate thermal behavior in which the changes in materials due to heat are measured. 5 mg of quercetin in powder form, 2 ml of quercetin-containing nanoliposomes were lyophilized, lecithin and glycerol were dissolved in water to be lyophilized, and 1 gram of quercetin and 1 gram of lecithin are physically combined and used as a mixed powder. Analysis will be performed for each of the above sample conditions.

Antimicrobial properties

In order to investigate the antimicrobial effects of quercetin nanoliposomes and free quercetin on *L. monocytogenes* strain ATCC 7644, antimicrobial tests were performed on Mueller-Hinton agar plates. Holes were created in the agar medium aseptically, and 50 µl aliquots of molten agar were poured into the holes. In the next step, 100 µl aliquots of quercetin-containing nanoliposome solution (500 mg/ml) were poured into the holes. On the other part of the plate, which was inoculated with the

L. monocytogenes strain ATCC7644, 50 ng of free quercetin at a concentration of 500 mg/ml was dotted. Finally, the plate was incubated for 24 hours at 37°C and then the results were examined.

To investigate the minimum inhibitory and lethal concentration of the prepared quercetin-containing nanoliposomes against *L. monocytogenes* strain ATCC7644, a sterile 96-well microplate was used. To perform this test, it was first repeated several times with different initial concentrations, and the concentration and amount that was effective and efficient was performed in the following manner. *L. monocytogenes* strain ATCC 7644 was cultured for 24 hours, and a turbidity equivalent to the 0.5 McFarland standard was prepared from the bacterial strain in TSB medium.

Then, 95 µl of TSB broth medium was added to the wells of a 96-well microplate. In the next step, 100 µl of free quercetin at a concentration of 500 mg/ml was added to the first well and serial dilutions (0.97, 1.953, 3.9, 7.812, 15.625, 31.25, 62.5, 125, 250, 500 mg/ml) were performed until the end, except for the positive control well. Finally, 100 µl from the negative control well was discarded. Next, 200 µl of quercetin-containing nanoliposomes at a concentration of 200 mg/ml was removed and added to the desired row in the first well. Then, serial dilution (0.097, 0.195, 0.39, 0.781, 1.562, 3.125, 6.25, 12.5, 25, 50, 100, 200 mg/ml) was performed until the end except for the positive control well, and 100 µl from the negative control well were discarded. In this test, two wells were considered as positive and negative controls. The positive control well contained culture medium and the bacterial strain, and the negative control well contained culture medium and nanoliposomes without quercetin.

Then, 100 µl of the bacterial culture were taken from the tube in which we prepared a turbidity equivalent to the McFarland standard 0.5 and 10-times diluted with TSB medium in a sterile tube. Next, 5 µl of the bacterial culture was added to all wells except the negative control well, which contained only medium and nanoliposomes without quercetin. Finally, the above microplate was incubated at 37°C for 24 hours and the results were reported by observation with an ELISA reader at a wavelength of 570 nm. This test was repeated three times.

Real Time PCR

Two primers for the genes under study

icaA: 5-GAGGTAAAGCCAACGCACTC-3, 5-CCTGT AACCGCACCAAGTTT-3

icaD: 5- ACCCAACGCTAAAATCATCG-3, 5-GCGAAAATGCC CATAGTTTC-3

and one pair primer for the internal control gene:

16S: 5-GGAGCATGTGGTT TAATTCGA-3, 5-TGCGGGACTTAACCCAACA-3 were selected to perform the reaction [17].

The cycling condition used was as follows: polymerase activation at 95°C for 10 minutes, followed by 40 cycles of; denaturation at 95°C for 20 seconds, annealing at 60 for 40 seconds, and extension step at 72°C for 30 seconds. Temperature for melting curve analysis (MCA), was 65-95°C with a gradual increase of 0.5°C/5 seconds.

Amplicon's ROX dye-free master mix was used to perform the reaction, and a Rotor gene 5 Plex device was used for the operation. After completing the steps, the results were reviewed and the expression of the desired genes was analyzed. This analysis was repeated three times in all steps.

RESULTS

Nanoliposomes size and zeta potential analysis

According to the DLS analyses, about 50% of quercetin-containing nanoliposomes had a diameter of 324 nm (Fig. 1).

Zeta potential Analysis

Nanoliposomes containing quercetin were reported to have a negative charge during this study. The zeta potential of quercetin-containing nanoliposomes was reported to be -88.1, -85.7, and -88 mV in three replicates, indicating proper distribution of quercetin-containing nanoliposomes (Fig. 2).

Standard curve and spectrophotometry

The standard curve was prepared based on spectrophotometry analysis of various concentrations of quercetin. The $\lambda_{\max}$ of quercetin was 372 nm as spectrophotometry analyses indicated. The standard chart was drawn as follows with an R^2 of approximately 0.990 (Fig. 3).

Measurement of intra-nanoliposome entrapped quercetin

To calculate the percentage of quercetin contained within the nanoliposome, the absorption at the wavelength or $\lambda_{\max}$ (372 nm) was converted into concentration based on the prepared standard

Analysis Results

° d(0)	81.9 nm / 81.9 nm / 81.9 nm	° d(5)	176 nm / 176 nm / 176 nm	° # of Peaks	1
° d(10)	203 nm / 203 nm / 203 nm	° d(25)	252 nm / 252 nm / 252 nm		321 nm
° d(50)	324 nm / 324 nm / 324 nm	° d(75)	409 nm / 409 nm / 409 nm		
° d(90)	510 nm / 510 nm / 510 nm	° d(95)	587 nm / 587 nm / 587 nm		
° d(100)	1.26 um / 1.26 um / 1.26 um				

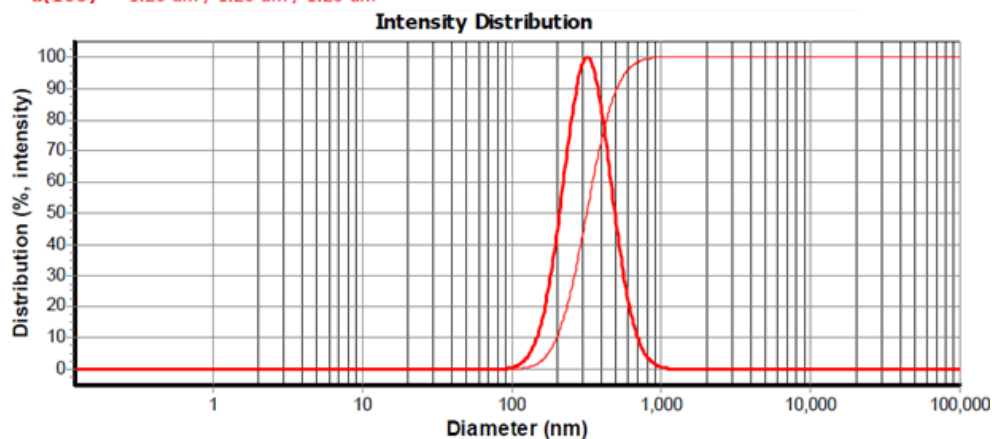


Fig. 1. DLS analysis results of the size of nanoliposomes containing quercetin.

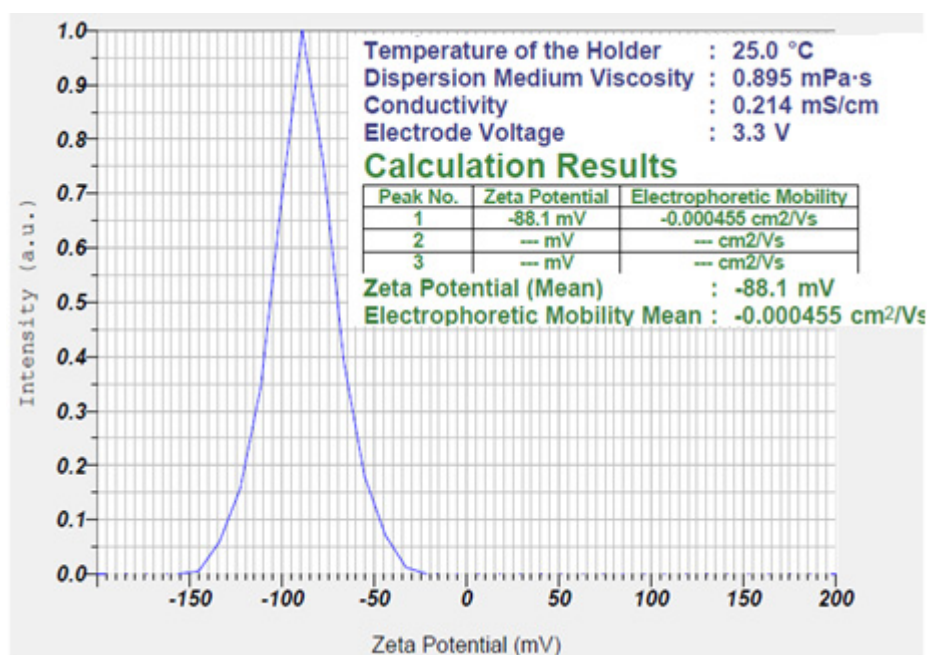


Fig. 2. Zeta potential Analysis of nanoliposomes containing quercetin.

curve. Calculations showed that 92.5% of the quercetin was inside the nanoliposome.

Transmission electron Microscopy of Nanoliposomes

After analyzing the size of the quercetin-containing nanoliposomes and performing a rapid

ultrafiltration test with an Amicon tube, which ensured the level of quercetin entrapment in the nanoliposomes, transmission electron microscopy imaging was also performed to examine the morphology and characterization. As can be seen, about 50% of the particles had an average size of 324

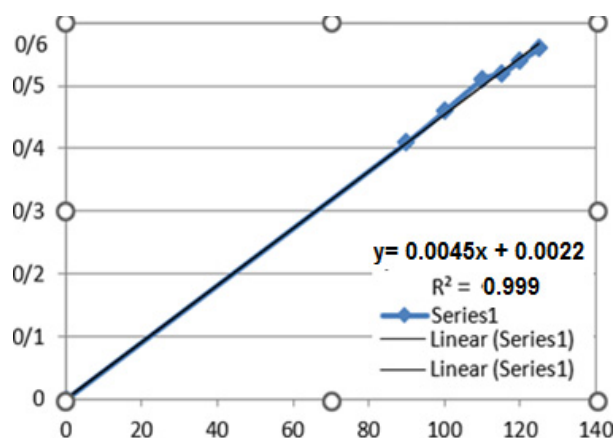


Fig. 3. Spectrophotometry-based standard curve for quercetin.

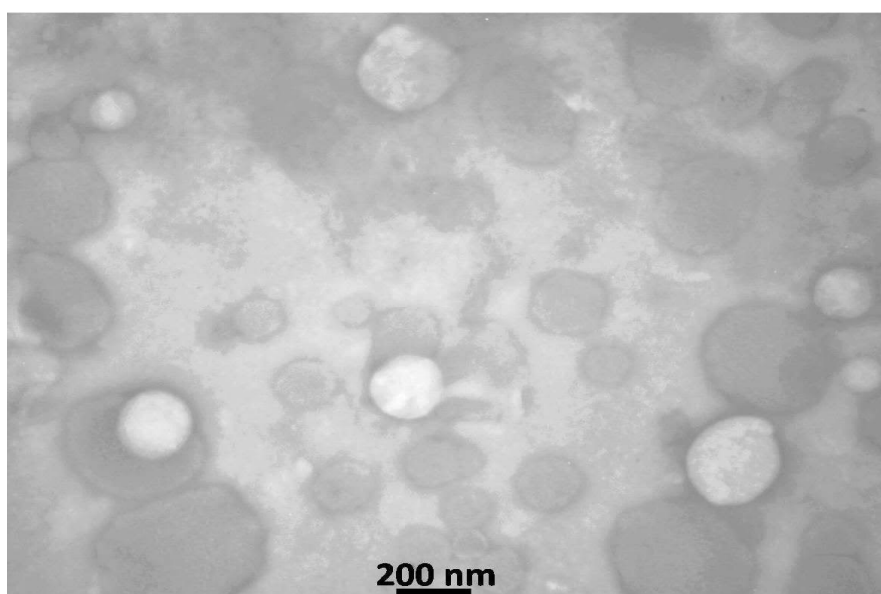


Fig. 4. Morphology of quercetin-containing nanoliposomes based on transmission electron microscopy analysis.

nm, which can also be confirmed by transmission electron microscopy (Fig. 4).

DISCUSSION

In the present study, quercetin-containing nanoliposomes with an average size of 324 nm were prepared and used to assess the antimicrobial effects against *L. monocytogenes* ATCC 7644. Also, modulatory effects of quercetin containing nanoliposomes on the expression of virulence genes *actA* and *hlyA* by *L. monocytogenes* ATCC 7644 was studied. Also, the antibacterial effects of quercetin-containing nanoliposomes was compared to free quercetin. In a similar study, quercetin-

containing nanoliposomes were shown to have antibacterial activity against *L. monocytogenes*. Comparatively, free quercetin has been reported with the least antibacterial activity so that no microbial growth at the minimum inhibitory concentration (250 µg/mL) has been detected and also inhibited biofilm formation at MIC. The expression level of various genes including quorum sensing (*flaA*, *fbp*, *agrA*, *hlyA*, and *prfA*) have been significantly reduced and impaired the biofilm formation [18].

In the present study, quercetin-containing nanoliposomes with 92.5% entrapment also had a significant effect on the survival of

L. monocytogenes ATCC 7644 compared to free quercetin and also reduced the expression of the desired biofilm genes compared to the control and free quercetin groups. In comparison with the similar studies, nanoliposomes with different amounts of initial quercetin were used to indicate how amount of quercetin affects the properties of nanoparticles and antimicrobial activity. *L. monocytogenes*, *Salmonella typhimurium*, *Escherichia coli* and *Staphylococcus aureus* were selected as model food pathogens. The results of the antimicrobial activity study with three different methods showed that the antimicrobial activity of both quercetin nanoparticles and free quercetin was effective on Gram-positive strains (*L. monocytogenes* and *S. aureus*). In addition, it was found that Q31 nanoparticles have more effective antimicrobial activity than other synthesized quercetin nanoparticles [19].

Based on spectrophotometry analyses 372 nm was reported as the $\lambda_{\max}$ of quercetin. In another study that examined the structure of quercetin, the highest absorption of quercetin was also reported at 372 nm which is in line with the results of this research [20].

According to our results, quercetin can be used in nanoliposomal form to have improved effects against *L. monocytogenes*. The advantage of the liposomal form is due to the continuous release of quercetin which lead to more stability. In this regard, a study was conducted on the optimization of quercetin nanoliposomes for oral use. Due to the poor water solubility of quercetin and the low stability of its free form, quercetin-containing nanoliposomes with an optimal size of 134 nanometers were used. Then, by analyzing and simulating the storage time in the digestive fluid, it was determined that quercetin-containing nanoliposomes show a considerable entrapment and stability and have a sustained release [21].

The zeta potential should be a negative or positive value and not close to zero because if the zeta potential is around zero, it will be a sign of coagulation and less stability of the solution. Higher negative and positive zeta potentials mean stability due to repulsion and uniformity between nanoliposomes.

Also, in another study, the antibacterial effect of nanoparticles containing quercetin against *Salmonella typhimurium*, *Bacillus subtilis*, *Escherichia coli*, and *Staphylococcus aureus* as

major foodborne bacterial pathogens showed that quercetin had bactericidal activity and a strong inhibitory effect on above-mentioned pathogens [22].

Zhao proposed an electrostatic precipitator method to encapsulate quercetin in chitosan/lecithin polymer nanocapsules with the aim of protecting quercetin from degradation and enhancing its biocompatibility. Quercetin-loaded polymer nanocapsules were investigated in terms of size, morphology, storage stability, and antioxidant activities, and the results showed increased stability and improved antioxidant activity of quercetin compared to free quercetin. MTT and trypan blue assays showed that quercetin-containing polymer nanocapsules (Q-NPs) had a greater inhibitory effect on liver cancer cells (HepG2) compared to free quercetin. This nanocapsule provided a novel system for protecting and delivering hydrophobic chemicals in vivo and in food products [23].

Also, in examining the expression of *actA* and *hlyA* genes, a decrease in the expression of biofilm genes was observed in samples treated with free quercetin and quercetin nanoliposomes compared to the control group, which suggests that the nanoliposomal form of quercetin can also be used for other pathogenic and microbial agents and research [24-26].

In the present research, the minimum inhibitory and lethal concentration of nanoliposomes containing quercetin and free quercetin and its inhibitory effect on *L. monocytogenes* was confirmed. Based on the findings of the study, quercetin and free quercetin nanoliposomes led to a decrease in the expression of the biofilm genes *actA* and *hlyA* in *L. monocytogenes*, compared to the control group.

CONCLUSION

Therefore, in the present study, it was observed that quercetin in free form has an inhibitory effect on *L. monocytogenes*, but quercetin-containing nanoliposomes tend to be more stable and have improved inhibitory effects against the studied bacterial pathogen.

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DISCLOSURE

No competing interests to declare.

AUTHOR CONTRIBUTIONS

Sedighe Dehghan Morabadi:

Investigation, Writing—original draft

Mohammad Mehdi Soltan Dallal:

Conceptualization, Project administration, Writing-reviewing and editing

Kaveh Sadeghi and Zahra Rajabi:

Conceptualization, Investigation

Omid Mangane Noraei: Methodology

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