LWT - Food Science and Technology 134 (2020) 109965

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Characterized nano-size curcumin and rosemary oil for the limitation microbial spoilage of rainbow trout fillets

Zafer Ceylan [a,*], Raciye Meral [b], Senol Kose [b], Gülgün Sengor [c], Yuksel Akinay [d], Mustafa Durmus [e], Yilmaz Ucar [e,f]

[a] Van Yüzüncü Yıl University, Faculty Fisheries, Department of Seafood Processing Technology, Van, Turkey
[b] Van Yüzüncü Yıl University, Engineering Faculty, Food Engineering Department, Van, Turkey
[c] Istanbul University, Faculty of Aquatic Sciences, Department of Seafood Processing Technology, Istanbul, Turkey
[d] Van Yüzüncü Yıl University, Engineering Faculty, Department of Mining Engineering, Van, Turkey
[e] Cukurova University, Faculty Fisheries, Department of Seafood Processing Technology, Adana, Turkey
[f] Fatsa Faculty of Marine Sciences, Ordu University, Ordu, Turkey

ARTICLE INFO

Keywords:
Microbial safety
Rosemary
Curcumin
Antibacterial nanoemulsions
Fish fillets

ABSTRACT

Curcumin and rosemary oil nanoemulsions (CUR and RON), having 184.3 nm and 158.3 nm average diameters, were successfully produced by a single sonication technique. Effectiveness of nanoemulsions against *P. aeruginosa*, *E. coli*, and *S. typhimurium* were tested by agar diffusion method. Total mesophilic bacteria (TMABc) growth in fish fillets treated with RON and CUR nanoemulsions was acceptable for human consumption up to the 9th day. Total psychrophilic bacteria counts (TPBc) in the fish fillets treated with RON and CUR was found to be lower (26% and 17%) than the control group samples, respectively. **While** TMAB growth in fish fillets treated with RON was effectively **declined** from 5.59 to 3.48 log CFU/g, TMAB count of the **fish fillets treated with** CUR was **decreased** from 7.42 to 6.53 log CFU/g during the analysis period. Therefore, the obtained novel nanomaterial could be effectively used to limit the rapid increase in bacterial spoilage of fish meat in the food industry.

1. Introduction

Different food preservation methods have been using for a long time in the food sector all over the world. However, some preservation methods are not cost-effective while some of them are not healthy for human. Therefore, in addition to conventional food preservation methods, the necessity of towards to novel application or approaches related to food safety is getting increase day by day in the scientific area and food industry (Ceylan, Unal Sengor, Sağdıç, & Yilmaz, 2017). In this sense, the application of microencapsulation, nanoencapsulation, nanofibers, nanoparticles, and nanoemulsions on fish quality are gaining much more important. The nanomaterials provide high surface area associated with their greater strength, stability and chemical and biological activities as compared to the applications of micro and macro scale food materials. Different probiotic bacteria and bioactive materials can be successfully used in order to increase stability, chemical and biological activities of any nanomaterial (Ceylan, Meral, Karakaş, Dertli, & Yilmaz, 2018). For example, thyme oil and thymol were successfully encapsulated into the nanofiber in order to delay the microbial spoilage and chemical deterioration of fish fillets (Ceylan et al., 2017). Besides chemical, physical and sensory changes in fish meat, microorganism activity beginning after rigor mortis in fish meat is the main factor, which limits the shelf life of fish. In this regard, especially, psychrophilic and mesophilic bacteria play a key role in the fish spoilage.

Medicinal plants have been used for many years in order to protect the quality of seafood stored at cold conditions (Gokoglu, 2019; Gudipati, 2017; Ozogul et al., 2010; Shi et al., 2019; Özyurt et al., 2012). Several studies have shown that curcumin and rosemary oil have antibacterial, antifungal, anticarcinogenic, and antioxidant effects. Curcumin and rosemary oil are widely utilized to be antimicrobial and antioxidant agents for food preservation. However, there are limitation related with the use of rosemary oil and curcumin in food formulation. They have intense aroma, which limits their use in foods and also they are insoluble in water. In this regard, nanoemulsions are good choice to use the rosemary oil and curcumin in food formulation, since in the nanoemulsion application, very low levels of active ingredients have

* Corresponding author.
E-mail addresses: zceylan@istanbul.edu.tr, zaferceylan@yyu.edu.tr (Z. Ceylan).

https://doi.org/10.1016/j.lwt.2020.109965
Received 7 April 2020; Received in revised form 16 June 2020; Accepted 27 July 2020
Available online 30 July 2020
0023-6438/© 2020 Elsevier Ltd. All rights reserved.

been used. In the present study, curcumin and rosemary oil have been used to obtain nanoemulsions. The treatment of fish surfaces with **rosemary oil (RON) and curcumin nanoemulsions (CUR)** could be an effective approach **to** limit total mesophilic bacteria and total psychrophilic bacteria **growth** in fish meat.

The primary goal of the presented study was successfully to obtain rosemary and curcumin nanoemulsions. For this aim, the nanoemulsions were characterized in terms of morphological, colloidal properties. The main target of the presented study was to reveal to what effective RON and CUR nanoemulsions providing a higher contact area **c**ould be used **as** an effective nanomaterial **to** delay the microbial growth of fish flesh.

2. Material and method

2.1. Materials

Skinless fish fillets (*Oncorhynchus mykiss*) were **treated with CUR and RON nanoemulsions**. Curcumin from *Curcuma longa* (368.38 Mw, %81 purity), maltodextrin and rosemary oil were obtained from Sigma-Aldrich Company (St. Lois, MO, USA). Tween 20 **and** plate count agar (PCA) were purchased from Merck (Darmstadt, Germany). *Pseudomonas aeruginosa* ATCC 19429, *Escherichia coli* ATCC 11303, *Salmonella typhimurium* ATCC 13311, Mueller-Hinton agar, Mueller- Hinton broth, 10 μg ampicilline, and 30 μg tetracycline were obtained from Oxoid (Istanbul, Turkey). An ultrasonicator (Bandelin Sono Plus HD 2200, Germany) was utilized in order to produce the nanoemulsions (Fig. 1).

2.2. Methods

2.2.1. Preparation of nanoemulsions

Preparation of nanoemulsions were done according to the method proposed by (Meral, Ceylan, & Kose, 2019). Firstly, the aqueous phase was prepared by dissolving maltodextrine in water (1% w/v). Curcumin (0.01 g) was dissolved in 1 mL ethanol. To prepare oil phases, 1 mL of ethanol-curcumin mixture and 1 mL rosemary oil (separately) and 1 mL surfactant (Tween 20) were added into tubes and stirred by magnetic stirrer for 30 min to obtain homogenous mixture. Oil phases were taken into a plastic syringe and placed in a syringe pomp (New Era, USA). 10 mL of aqueous phase was mixed with oil phase injected from syringe at a feed rate of 0.2 mL/min in a beaker using magnetic stirrer at 1200 rpm. To prepare coarse emulsion, the contents were homogenized using Ultra-Turrax (T50, IKA Labortechnik, Staufen, Germany) at 6000 rpm for 5 min. Then, probe sonicator (Bandelin Sonoplus, Germany) were used for 10 min at 60% amplitude to reduce the particle size to nano-scale.

2.2.2. Characterization of nanoemulsions (CUR and RON)

The size (ZS), zeta potential (ZP), and polydispersity index (PDI) of CUR and RON nanoemulsions were determined **using** Zeta-Sizer Nano-ZS90 (Malvern, U.K.) at 25 °C. The nanoemulsion samples were prepared by diluting 500 μL of nanoemulsion with 18 mL of distilled water. Zeta potential **values of the used nanoemulsions were** calculated using the Smoluchowski model as described by Sze, Erickson, Ren, and Li (2003). The morphologies of nanoemulsions (CUR and RON) carried out via field emission scanning electron microscope (FESEM) Carl Zeiss sigma 300 with different magnifications. The SEM images of CUR and RON nanoemulsion specimens were observed under high vacuum with a working distance of 8 mm and at acceleration voltage (EHT) of 3 kV.

2.2.3. Surface-coating of fish fillets with nanoemulsions

Fish fillets (10 ± 2 g) were randomly separated into three groups. The untreated first group was coded as the control (C). The fillets of the second group were only treated with curcumin loaded nanoemulsions (CUR) and third group were solely treated with rosemary loaded nanoemulsions (RON). 100 μL nanoemulsion was applied onto the rainbow fish fillet surface for each group. The all samples were placed into polyethylene bags that were kept for 9 days at 4 ± 1 °C.

2.2.4. Microbiological analysis in fish flesh

Total psychrophilic bacteria count (TPBc) and total mesophilic aerobic bacteria count (TMABc) **of fish fillets** were determined. For each fish sample, 10 g of sample was homogenized for 150 s in a stomacher (IU Instruments, Spain) with 90 mL peptone water (0.1%). Serial dilutions were prepared from 10^1 to 10^7 for each sample. Diluted samples were placed PCA, and incubated at 35 °C for 48 h in order to estimate TMAB count in control (C), RON, and CUR fish flesh. The fish flesh samples were incubated at 7 °C for 10 days in order to estimate TPBc. Microbiological measurements were conducted on three fish samples and each measurement was repeated four times that resulted in twelve measurements for each enumeration (n = 12).

2.2.5. Antibacterial activity of nanoemulsions

The antibacterial effects of RON and CUR nanoemulsions against *Pseudomonas aeruginosa* (ATCC 19429), *Escherichia coli* (ATCC 11303), *and Salmonella typhimurium* (ATCC 13311) were carried out using agar diffusion method (NCCLS, 1999). Firstly, tested microorganisms were inoculated into Mueller Hinton Broth and incubated at 37 °C for 24 h. Subsequently, 18–24 h of fresh bacteria cultures were suspended in sterile physiological solutions and density of bacterial suspensions adjusted according to the 0.5 Mcfarland standards. 100 μL prepared bacteria cultures were spread on Muller-Hinton Agar surface and then 100 μL nanoemulsions were placed into the wells of agar plates. Petri dishes prepared in this way were incubated at 20–25 °C for 2 h and then incubated at 37 °C for 24 h. The inhibition zone of each well was measured in millimeters with a digital caliper. Standard antibiotic discs (10 μg Ampicillin and 30 μg Tetracycline) were used as a positive

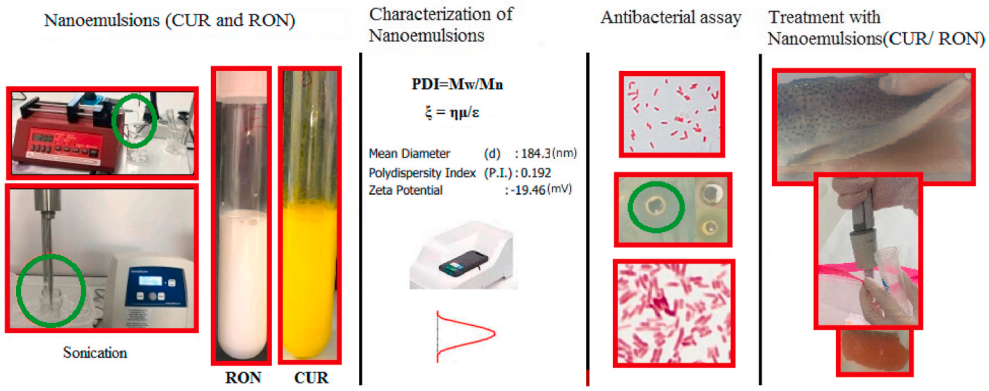

Fig. 1. Flow chart of nanoemulsions (CUR and RON) process for fish fillets.

control, whereas water was used as a negative control.

2.2.6. Statistical methods

Statistical analyses were done using JMP version 9.0.2 (SAS Institute, Inc. Cary, USA). All data were reported as means ± SD (standard deviation). Tukey's multiple range tests were used to compare the samples ($p < 0.05$).

3. Result and discussion

3.1. Characterization of nanoemulsions

Table 1 indicates ZS, ZP, and PDI values of successfully obtained nanoemulsions. As can be seen from Table 1, **the type of** using material affected the droplet size of the nanoemulsions. The obtained droplet sizes were 158.3 nm and 184.3 nm for RON and CUR nanoemulsions, respectively. **T**he small droplet size may provide resistance to gravitational separation, flocculation, and **also** coalescence. According to the previous studies results, the average droplet size of thyme oil nanoemulsions was found in the range of 148 and 219 nm (Bhargava, Conti, da Rocha, & Zhang, 2015; Meral et al., 2019). In the **present** study, a difference was observed between the droplet sizes of two groups. **The results revealed that RON nanoemulsion treatment successfully limited the TMAB growth in fish fillets.** Also, according to Wooster, Golding, and Sanguansri (2008) the low molar volume of oils gives them appreciable solubility in water resulting in destabilization by Ostwald ripening. Furthermore, the use of nanoform of rosemary having 158.3 nm diameters may have been successfully delayed the rapid TMAB growth in the fish fillets.

In the **present** work, PDI was used to be a measurement of the size distribution. As stated by Majeed et al. (2016). PDI values of nanoemulsion including eugenol ranged between 0.082 and 0.172. Meral et al. (2019) noted that PDI distribution of thyme oil can be found in the range of 0.24 and 0.054. In the **present** study, CUR nanoemulsions showed a monodispersity behavior as compared to the RON. In this respect, RON nanoemulsions having a higher heterogeneity property more effectively delayed the microbial growth in the fish fillets. Actually, the PDI value of nanoemulsions can change depending on different factors such as concentration and material type (Tastan, Ferrari, Baysal, & Donsì, 2016); (Meral et al., 2019).

In addition to the ZS and PDI values of the nanoemulsions, a greater ZP value leads to repulsive forces between particles that may improve the physical stability of multiphase systems. **So, nanoemulsion zeta potential value may be decreased when the concentration of thyme oil is increased.**

In this respect, oil concentration plays an important role in determining ZP. As oils are composed of fatty acids, the negative charge could be attributed to carboxylic acid groups of fatty acids (Sood, Jain, & Gowthamarajan, 2014). As can be seen from the results of the present study, ZP values of CUR and RON nanoemulsions were found to be negative **($p < 0.05$).** Bhargava et al. (2015) revealed that the surface of the nanoemulsion was negatively charged**. Also,** Ceylan et al. (2018) and Ceylan et al. (2017) also reported that loading different material into the nanomaterial can affect the ZP of the nanostructures. Thus, the obtained results are in accordance with the previous study finding and comments.

SEM images of CUR and RON nanoemulsions are given in Figs. 2 and 3. Before SEM analysis, the nanoemulsions were dried via using freeze dryer and then coated with Au/Pd. Since the CUR and RON nanoemulsions were exposed to the freeze dryer, the obtained SEM images indicated that CUR and RON nano-emulsions were locally agglomerated and dispersed. However, it can be clearly seen that the CUR and RON have almost spherical shapes. It is known that the use of different material provides obtaining nano-scale materials such as nanofiber, nanoparticle or nanoemulsions having different morphological properties and diameters. In this sense, according to Da Silva et al. (2015) the average fiber diameter of the poly(Ɛ-caprolactone)-based nanofibers was found to be 130 ± 60 nm. Yet, the average diameter of chitosan nanofiber was found to be 330 nm (Jayakumar et al., 2009). Meral et al. (2019) reported that 219 nm and 163 nm diameters thyme oil nanoemulsions were successfully obtained depending on the amount of used material in the nanoscience process. Moreover, in the present study, the size and shape of these nanoemulsions were determined to be spherical and in the range 50–100 nm. Abdou, Galhoum, and Mohamed (2018) obtained CUR nanoemulsion in the range of <100 nm and reported that the spherical shape of nanoemulsions was obtained in the differences of viscosity. As understood from Figs. 2 and 3, the CUR and RON displayed irregular spherical shapes due to the freeze-dryer process. The adherent and irregular forms of the CUR and RON can be attributed to the pre-preparation process such as freeze-dryer. Nanoemulsion application on the fish surface may have provided a better microbial safety in fish, because of the fact that nanoemulsions (CUR and RON) provides a higher contact area as compared to the micro and macro scale of materials used in food industry.

Table 1
Zeta size, polydispersity index and zeta potential values of nanoemulsions (n = 3, ±SD).

Nanoemulsions	Zeta Size (nm)	Polydispersity Index	Zeta Potential (mV)
RON	158.3 ± 1.20[a]	0.376 ± 0.03[a]	−20.96 ± 0.09[a]
CUR	184.3 ± 2.01[b]	0.192 ± 0.01[b]	−19.46 ± 0.03[b]

Values followed by different superscripts within the same column are significantly different ($p < 0.05$). RON: nanoemulsions including rosemary oil, CUR: nanoemulsions including curcumin.

3.2. Antibacterial assay of nanoemulsions

The inhibitory effect of RON and CUR nanoemulsions against tested microorganisms is presented in Table 2. As shown in Table 2, RON and CUR nanoemulsions produced the largest inhibition zone against *Salmonella typhimurium*, followed by *Escherichia coli* and the lowest inhibition zone was found against *Pseudomonas aeruginosa.* The size of inhibition zones changed between 7 and 21.50 mm. CUR nanoemulsions exhibited the best inhibitory activity against all bacteria evaluated by agar diffusion method (change 7.00–21.50 mm). Although CUR nanoemulsions showed the varying levels of antibacterial activity against three bacteria species (*Pseudomonas aeruginosa*, *Escherichia coli* and *Salmonella typhimurium*), RON nanoemulsions showed antibacterial activity only against the *Salmonella typhimurium*. The inhibition zone of CUR nanoemulsion is similar in comparison to Tetracycline 30 μg for *Salmonella typhimurium*. Also, CUR nanoemulsion showed higher

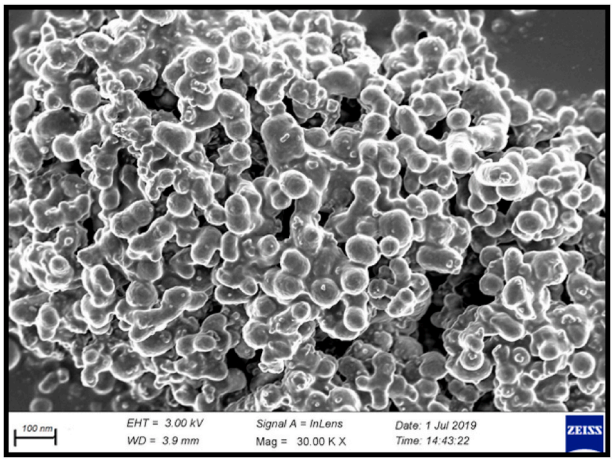

Fig. 2. SEM images of CUR nanoemulsions.

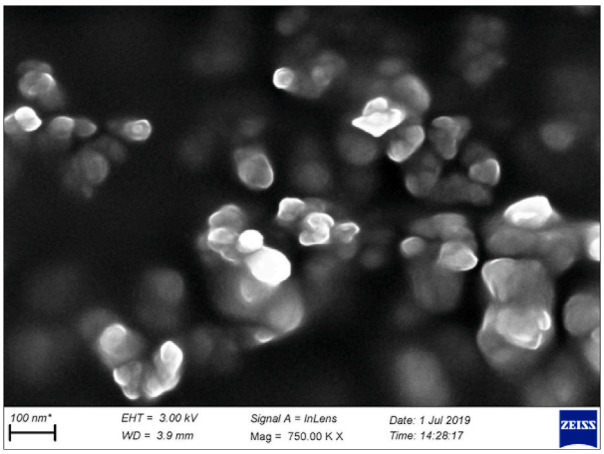

Fig. 3. SEM images of RON nanoemulsions.

Table 2
Bacterial inhibition assay.

Sample	*P.aeruginosa* (ATCC 19429)	*E.coli* (ATCC 11303)	*S.typhimurium* (ATCC 13311)
RON	0.00 ± 0.00^{aA}	0.00 ± 0.00^{aA}	9.00 ± 0.00^{aB}
CUR	7.00 ± 0.00^{bA}	17.50 ± 0.71^{bB}	21.50 ± 0.71^{bC}
Tetracycline30μg	14.25 ± 0.35^{cA}	21.00 ± 0.00^{cB}	21.50 ± 0.35^{bB}
Ampicilline10μg	0.00 ± 0.00^{aA}	22.50 ± 0.71^{dB}	25.50 ± 0.71^{cC}

Data values are expressed as means ± standard deviation, Means in the same column with different letters ($^{a-d}$) are significantly different at $p < 0.05$ in terms of comparing sample, Means in the same row with different letters ($^{A-C}$) are significantly different at $p < 0.05$ in terms of comparing bacteria. RON: nanoemulsions including rosemary oil, CUR: nanoemulsions including curcumin.

antibacterial activity than Ampicilline 10 μg against *Pseudomonas aeruginosa*. As clearly seen in Table 2, CUR nanoemulsions can be applied as a natural antibacterial agent against *Pseudomonas aeruginosa*, *Escherichia coli*, *Salmonella typhimurium* in food systems. Therefore, further studies are needed to determine the potential for utilizing CUR and RON nanoemulsion as an additive to extend the shelf-life and safety of food products. The antimicrobial activity of essential oils is due to the phenolic components presented in their composition. Generally, essential oils containing phenolic components such as thymol, carvacrol, and eugenol at high levels exhibit strong antimicrobial activity against pathogenic microorganisms. These compounds inactivate the essential enzymes, disturb the genetic material functionally, or react with the cell membrane activity, structural component synthesis and disturb energy production. The diameters of the inhibition zones of essential oils vary according to bacterial strains and their compounds (Tural & Turhan, 2017). The higher and wide spectrum antibacterial effect of curcumin could be attributed to its flavonoids and terpenes particularly to borneol, cuparene, careen and cymene (Parveen, Nawaz, Siddique, & Shahzad, 2013). The antimicrobial activity of RON and CUR nanoemulsions against some pathogenic bacteria was determined by other researches (Akarchariya, Sirilun, Julsrigival, & Chansakaowa, 2017; Elbanna et al., 2018; Negi, Jayaprakasha, Rao, & Sakariah, 1999; Stojiljkovic, 2018; Tural & Turhan, 2017; Özcan & Chalchat, 2008). When we compared our results with literature, some differences were determined. The differences could be ascribed to varied ecological and environmental properties of the plants, extraction method of the essential oils, analysis methods and bacterial strains.

3.3. TMAB and TPB growth in fish flesh treated with RON and CUR nanoemulsions

Effect of nanoemulsions obtained from curcumin and rosemary oil on microbial growth of fish flesh during storage at 4 ± 1 °C is shown in Table 3. As well known that the shelf life of fish is correlated with TMAB and TPB loads during cold storage of fish. In this regard, TMAB count of fish fillet sample (C) increased from 3.02 to 7.42 log CFU/g. Microbial growth in C samples more rapidly increased and reached to 7.42 on the 9th day. Also, the growth in TMAB of fish flesh treated with RON and CUR nanoemulsions was found to be lower than control group samples ($p < 0.05$). At the end of the 2nd and 7th day of cold storage, **TMAB counts of fish samples treated with** RON nanoemulsions were 2.96 and 5.36 log CFU/g. **However,** TMAB counts of C samples were determined to be 3.58 and 6.35 log CFU/g, respectively.

Moreover, it was clearly seen that fish flesh treated with RON nanoemulsions did not exceed the limit value until the 7th day of cold storage. Similarly, TMAB count of fish flesh treated with CUR nanoemulsions reached 5.39 log CFU/g, at the end of the 7th days of cold storage. At the end of the 9th day of storage, TMAB count of fish flesh treated with RON and CUR reached unacceptable levels for human consumption with 6.37 and 6.53 log CFU/g, respectively. Meral et al. (2019) cited to the Chotimarkorn (2014) total viable bacteria counts between 6 and 7 log CFU/g in fresh fish was determined to be unfit for human consumption. Foujdar, Chopra, and Bera (2018) reported that the rate of increase in the total viable count of fish fillet sample treated with nanoemulsion containing turmeric extract was less in comparison to fish fillet sample treated with nanoemulsion without turmeric extract and control sample. Also, Meral et al. (2019) reported that nanoemulsions thyme oil provided an effective antimicrobial activity on some gram-negative bacteria and they successfully delayed TMAB growth in fish fillets stored at 4 °C.

Besides TMAB growth in fish flesh samples, in the present study, TPB count was also observed. In this sense, TPB count of C samples rapidly increased from 3.85 to 8.80 log CFU/g up to the 9th days. Also, once TMAB growth in C samples exceeded 6 log CFU/g value, TPB count of C samples was detected to be 8.73 log CFU/g. The amount of used active material in the present nanotechnology application on fish flesh was lower than the amount of micro and macro size materials. In this respect, the results indicated that RON nanoemulsions were **highly effective** in order to delay the TMAB and TPB growth. Previous researches also reported that curcumin, rosemary oil, etc. essential oils had potential antibacterial and antioxidative activity (Abdou et al., 2018; Arulkumar,

Table 3
Microbial growth (MG: log CFU/g) in C, RON and CUR fish fillets (n = 12, ±SD).

Group	MG	Storage Days			
		2	4	7	9
C	TMABc	3.58 ± 0.01^{aD}	5.59 ± 0.11^{aC}	6.35 ± 0.09^{aB}	7.42 ± 0.15^{aA}
	TPBc	4.81 ± 0.08^{aC}	6.07 ± 0.06^{aB}	8.73 ± 0.04^{aA}	8.80 ± 0.21^{aA}
RON	TMABc	2.96 ± 0.05^{cD}	3.48 ± 0.02^{cC}	5.36 ± 0.03^{bB}	6.37 ± 0.06^{bA}
	TPBc	4.04 ± 0.05^{cD}	5.43 ± 0.04^{cC}	6.46 ± 0.14^{cB}	7.51 ± 0.24^{bA}
CUR	TMABc	3.36 ± 0.09^{bD}	5.08 ± 0.07^{bC}	5.39 ± 0.02^{bB}	6.53 ± 0.09^{bA}
	TPBc	4.51 ± 0.11^{bD}	5.91 ± 0.03^{bC}	7.30 ± 0.16^{bB}	8.43 ± 0.22^{aA}

$^{a-c:}$Within each column, different superscript lowercase letters show differences between treatment groups for same storage times ($p < 0.05$). $^{A-C}$ Within each row, different superscript upper case letters show differences between the storage times within same analysis group ($p < 0.05$). C: control fish fillets; RON: fish fillets treated with nanoemulsions including 5.5% rosemary oil; CUR: fish fillets treated with nanoemulsions including 5.5% curcumin.

Ramanchandran, Paramasivam, Palanivel, & Miranda, 2017; Fernandes, Cervi, Aparecida de Carvalho, & Lapa-Guimarães, 2017; Pires, de Souza, & Fernando, 2018). In the present study, it was clearly observed that nanotechnology application provided a larger contact area on the surface of the fish flesh, so penetration of oxygen and other physical/external factors **could** be effectively **limited by** RON and CUR nanoemulsions. In this sense, for further studies, the present study revealed a novel perspective in order to delay microbiological spoilage in fish flesh treated with RON and CUR nanoemulsions.

4. Conclusions

CUR and RON nanoemulsions were successfully obtained. CUR and RON nanoemulsions inhibited some pathogenic microorganism, which can be determined in the fish meat. Also, the use of nanoemulsions with 184.3 nm diameters delayed the rapid TMAB and TPB growth in fish fillets during the 9 days as compared to the untreated fish samples. Moreover, this nanoscience study can play a guiding role in further food studies.

CRediT authorship contribution statement

Zafer Ceylan: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Raciye Meral:** Resources, Investigation, Writing - review & editing. **Senol Kose:** Resources, Investigation. **Gülgün Sengor:** Data curation. **Yuksel Akinay:** Resources, Writing - review & editing. **Mustafa Durmus:** Writing - review & editing. **Yilmaz Ucar:** Writing - review & editing.

Declaration of competing interest

There is no conflict of interest among the authors.

Acknowledgement

This project was supported by the Scientific Research Project Chairmanship of Van Yuzuncu Yil University (FBA-2019-7518).

References

Abdou, E. S., Galhoum, G. F., & Mohamed, E. N. (2018). Curcumin loaded nanoemulsions/pectin coatings for refrigerated chicken fillets. *Food Hydrocolloids, 83* (May), 445–453. https://doi.org/10.1016/j.foodhyd.2018.05.026.

Akarchariya, N., Sirilun, S., Julsrigival, J., & Chansakaowa, S. (2017). Chemical profiling and antimicrobial activity of essential oil from Curcuma aeruginosa Roxb., Curcuma glans K. Larsen & J. Mood and Curcuma cf. xanthorrhiza Roxb. collected in Thailand. *Asian Pacific Journal of Tropical Biomedicine, 7*(10), 881–885. https://doi.org/10.1016/j.apjtb.2017.09.009.

Arulkumar, A., Ramanchandran, K., Paramasivam, S., Palanivel, R., & Miranda, J. M. (2017). Effects of turmeric (Curcuma longa) on shelf life extension and biogenic amine control of cuttlefish (Sepia brevimana) during chilled storage. *CyTA - Journal of Food, 15*(3), 441–447. https://doi.org/10.1080/19476337.2017.1296495.

Bhargava, K., Conti, D. S., da Rocha, S. R. P., & Zhang, Y. (2015). Application of an oregano oil nanoemulsion to the control of foodborne bacteria on fresh lettuce. *Food Microbiology, 47*, 69–73. https://doi.org/10.1016/j.fm.2014.11.007.

Ceylan, Z., Meral, R., Karakaş, C. Y., Dertli, E., & Yilmaz, M. T. (2018). A novel strategy for probiotic bacteria: Ensuring microbial stability of fish fillets using characterized probiotic bacteria-loaded nanofibers. *Innovative Food Science & Emerging Technologies, 48*, 212–218. https://doi.org/10.1016/j.ifset.2018.07.002.

Ceylan, Z., Unal Sengor, G. F., Sağdıç, O., & Yilmaz, M. T. (2017). A novel approach to extend microbiological stability of sea bass (Dicentrarchus labrax) fillets coated with electrospun chitosan nanofibers. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 79*, 367–375. https://doi.org/10.1016/j.lwt.2017.01.062.

Chotimarkorn, C. (2014). Quality changes of anchovy (Stolephorus heterolobus) under refrigerated storage of different practical industrial methods in Thailand. *Journal of Food Science & Technology, 51*(2), 285–293. https://doi.org/10.1007/s13197-011-0505-y.

Da Silva, G. R., Lima, T. H., Oréfice, R. L., Fernandes-Cunha, G. M., Silva-Cunha, A., Zhao, M., et al. (2015). In vitro and in vivo ocular biocompatibility of electrospun poly(å-caprolactone) nanofibers. *European Journal of Pharmaceutical Sciences*. https://doi.org/10.1016/j.ejps.2015.03.003.

Elbanna, K., Assiri, A. M. A., Tadros, M., Khider, M., Assaeedi, A., Mohdaly, A. A. A., et al. (2018). Rosemary (rosmarinus officinalis) oil: Composition and functionality of the cold-pressed extract. *Journal of Food Measurement and Characterization, 12*(3), 1601–1609. https://doi.org/10.1007/s11694-018-9775-7.

Fernandes, M. G., Cervi, C. B., Aparecida de Carvalho, R., & Lapa-Guimarães, J. (2017). Evaluation of turmeric extract as an antioxidant for frozen streaked prochilod (Prochilodus lineatus) fillets. *Journal of Aquatic Food Product Technology, 26*(9), 1057–1069. https://doi.org/10.1080/10498850.2017.1376025.

Foujdar, R., Chopra, H. K., & Bera, M. B. (2018). Optimization and production of turmeric extract-based nanoemulsion (TEBN) and its application in preservation of fatty fish fillet. *Journal of Food Processing and Preservation, 42*(9). https://doi.org/10.1111/jfpp.13750.

Gokoglu, N. (2019). Novel natural food preservatives and applications in seafood preservation: A review. *Journal of the Science of Food and Agriculture, 99*, 2068–2077. https://doi.org/10.1002/jsfa.9416.

Gudipati, V. (2017). Role of plant extracts as natural additives in fish and fish products-A review stress response in carps view project some cycloadditions and photochemical reactions on isoxazoles view project. In *Fishery technology* (Vol. 54). Retrieved from https://www.researchgate.net/publication/321945174.

Jayakumar, R., Divya Rani, V. V., Shalumon, K. T., Kumar, P. T. S., Nair, S. V., Furuike, T., et al. (2009). Bioactive and osteoblast cell attachment studies of novel α- and β-chitin membranes for tissue-engineering applications. *International Journal of Biological Macromolecules, 45*(3), 260–264. https://doi.org/10.1016/j.ijbiomac.2009.06.002.

Majeed, H., Antoniou, J., Hategekimana, J., Sharif, H. R., Haider, J., Liu, F., et al. (2016). Influence of carrier oil type, particle size on invitro lipid digestion and eugenol release in emulsion and nanoemulsions. *Food Hydrocolloids, 52*, 415–422. https://doi.org/10.1016/j.foodhyd.2015.07.009.

Meral, R., Ceylan, Z., & Kose, S. (2019). Limitation of microbial spoilage of rainbow trout fillets using characterized thyme oil antibacterial nanoemulsions. *Journal of Food Safety*. https://doi.org/10.1111/jfs.12644.

Negi, P. S., Jayaprakasha, G. K., Rao, L. J. M., & Sakariah, K. K. (1999). Antibacterial activity of turmeric oil: A byproduct from curcumin manufacture. *Journal of Agricultural and Food Chemistry, 47*(10), 4297–4300. https://doi.org/10.1021/jf990308d.

Özcan, M. M., & Chalchat, J. C. (2008). Chemical composition and antifungal activity of rosemary (Rosmarinus officinalis L.) oil from Turkey. *International Journal of Food Sciences & Nutrition, 59*(7–8), 691–698. https://doi.org/10.1080/09637480701777944.

Ozogul, Y., Ayas, D., Yazgan, H., Ozogul, F., Boga, E. K., & Ozyurt, G. (2010). The capability of rosemary extract in preventing oxidation of fish lipid. *International Journal of Food Science and Technology, 45*(8), 1717–1723. https://doi.org/10.1111/j.1365-2621.2010.02326.x.

Özyurt, G., Kuley, E., Balikçi, E., Kaçar, Ç., Gökdogan, S., Etyemez, M., et al. (2012). Effect of the icing with rosemary extract on the oxidative stability and biogenic amine formation in sardine (Sardinella aurita) during chilled storage. *Food and Bioprocess Technology, 5*(7), 2777–2786. https://doi.org/10.1007/s11947-011-0586-7.

Parveen, Z., Nawaz, S., Siddique, S., & Shahzad, K. (2013). Composition and antimicrobial activity of the essential oil from leaves of Curcuma longa L. Kasur variety. *Indian Journal of Pharmaceutical Sciences, 75*(1), 117. https://doi.org/10.4103/0250-474x.113544.

Pires, J. R. A., de Souza, V. G. L., & Fernando, A. L. (2018). Chitosan/montmorillonite bionanocomposites incorporated with rosemary and ginger essential oil as packaging for fresh poultry meat. *Food Packaging and Shelf Life, 17*(July), 142–149. https://doi.org/10.1016/j.fpsl.2018.06.011.

Shi, J., Lei, Y., Shen, H., Hong, H., Yu, X., Zhu, B., et al. (2019). Effect of glazing and rosemary (Rosmarinus officinalis) extract on preservation of mud shrimp (Solenocera melantho) during frozen storage. *Food Chemistry, 272*, 604–612. https://doi.org/10.1016/j.foodchem.2018.08.056.

Sood, S., Jain, K., & Gowthamarajan, K. (2014). Optimization of curcumin nanoemulsion for intranasal delivery using design of experiment and its toxicity assessment. *Colloids and Surfaces B: Biointerfaces, 113*, 330–337. https://doi.org/10.1016/j.colsurfb.2013.09.030.

Stojiljkovic, J. (2018). Antibacterial activities of rosemary essential oils and their components against pathogenic bacteria. *Advances in Cytology & Pathology, 3*(4), 93–96. https://doi.org/10.15406/acp.2018.03.00060.

Sze, A., Erickson, D., Ren, L., & Li, D. (2003). *Zeta-potential measurement using the Smoluchowski equation and the slope of the current – time relationship in electroosmotic flow* (Vol. 261, pp. 402–410). https://doi.org/10.1016/S0021-9797(03)00142-5.

Tastan, Ö., Ferrari, G., Baysal, T., & Donsì, F. (2016). Understanding the effect of formulation on functionality of modified chitosan films containing carvacrol nanoemulsions. *Food Hydrocolloids, 61*, 756–771. https://doi.org/10.1016/j.foodhyd.2016.06.036.

Tural, S., & Turhan, S. (2017). Antimicrobial and antioxidant properties of thyme (*Thymus vulgaris* L.), Rosemary (*Rosmarinus officinalis* L.) and laurel (*Lauris nobilis* L.) essential oils and their mixture. *Gida/Journal of Foodservice, 42*(5), 588–596. https://doi.org/10.15237/gida.gd17030.

Wooster, T. J., Golding, M., & Sanguansri, P. (2008). *Ripening stability*, 10.