Curcumin-mediated sono/photodynamic treatment preserved the quality of shrimp surimi and influenced its microbial community changes during refrigerated storage

Dehuang Wang¹,², Feng Zhou², Danning Lai², Yi Zhang¹,², Jiamiao Hu¹,²,⁎, Shaoling Lin²,³,⁴

¹ Engineering Research Centre of Fujian-Taiwan Special Marine Food Processing and Nutrition, Ministry of Education, Fuzhou 350002, Fujian, China
² College of Food Science, Fujian Agriculture and Forestry University, Fuzhou 350002, China
³ State Key Laboratory of Food Safety Technology for Meat Products, Xiamen 361100, Fujian, China
⁴ College of Food Science, Fujian Agriculture and Forestry University, Fuzhou 350002, China

A R T I C L E   I N F O

Keywords:
Sono/photodynamic treatment
Shrimp surimi
Microbial community
Curcumin

A B S T R A C T

Shrimp surimi is widely acknowledged as a value-added shrimp product due to its delicious taste, rich flavor, and nutrition. However, the refrigerated shrimp surimi is prone to deterioration due to rapid microbial growth during storage. The present study sought to assess the effects of curcumin-mediated sono/photodynamic treatment on bacterial spoilage and shrimp surimi quality stored at 4 °C. The total viable count (TVC), microbiota composition, and quality parameters, including the total volatile basic nitrogen (TVB-N), thiobarbituric acid reactive substance (TBARs), and pH were investigated. The results showed that the spoilage bacteria in shrimp surimi rapidly increased with a surge on day 2 during refrigeration storage. The Psychrobacter and Brochothrix were identified as the Specific Spoilage Organisms (SSOs), which were also positively correlated with TVB-N and TBARs. The results further elucidated that the sono/photodynamic treatment could significantly inhibit the rapid growth of SSOs on the surface and interior of shrimp surimi and delay shrimp surimi quality deterioration. In conclusion, the sono/photodynamic treatment as a non-thermal sterilization method could be a reliable and potential method for inactivating spoilage microorganisms and preserving shrimp surimi quality.

1. Introduction

In recent years, shrimp surimi has extensively attracted the attention of consumers as a value-added food due to its delicious taste, rich flavor, high-protein, and low-fat content. The shrimp surimi consists of shrimp with egg white, starch, and other ingredients, repeatedly grounded to form the creamy appearance and excellent gelling properties [1]. However, shrimp surimi is vulnerable to microbial contamination and thus becomes spoilage-prone [2]. So far, frozen storage is the most widely adopted preservation method that enables the long-term storage of shrimp surimi. However, this method significantly deteriorates shrimp quality and taste [1]. Similarly, refrigerated storage between 0 and 4 °C has been widely adopted for short-term shrimp surimi storage, which maintains its flavor, color, texture, and nutrients [3], thus making the refrigerated shrimp surimi increasingly popular. For instance, most hot-pot restaurants prefer refrigerated shrimp surimi due to its better taste and popularity among consumers. However, the very short shelf life of refrigerated shrimp surimi increases tremendous challenges for inventory management, and sometimes results great waste. Besides, this increases the outbreak risk of safety issues. Thus, developing safe and effective approaches for the preservation of refrigerated shrimp surimi is highly necessitated.

Sono/photodynamic treatment (SPDT) is a novel non-thermal sterilization method based on photodynamic treatment (PDT) and sonodynamic therapy (SDT). PDT takes advantages of the bactericidal activity of reactive oxygen species (ROS) generated by light irradiating photosensitizers (PSs). However, the depth of visible light penetration to activate PS is limited, restricting the sterilization of surimi due to the rapid growth of spoilage bacteria in the interior of surimi. SDT shares a similar bactericidal mechanism but replacing light with a low-frequency ultrasonic wave to activate the sensitizers [4]. Particularly, certain sensitizers could be activated simultaneously by light and ultrasound to produce ROS. Therefore, the sono/photodynamic treatment (SPDT) might combine the advantages of both PDT and SDT as a novel sterilization method. For instance, N. Grevika [5] compared the killing efficacy of PDT, SDT, and SPDT against Staphylococcus aureus biofilm and

⁎ Corresponding authors at: College of Food Science, Fujian Agriculture and Forestry University, Fuzhou 350002, China.
E-mail addresses: jiamiao.hu@fafu.edu.cn (J. Hu), shaoling.lin@fafu.edu.cn (S. Lin).

https://doi.org/10.1016/j.ultsonch.2021.105715
Received 26 June 2021; Received in revised form 2 August 2021; Accepted 6 August 2021
Available online 10 August 2021
1350-4177/© 2021 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
found the highest microbicidal efficacy by SPDT. Similarly, M. Pourhajibagher [6] found that the cell viability, metabolic activity, and biofilm growth in *Aggregatibacter actinomycetemcomitans* could be effectively reduced by SPDT using curcumin-decorated nanophytosomes.

Curcumin, as a food additive approved by the European Food Safety Authority, is a yellow pigment isolated from *Curcuma longa* [7–10]. At present, several studies have reported that curcumin, activated by ultrasonic sound and blue LED light, showed desirable bactericidal activity against a range of bacteria, such as *Staphylococcus aureus* [11,12], *Pseudomonas aeruginosa* [13], and *Escherichia coli* [14,15]. Therefore, the antibacterial properties and the changes in shrimp surimi quality during the curcumin-based sono/photodynamic sterilization at 4 °C storage were evaluated in this study based on the adequate penetration activity of ultrasound.

2. Materials and methods

2.1. Photo/sonosensitizer, light and ultrasonic sound source

Curcumin (IUPAC name: (1E,6E)-1,7-Bis(4-hydroxy-3-methoxyphenyl) hepta-1,6-diene-3,5-dione) was purchased from Sigma-Aldrich (St. Louis, MO, USA). A stock solution of curcumin (25 mM) was prepared in ethanol and then diluted in sterile water to obtain the concentrations to be tested. A light-emitting diode (LED) (M425L, Zolix Instruments Co., Ltd, Beijing, China) with peak emission wavelength of

![Fig. 1. The process of sono/photodynamic treatment for shrimp surimi.](image-url)
425 nm was used as the light source. Ultrasonic generator XH300B (Beijing Xianghao Tech CO., LTD, Beijing, China) was used to generate ultrasound at 24 KHz.

2.2. Sample treatment

Shrimp surimi was provided by Haixin Foods Co., Ltd, which was composed of shrimp (>90% w/w), starch and egg white. The procedure of sono/photodynamic treatment of shrimp surimi samples was illustrated in Fig. 1. Briefly, the shrimp surimi samples were mixed with curcumin and then processed with ultrasound and blue lights. For each batch, 25 g shrimp surimi was treated in water (volume 6 × 7.5² × π cm³) in a crystallizing dish, and the distance between the ultrasonic probe and the shrimp surimi was 2 cm. Then the shrimp surimi samples were packed in airtight PE bag (7 × 15 cm, 0.12 mm; JGQUA, Zhejiang, China) and stored at 4°C for subsequent quality and bacterial analyses.

2.3. Orthogonal test

Table 1

| Levels | Factors |
|--------|---------|
|        | A Curcumin concentration (nmol/g) | B Ultrasonic power /W | C Sono/photodynamic treatment time/min |
| 1      | 200     | 300       | 15     |
| 2      | 400     | 600       | 30     |
| 3      | 600     | 900       | 45     |

An orthogonal L9(3³) test design was used for the optimization of sono/photodynamic treatment (Table 1). Total viable counts (TVC) of surimi samples upon SPDT treatment at different parameters (curcumin concentration at 200, 400 or 600 nmol/g, ultrasonic power at 300, 600 or 900 W, and sono/photodynamic treatment for 15, 30 or 45 min) were determined.

2.4. Determination of TVC

TVC was determined according to the method of Li [16]. Briefly, 10 g of shrimp surimi were homogenized by a food processor (JYL-C012, Joyoung Co., Ltd. China) in 90 mL stroke-physiological saline solution. This initial sample suspension (1/10) and its subsequent dilutions were prepared in accordance with the procedures described previously, and inoculated on aerobic plate count agar (PCA) (CM0325, Oxoid, Hampshire, UK). After incubation at 30 °C for 72 h, the number of colony-forming units (CFU) was counted. Each assay was performed in triplicates.

2.5. 16S microbiome analysis

Samples for microbiota analysis were collected from shrimp surimi samples on days 0 (immediately after treatment), 1, 3 and 6 during the refrigerated storage. For microbial DNA extraction, E.Z.N.A.® bacteria DNA Kit (Omega Bio-tek, Norcross, GA, U.S.) was used according to the manufacturer protocol. Then, the V3-V4 hypervariable regions of the bacteria 16S rRNA gene were amplified with primers 338F (5′-ACTCTACGGGAGGCAGCAG-3′) and 806R (5′-GGAC-TACHVGGGTWTCTAAT-3′) by thermocycler PCR system (GeneAmp 9700, ABI, USA). The PCR products was extracted from a 2% agarose gel with bright strip between 400 and 450 bp were chose for further analyses. The amplicon library was prepared with a Sample Preparation Kit (Illumina, USA) and sequenced on an Illumina Miseq platform according to standard protocols. Sequences with 97% similarity were defined as operational taxonomic unit (OTU) and the representative sequence reads of various OTUs were hierarchically classified into different taxa. Beta diversity was calculated to evaluate species richness and genetic diversity of the microbial community according to Y. Zhang [17].

2.6. Determination of TVB-N, TBARs, and pH

TVB-N value was determined according to the method by Jia [18] with minor modification. Briefly, 4 g of shrimp surimi was dispersed in 40 mL distilled water and homogenized by a food processor for 3 min. And then the TVB-N was determined by Kjeldahl Apparatus (KDY9820, Beijing, China). TBARs was determined as described by Deyang Li [19] with minor modification. Briefly, TBARs was calculated by multiplying the absorbance with a coefficient of 7.8 and expressed as mg malondialdehyde (MDA) eq/kg sample. Meanwhile, the pH of the supernatant was measured using a digital pH meter (Mettler Toledo FE20/EL20, Shanghai, China).

2.7. Electronic tongue evaluation

Differences in taste of the shrimp surimi were measured by electronic tongue evaluation system according to the method of Pattarapon [20]. The shrimp surimi was diluted and stirred with purified water at the ratio of 1:5, and then centrifuged. The supernatant was taken for testing with the taste analysis system TS-5000Z (INSENT, Japan). Reference solution (simulated saliva) was selected as 30 mM KCl + 0.3 mM tartaric acid. The tasteless points for the taste components were observed to be −13 for sourness, −6 for saltiness, and 0 for others [21].

2.8. Statistical analysis

The differences in TVC, TVB-N, TBARs, and pH among samples were assessed using one-way ANOVA analysis of variance in SPSS 20. Differences were considered significant if P < 0.05. Data graphs were drawn using GraphPad Prism 8.0 software. Microbiota analysis was performed using Majorbio Cloud Platform (www.majorbio.com). The correlation among physicochemical indicators and microbial populations were conducted by Pearson correlation analysis using R software version 3.5.1. and RStudio (R Package, USA), and the significance was verified via Student’s t-test.

3. Results

3.1. The effects of sono/photodynamic treatment on TVC of shrimp surimi

As depicted in Fig. 2, the TVC of shrimp surimi showed a continuous increase with a surge on day 2 during storage at 4 °C. This result revealed that the refrigerated shrimp surimi could only last 2-3 days. A previous study suggested that the edibility and market value of shrimp products are severely jeopardized when their TVC reaches 10⁶ CFU/g [22]. The results further demonstrated both PDT and SPDT treatment could significantly decline the increase in TVC, with SPDT showing better bactericidal effects. The TVC of SPDT treated samples were kept below 10⁶ CFU/g till day 4.

The single-factor analyses suggested that the desirable bactericidal effects (>1.3 lg (CFU/mL) decrease) could be achieved when curcumin concentration was above 400 nmol/g, the ultrasonic power > 600 W, and the sono/photodynamic treatment time was longer than 30 min.

Based on the single-factor analyses, curcumin concentration, ultrasonic power, and treatment time were further optimized using an orthogonal L9 (3³) test design. As summarized in Table 2, the results indicated that the minimum TVC (5.89 lg CFU/g) of shrimp surimi was obtained when the curcumin concentration, ultrasonic power, and sono/photodynamic treatment time were 400 nmol/g, 300 W, 30 min (A₂B₃C₂), respectively. It is noteworthy that curcumin concentration plays an essential factor in determining TVC. Thus, this optimized
The effects of sono/photodynamic treatment on microbial community during storage

High-throughput sequencing analysis based on the Illumina HiSeq2500 platform was performed to assess diversity in microbial communities of shrimp surimi during cold storage and identify the specific spoilage organisms (SSOs) responsible for spoilage of refrigerated shrimp surimi. A total of 1,760,599 sequences (after quality trimming) from the 32 shrimp surimi samples were yielded (raw data can be accessed from NCBI’s Sequence Read Archive with SRP324256). The coverage rates of all groups were more than 99%, indicating the reliability of the sequencing data for further study.

β-Diversity visualized by the principal component analysis (PCA) also supported that SPDT could decline the changes in microbial community during storage (Fig. 3). The maximum variations in the microbiota of different shrimp surimi samples were 62.6% (PC1) and 29.66% (PC2), suggesting a strong separation by region. As shown in Fig. 4d, the untreated control samples showed significant differences at different time points, while the samples on day 0 and day 1 (SPDT 0 and SPDT 1) were similar in the treatment group. Moreover, the PCA results showed similar microbiota composition in control 1, and SPDT 3 samples, which was consistent with the heat-map generated clustering results.

Table 2
Orthogonal test results.

| No. | A curcumin concentration | B ultrasonic power | C sono/photodynamic treatment | TVC  |
|-----|--------------------------|--------------------|-------------------------------|------|
| 1   | 200                      | 600                | 45                            | 6.13 |
| 2   | 200                      | 900                | 30                            | 6.27 |
| 3   | 200                      | 300                | 15                            | 6.66 |
| 4   | 400                      | 900                | 45                            | 6.03 |
| 5   | 400                      | 600                | 15                            | 6.37 |
| 6   | 400                      | 300                | 30                            | 6.20 |
| 7   | 600                      | 900                | 15                            | 6.27 |
| 8   | 600                      | 300                | 45                            | 6.05 |
| 9   | 600                      | 600                | 30                            | 5.89 |
| K1  | 19.06                    | 18.44              | 18.39                         |      |
| K2  | 18.61                    | 18.69              | 18.20                         |      |
| K3  | 24.49                    | 18.75              | 19.30                         |      |
| R   | 5.88                     | 0.32               | 1.10                          |      |
| The optimal level | A2 | B1 | C2 |      |
| Primary and secondary factors | A > C > B | | | |
| Optimal combination | A2B1C2 | | | |

3.2. The effects of sono/photodynamic treatment on microbial community during storage
3.3 Changes of quality in shrimp surimi treated with/without SPDT

TVB-N is one of the most important indicators to assess food deterioration. Hence, TVB-N was measured to further evaluate the preservative effects of sono/photodynamic treatment on shrimp surimi. As shown in Fig. 6a, the sono/photodynamic treatment could effectively inhibit the increase in TVB-N. The TVB-N values of all samples at day 0 were below 6 mg/100 g. In the control samples, TVB-N increased continually to over 12.1 mg/100 g after 6 days of refrigerated storage, while the samples with sono/photodynamic treatment showed significantly lower TVB-N values (7.28 mg/100 g). Similarly, TBARs also showed a time-dependent increase during the 6 days of storage (Fig. 6b), while sono/photodynamic treatment significantly inhibited this upward trend. Fig. 6c depicts the changes in pH of the shrimp surimi stored at 4°C. In the control group, the pH decreased from 8.34 to 7.65. The sono/photodynamic treatment prevented the shrimp surimi from being sour. On the 4th day of storage, the pH of the treatment group was significantly higher than in the control group (P < 0.05) and remained 7.88 for the next two days of storage.

Further, the electronic tongue system was employed to evaluate surimi taste by measuring eight basic senses of taste: sourness, bitterness, astringency, aftertaste-B, aftertaste-A, umami, richness, and saltiness, as presented in Table 3. The electronic tongue showed that the SPDT treated samples stored for 6 days had higher scores in umami, richness, and saltiness, as well as lower sourness and astringency after 6 days. Additionally, the aftertaste-B showed no significant difference in all the samples. This observation suggested that sono/photodynamic treatment could retain the umami and saltiness in the surimi samples but develop some bitterness and aftertaste A. On the contrary, this treatment also decreased sourness and astringency.

3.4 Pearson correlation analysis among TVB-N, TBRAS, taste, and microbial

As depicted in Fig. 7, the Pearson correlation analysis was employed to analyze the correlation of TBRAS, TVB-N values with the top 10 abundant microbial composition at the genus level as inputs. Notably, TVB-N and TBARs as deteriorative indicators showed a significant positive correlation. Moreover, Psychrobacter and Brochothrix showed a...
significantly positive correlation with TVB-N and TBARs, and a significantly negative correlation with Micrococcus, Streptococcus, Enterococcus, Lactococcus, and Corynebacterium. Additionally, the results revealed a correlation between bacteria. For instance, Psychrobacter and Brochothrix might promote each other’s growth (positive correlation), while Psychrobacter and Enterococcus might share a competitive relationship (negative correlation).

Similarly, the Pearson correlation analysis was used to analyze the correlation of electronic tongue taste attributes and microbial composition (Fig. 8). Bitterness was found to have a significantly positive correlation with Macrococcus, Streptococcus, and Enterococcus, and a significantly negative correlation with Psychrobacter, Brochothrix, and Carnobacterium. Astringency was showed a significantly positive correlation with Vagococcus, Macrococcus, and Carnobacterium, and have a significantly negative correlation with Psychrobacter and Brochothrix. Afertaste-A showed a significantly positive correlation with Vagococcus while a significantly negative correlation with Streptococcus, Enteroococcus, Lactococcus, and Corynebacterium. Umami showed a significantly positive correlation with Micrococcus, Streptococcus, Enterococcus, Lactococcus, and Corynebacterium, and a significantly negative correlation with Psychrobacter and Brochothrix. Richness showed a significantly positive correlation with Micrococcus, Corynebacterium, and Brochothrix, and a significantly negative correlation with Vagococcus, Macrococcus, and Enterococcus. Saltness showed a significantly positive correlation with Macrococcus, Enterococcus, and Lactococcus and a significantly negative correlation with Psychrobacter, Corynebacterium, and Brochothrix.

4. Discussion

Sono/photodynamic, a non-thermal sterilization method, utilizes the activated sono/photosensitizer to inactivate foodborne bacterial pathogens [23]. Herein, the preservative effects of curcumin-mediated sono/photodynamic treatment on the quality and microbiota composition of shrimp surimi during refrigerated storage were assessed. The obtained results demonstrated that fresh shrimp surimi rapidly deteriorated during cold storage. The spoilage by rapid microbial growth occurred after 2–3 days of storage at 4 °C, limiting the shelf life of shrimp surimi. This finding was consistent with the previous study results reported by M. Wang et al., demonstrating that the shelf of Hypophthalmichthys molitrix surimi was less than 2 days during cold storage and the TVC increased significantly within 24 h of refrigeration [1].

Additionally, the present study results elucidated that curcumin-mediated sono/photodynamic treatment inhibited the growth of spoilage bacteria and declined the deterioration of shrimp surimi. According to the CFU measurements, the sono/photodynamic treatment might double the shelf life of shrimp surimi at optimum treatment conditions (curcumin at 400 nmol/g, ultrasonic power at 300 W, and treatment for 30 min). Indeed, Bhavya [24] showed that curcumin can be used as the sonosensitizer to sterilize orange juice infected with Escherichia coli and Staphylococcus aureus and prolong its shelf life. Accumulating studies have also revealed that the sono/photodynamic treatment could effectively inhibit the growth of spoilage bacteria, such as Staphylococcus aureus [25] and Aggregatibacter actinomycetemcomitans [6], which was consistent with our study results. Therefore, sono/
Fig. 5. The heat-map of microbiota composition at the genus level in the control group and the sono/photodynamic treatment group during the refrigerated storage at 4 °C.

Fig. 6. The effects of sono/photodynamic treatment on the changes in TVB-N, TBARs, and pH of shrimp surimi samples during the refrigerated storage at 4 °C.
photodynamic could be a potential method to inhibit food-borne microbial growth and used for food preservation.

The changes in the microbial community of shrimp surimi during the refrigerated storage were determined to analyze the antimicrobial effects of curcumin-mediated SPDT in shrimp surimi. *Psychrobacter* and *Brochothrix* were identified as the SSO of shrimp surimi during storage, which was consistent with the previously reported results [26]. For instance, *Psychrobacter* was found to be the SSO in refrigerated fish [27–29]; while *Brochothrix*, a Gram-positive bacterium, was considered as the predominant spoilage microbe of shrimp and fish [30]. Zhang et al. [31] isolated *Psychrobacter glacincola 38–1*, *Brochothrix thermosphaeta 38–2*, and *Pseudomonas fragi 38–8* from fish balls and found that their rapid growth could inhibit the growth of other bacteria during the cold storage.

Moreover, the Pearson correlation also revealed the possible associations between microbial growth and surimi quality deterioration. Both *Psychrobacter* and *Brochothrix* were positively correlated with the increase in TVB-N and TBARs, which was also consistent with the previous reports. TVB-N is usually associated with protein macromolecules degraded by microorganisms [32]. A previous study has reported that *Psychrobacter* was one of the dominant microbiota of brown shrimp during aerobic storage and associated with volatile compounds formation [33]. In another study, *Psychrobacter* was reported as one of the dominant microorganisms in the spoiled cuttlefish stored at 2°C and associated with TVB-N accumulation [34]. Meanwhile, *Brochothrix*, as a facultative anaerobe, was also found to be associated with TVB-N accumulation in fresh chicken burgers [35].

Additionally, the electronic tongue system results also supported that the sono/photodynamic could delay the quality deterioration of shrimp surimi during cold storage. Besides, microbial growth plays a vital role in the flavor quality of foods as the changes in the food taste are deeply influenced by the changes in taste substances (including sugar, amino acids, inorganic salts and acids). Our study results also suggested that microorganisms, such as *Psychrobacter* and *Brochothrix* could attribute to the change in flavor by decomposing protein, carbohydrate, fat, and other nutrients of shrimp surimi.

### 5. Conclusion

In conclusion, the TVC of refrigerated shrimp surimi rapidly increased and approached 10⁶ CFU/g by the end of day 2, while the sono/photodynamic effectively inhibited bacterial growth in shrimp surimi. The sono/photodynamic showed some preservative effects on the quality parameters, such as TVB-N and TBARs of shrimp surimi. This
phenomenon might also be associated with the inhibition of shrimp surimi SSOs (Psychrobacter and Brochothrix) identified by sono/photo-dynamic. Overall, the sono/photodynamic treatment could be a potential non-thermal sterilization method for preserving shrimp surimi and other refrigerated surimi products.

CRediT authorship contribution statement

Dehuang Wang: Methodology, Formal analysis, Data curation, Writing - original draft. Feng Zhou: Investigation. Danning Lai: Validation. Yi Zhang: Supervision, Funding acquisition. Jiamiao Hu: Supervision, Funding acquisition, Writing - review & editing. Shaoling Lin: Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The study was financially supported by the National Natural Science Foundation of China (31801649), Natural Science Foundation of Fujian Province (2020I0010; 2020I0012; 2021N5001), Science Fund for Distinguished Young Scholars of Fujian Agriculture and Forestry University (xj201918; CXZX2018063) and Fujian Science and Technology Economic Integration Service Platform of Fujian Association for Science and Technology (2020K02).

References

[1] M. Wang, Research and the quality change of flavor fish paste in the process of storage, Huazhong Agricultural University (2017) 70.
[2] W. Guan, X. Ren, Y. Li, L. Mao, The beneficial effects of grape seed, sage and oregano extracts on the quality and volatile flavor component of hairtail fish balls during cold storage at 4 °C, LWT 101 (2019) 25–31.
[3] C. Pan, S. Chen, S. Hao, X. Yang, Effect of low-temperature preservation on quality changes in Pacific white shrimp, Litopenaeus vannamei: a review, J. Sci. Food Agric. 99 (2019) 6121–6128.
[4] X. Pang, D. Li, J. Zhu, J. Cheng, Q. Liu, Beyond antibiotics: photo/sonodynamic approaches for bacterial theranostics, Nano-Micro Lett. 12 (2020) 144.
[5] N. Drantantiyas, S. Astuti, A. Nasution, Comparison microbial killing efficacy between sonodynamic therapy and photodynamic therapy, Nanoscale (2021) 385–392.
[6] J. Wu, W. Hou, B. Cao, Z. Zuo, X. Xu, W. Leung, W. Tang, Virucidal efficacy of treatment with photodynamically activated curcumin on marine norovirus bio-accumulated in oysters, Photodiagn. Photodyn. Ther. 12 (2015) 385–392.
[7] EFSA, Refined exposure assessment for curcumin (E 100), EFSA J. 12 (2014) 3876.
[8] EFSA, Scientific Opinion on the re-evaluation of curcumin (E 100) as a food additive, EFSA J. 8 (2010) 1679.
[10] R.-H. Mu, Z.-J. Ni, Y.-Y. Zhu, K. Thakur, F. Zhang, Y.-Y. Zhang, F. Hu, J.-G. Zhang, J.-J. Wei, A recent update on the multifaceted health benefits associated with ginger and its bioactive components, Food Funct. 12 (2021) 519–542.

[11] Y. Li, Y. Xu, Q. Liao, M. Xie, H. Tao, H.-L. Wang, Synergistic effect of hypochorill B and curcumin on photodynamic inactivation of Staphylococcus aureus, Microbi. Biotechnol. 14 (2021) 692–707.

[12] X. Wang, M. Ip, A.W. Leung, C. Xu, Sonodynamic inactivation of methicillin-resistant Staphylococcus aureus in planktonic condition by curcumin under ultrasound sonication, Ultrasonics 54 (2014) 2109–2114.

[13] H. Abdulrahman, L. Misba, S. Ahmad, A.U. Khan, Curcumin induced photodynamic therapy mediated suppression of quorum sensing pathway of Pseudomonas aeruginosa: An approach to inhibit biofilm in vitro, Photodiagn. Photodyn. Ther. 30 (2020) 101645.

[14] X. Wang, M. Ip, A.W. Leung, Z. Yang, P. Wang, B. Zhang, S. Ip, C. Xu, Sonodynamic action of curcumin on foodborne bacteria Bacillus cereus and Escherichia coli, Ultrasonics 62 (2015) 75–79.

[15] R. Tao, F. Zhang, Q.-J. Tang, C.-S. Xu, Z.-J. Ni, X.-H. Meng, Effects of curcumin-based photodynamic treatment on the storage quality of fresh-cut apples, Food Chem. 274 (2019) 415–421.

[16] Y. Li, Z. Yang, J. Li, Shelf-life extension of Pacific white shrimp using algae extracts during refrigerated storage, J. Sci. Food Agric. 97 (2017) 291–298.

[17] Y. Zhang, Y. Yao, L. Gao, Z. Wang, B. Xu, Characterization of a microbial community developing during refrigerated storage of vacuum packed Yao meat, a Chinese traditional food, LWT 90 (2018) 562–569.

[18] S. Jia, Y. Liu, S. Zhuang, X. Sun, Y. Li, H. Hong, Y. Lv, Y. Luo, Effect of e-polylysine and ice storage on microbiota composition and quality of Pacific white shrimp (Litopenaeus vannamei) stored at 0 °C, Food Microbiol. 83 (2019) 27–35.

[19] D. Li, H. Xie, Z. Liu, A. Li, J. Li, B. Liu, X. Liu, D. Zhou, Shelf life prediction and changes in lipid profiles of dried shrimp (Penaeus vannamei) during accelerated storage, Food Chem. 297 (2019), 124951.

[20] P. Pattarapon, M. Zhang, B. Bhandari, Z. Gao, Effect of vacuum storage on the freshness of grass carp (Ctenopharyngodon idella) fillet based on normal and electronic sensory measurement, J. Food Process. Preserv. 42 (2018) e13418.

[21] D. Liu, S. Li, N. Wang, Y. Deng, L. Sha, S. Gai, H. Liu, X. Xu, Evolution of taste compounds of Dezhou-braised chicken during cooking evaluated by chemical analysis and an electronic tongue system.

[22] L. Chen, F. Tao, C. Pan, X. Hu, H. Ma, C. Li, Y. Zhao, Y. Wang, Modeling quality changes in Pacific white shrimp (Litopenaeus vannamei) during storage: Comparison of the Arrhenius model and Random Forest model, J. Food Process. Preserv. 45 (2021), e14999.

[23] M. Pourhajibagher, A.R. RoKh, H.R. Barikani, A. Bahador, Photo-sonodynamic antimicrobial chemotherapy via chitosan nanoparticles-indocyanine green against polymicrobial periopathogenic biofilms: Ex vivo study on dental implants, Photodiagn. Photodyn. Ther. 31 (2020) 101834.

[24] M.I. Bhavya, H.U. Hebbar, Sono-photodynamic inactivation of Escherichia coli and Staphylococcus aureus in orange juice, Ultrason. Sonochem. 57 (2019) 108–115.

[25] D. Nike Dwi Grevikka, A. Suryani Dyah, M.T.N. Aulia, Comparison microbial killing efficacy between sonodynamic therapy and photodynamic therapy, Proc. SPIE (2016).

[26] T. Moretto, S. Langsrud, Residential bacteria on surfaces in the food industry and their implications for food safety and quality, Compr. Rev. Food Sci. Food Saf. 16 (2017) 1022–1041.

[27] X. Jiang, L. Meng, J. Feng, Z. Dai, Analysis of quality change and microbial assessment of chub mackerel in storage, Journal of Chinese Institute of Food Science and Technology 19 (2019) 197–205.

[28] X.D. Sun, R.A. Holley, Antimicrobial and antioxidative strategies to reduce pathogens and extend the shelf life of fresh red meats, Compr. Rev. Food Sci. Food Saf. 11 (2012) 340–354.

[29] C. González, J. Santos, M.-L. García-López, A. Otero, Psychrobuteros and related bacteria in freshwater fish, J. Food Protect. 63 (2000) 315–321.

[30] K. Mamlok, S. Macé, M. Guillaud, E. Jaffrès, M. Ferchichi, H. Prevost, M.-F. Pilet, X. Dossut, Quantification of viable Brochothrix thermosphacta in cooked shrimp and salmon by real-time PCR, Food Microbiol. 30 (2012) 173–179.

[31] Y. Zhang, J. Wei, Y. Yuan, H. Chen, L. Dai, X. Wang, T. Yue, Bactericidal effect of cold plasma on microbiota of commercial fish balls, Innov. Food Sci. Emerg. Technol. 52 (2019) 394–405.

[32] H. Hong, Y. Luo, Z. Zhou, H. Shen, Effects of low concentration of salt and sucrose on the quality of bighead carp ( Aristichthys nobilis ) fillets stored at 4 °C, Food Chem. 133 (2012) 102–107.

[33] K. Broekaert, B. Noseda, M. Heyndrickx, G. Vlaemynck, F. Devlieghere, Volatile compounds associated with Psychrobuteros spp. and Pseudolaterosporos spp., the dominant microbiota of brown shrimp (Crangon crangon) during aerobic storage, Int. J. Food Microbiol. 166 (2013) 487–493.

[34] F.F. Parlapani, S. Michailidou, D.A. Anagnostopoulou, A.K. Sakellariou, K. Panstina, F. Psomopoulos, A. Argiriou, S.A. Haroutounian, I.S. Bouzianis, Microbial spoilage investigation of thawed common cuttlefish ( Sepia officinalis ) stored at 2 °C using next generation sequencing and volatilome analysis, Food Microbiol. 76 (2018) 107–115.

[35] E. Assanti, V.K. Karabagias, I.K. Karabagias, A. Badeka, M.G. Kontominas, Shelf life evaluation of fresh chicken burgers based on the combination of chitosan dip and vacuum packaging under refrigerated storage, J. Food Sci. Technol. -Mysore- 58 (3) (2021) 870–883.