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Microbiological Analysis of Manufacturing Processes and Microbial Hazard Assessment of Quality and Safety of Commercial Salted Shrimp (*Saeu-jeot*)

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Abstract: The objective of this study was to evaluate the microbiological properties of commercially available traditional Korean salted shrimp *(Saeu-jeot*) and to analyze the effects of saltwater immersion and ultraviolet (UV) irradiation on the reduction of *Staphylococcus aureus* in *Saeu-jeot*. A microbiological analysis was conducted across 56 commercially available *Saeu-jeot* samples from the Korean, Chinese, and Vietnamese markets. The microbiological analysis revealed no presence of *Escherichia coli*, coliforms, or *Vibrio parahaemolyticus* in any commercial samples. The total viable count and *S. aureus* were 3.8 ± 0.4 and 0.6 ± 0.3 log CFU/g, respectively. An investigation of the procedures conducted on *Saeu-jeot* samples at various production stages by Hazard Analysis Critical Control Point (HACCP)-certified companies demonstrated the substantial relevance of the raw material (tiny shrimp) on *S. aureus* counts. In order to reduce *S. aureus* in *Saeu-jeot*, saltwater immersion and UV irradiation treatments were applied, which reduced the *S. aureus* counts by 1.4 log CFU/g and 0.3 log CFU/g, respectively, and *S. aureus*'s efficacy was limited to the food's surface. These results suggest that a co-treatment of saltwater immersion and UV irradiation could be effective in reducing *S. aureus*. The maintenance of hygienic handling and cleanliness are essential in the modern manufacturing processes of *Saeu-jeot*.

Keywords: *Saeu-jeot*; salted shrimp; manufacturing process; microbial hazard analysis; quality control

Key Contribution: As the heat sterilization of commercial *Saeu-jeot* is not possible, hygiene control during the manufacturing process is required to prevent the growth of pathogenic microorganisms. Non-heat-treatment methods, such as salting or UV treatment, are effective and should be applied to ensure microbiological safety.

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1. Introduction

Fermented fishery products are consumed all over the world, with the most popular forms including fish sauce and fish paste. A traditional Korean fermented fishery product is jeotgal, or jeot [1]. Jeotgal is a salted and fermented food in Korean cuisine with rich sensory attributes that can be consumed alone or utilized as an additive to enhance the sensory characteristics of kimchi. It is made by adding 20–30% (*w*/*w*) solar salt to various types of seafood, such as fish, shrimps, oysters, shellfish, fish eggs, and fish guts, and is made palatable by its subsequent preservation and fermentation [2]. Jeotgal is made using tiny shrimp (*Acetes japonicus*), usually caught during the spring to autumn seasons, that are called *Saeu-jeot*.

The tiny shrimp undergo rapid deterioration, becoming off-flavored, discolored, and experiencing microbial changes immediately after the catch. Therefore, in the earlier general manufacturing process of *Saeu-jeot*, the tiny shrimp are immediately pickled with solar salt to prevent their quality deterioration and spoilage [3]. The salted shrimp are then transferred to a large bulk container and allowed to ferment at ambient temperature over a period of time for the development of unique flavors and enhanced storability. A rise in food safety awareness has led to the development of an improved production method for *Saeu-jeot* via the establishment of sanitary processing plants. However, it has been reported that *Saeu-jeot* is exposed to various microorganisms due to the difficulty in hygienically handling it with the increase in its aging and fermentation periods [4].

The internationally recognized CODEX standard regulates fish sauce (CODEX STAN 302—2011) [5] but not *Saeu-jeot*. This standard primarily addresses the chemical specifications of fish sauce. In China's national standard for food safety, seafood seasonings (GB 10133-2014) [6], such as shrimp paste and shrimp sauce, which resemble *Saeu-jeot*, are included. The product standard for seafood seasoning focuses on microbiological safety, requiring an assessment of its total viable count, coliforms, and pathogens, such as *Salmonella*, *Vibrio parahaemolyticus*, and *Listeria monocytogenes*. The Ministry of Food and Drug Safety of Korea regulates the microorganism standards for salted fish, including *Saeu-jeot*, using the reference standard for *Escherichia coli* (n = 5, c = 1, m = 0, M = 10) [7]. In addition, it is recommended that a Hazard Analysis Critical Control Point (HACCP) system be applied to the manufacturing process for the safety management of seafood manufactured in Korea. However, out of approximately 500 companies manufacturing salted fish, only 32 (0.15%) were HACCP-certified as of 2023.

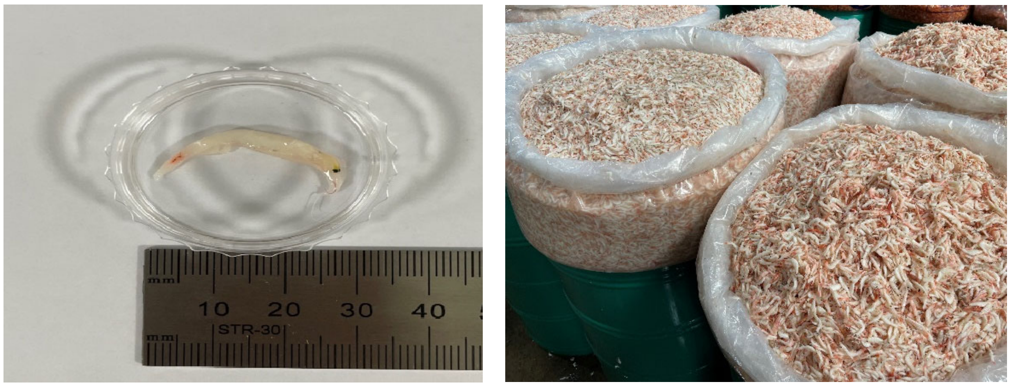
Recently, various studies have been conducted to improve the process of fishery food production. To minimize the quality deterioration of fishery foods, non-heat-treatment methods such as ultrasonic treatments, ultra-high-pressure treatments, and gamma irradiation have been considered [8]. Several studies have since evaluated the effects of using these treatment methods in the manufacturing process on the microbial safety of *Saeu-jeot*. A previous study confirmed that there was no significant difference in the microbial changes in raw shrimp when treated with sonication [9]. According to another study, a high hydrostatic pressure treatment at 6500 atm for 10 min effectively inhibited *Vibrio* and *Staphylococcus* spp. in *Saeu-jeot* [10]. Although gamma irradiation is effective in controlling microbial contamination, maintaining storage stability, and preserving the sensory quality of *Saeu-jeot*, it is challenging to employ in the manufacturing process due to negative consumer perceptions [11,12]. The application of ultraviolet (UV) treatment in *Saeu-jeot* has been rare. UV wavelengths are electromagnetic waves in the range of 100–400 nm and are classified into UV-A (315–400 nm), UV-B (280–315 nm), and UV-C (100–280 nm). UV-C, a non-heat sterilization treatment method, is used to inhibit the microbial contamination of food surfaces. A UV-C treatment at the 253.7 nm wavelength causes DNA modification and damage to microorganisms, and their survival rate decreases rapidly with increasing irradiation doses [13,14]. In addition, the commercial availability of deep UV (UV-C) has allowed for its widespread application in the food industry [15]. However, the microbial inactivation properties of such treatments and their overall efficacy are highly dependent on the surface's quality, which determines their penetration ability [16].

Therefore, the aim of this study was to analyze the overall microbial contamination of commercially available *Saeu-jeot* samples, including their levels of spoilage (total viable count), contamination (*E. coli* and coliforms), and safety (pathogenic microorganisms). Furthermore, microbial contamination assessments were conducted throughout the *Saeu-jeot* processing to trace its microbial contamination. Additionally, we aimed to evaluate the effectiveness of the HACCP system in enhancing microbial safety and to validate its inhibitory effects on pathogenic microorganisms through salting or UV irradiation.

2. Materials and Methods

2.1. Experimental Materials

A total of 56 commercially available *Saeu-jeot* preparations (49 from markets in Korea, 5 from China, and 2 from Vietnam) with a shelf life of more than one year were collected. Of these 56 samples, 16 had domestic HACCP certification. All samples used in this study were prepared by mixing 70–80% tiny shrimp (about 30 mm long; Figure 1a) with 20–30% salt. The samples (Figure 1b) were stored in a refrigerator at 4 °C while maintaining the manufacturer's packaging, and analysis was performed within 15 days of the date of purchase.



(**a**) (**b**)

Figure 1. Raw material for the production of tiny shrimp (**a**) and *Saeu-jeot* (**b**).

2.2. Investigation of the Microbial Contamination in Commercial Saeu-jeot

The total viable count, *E. coli*, coliforms, and food poisoning bacteria (*Staphylococcus aureus* and *Vibrio parahaemolyticus*) in *Saeu-jeot* were analyzed according to the quantitative microbial test method (detection limit 1.0 log colony-forming units [CFU]/g or less) presented in the Food Code (Jeotgal) [7]. For all microbiological analyses, a 10 g sample was homogenized in 90 mL of 0.1% buffered peptone water for 60 s. The homogenate was serially decimally diluted, and the upper layer of the diluted suspension (1 mL) was collected. The total viable count, *E. coli*, and coliforms were analyzed using a dry film (Petrifilm AC/EC/CC, 3M, Paul, MN, USA) and then incubated at 37 °C for 24 h. *S. aureus* was cultured at 37 °C for 48 h after the test solution was spread on Baird–Parker agar medium (Difco BD Biosciences, Franklin Lakes, NJ, USA). Black colonies surrounded by transparent bands were counted, inoculated on tryptic soy agar (Difco BD Biosciences), incubated at 37 °C for 24 h, and confirmed positive by conducting a coagulase test. Subsequently, biochemical experiments (Vitek 2, Biomerieux, Hazelwood, MO, USA) identified the bacterial species. *V. parahaemolyticus* was inoculated into thiosulfate citrate bile salt sucrose medium purchased from Difco BD and cultured at 35 °C for 24 h. The CFU per gram of sample was determined by counting the number of colonies formed. Each sample was tested in triplicate, and the experiments were repeated three times for each sample to obtain a mean value.

2.3. Investigation of the of Saeu-jeot Manufacturing Process of Contamination via the Sanitary Indicator Bacteria of Each Process

The manufacturing process of *Saeu-jeot* was investigated in Hongseong and Ganggyeong (Chungcheongnam-do province) and Buan (Jeollabuk-do province), the main production areas of *Saeu-jeot* in Korea. In particular, HACCP-certified companies following the general manufacturing process—fermentation by mixing tiny shrimp purchased from Shinan and Mokpo (Jeollanam-do province) with salt—were intensively investigated.

To evaluate the degree of contamination of the raw and subsidiary materials, the shrimp, salt, and empty bottles (packaging materials) used in the process were collected. A solid surface inspection was conducted to confirm the degree of contamination at each step of the manufacturing process. A 100 cm^2 area of the sorting basket, work table, work tool, and operator's hands (wearing gloves) was rubbed and swabbed using a cotton swab (3M Pipette Swab; 3M, Paul, MN, USA). The collected samples were observed for their total viable count, *E. coli*, coliforms, *S. aureus*, and *V. parahaemolyticus*.

2.4. UV-C Irradiation Treatment after Inoculating the S. aureus Strain into Saeu-jeot

Frozen stock cultures of *S. aureus* strains (strains ATCC 19095, ATCC 23235, FRI913, and ATCC 14458) were activated in 10 mL of tryptic soy broth (Difco, Becton Dickinson and Company, Sparks, MD, USA) at 37 °C for 24 h. The *S. aureus* cell suspensions were collected by centrifugation (2000× *g*, 15 min), the supernatant was decanted, and the cell pellets were suspended in sterile distilled water. As bacterial growths have obvious strain variations, a mixture of four *S. aureus* strains was used as an inoculum, and cocktails of *S. aureus* strains were serially diluted to 7 log CFU/mL. *S. aureus* was inoculated into 1 kg of commercially purchased *Saeu-jeot*, not including its solution, so that the initial number of bacteria was approximately 3–4 log CFU/g. Subsequently, the mixture was filled with brine, which is used to make *Saeu-jeot*, and mixed. Taking into consideration its distribution environment, the *Saeu-jeot* was stored for a day at 20 °C. The abundance of *S. aureus* in the sample was observed by dividing the sample into its upper layer (not immersed in saltwater) and lower layer (immersed in saltwater). For utilization in the food industry, the surface of the *Saeu-jeot* was sterilized by UV-C irradiation as it passed along a conveyor belt. Upon transferring the upper layer of the *Saeu-jeot* (not immersed in saltwater) to a Petri dish (3M), at a thickness of 0.5 cm, it was irradiated with UV-C (253.7 nm) at intervals of 10, 30, 60, 120, 300, and 600 s. After the UV irradiation treatment, the proliferation of *S. aureus* was evaluated. The test solution was smeared on Baird–Parker agar medium, the *S. aureus* was cultured at 37 °C for 48 h, and colonies were counted.

2.5. Statistical Analysis

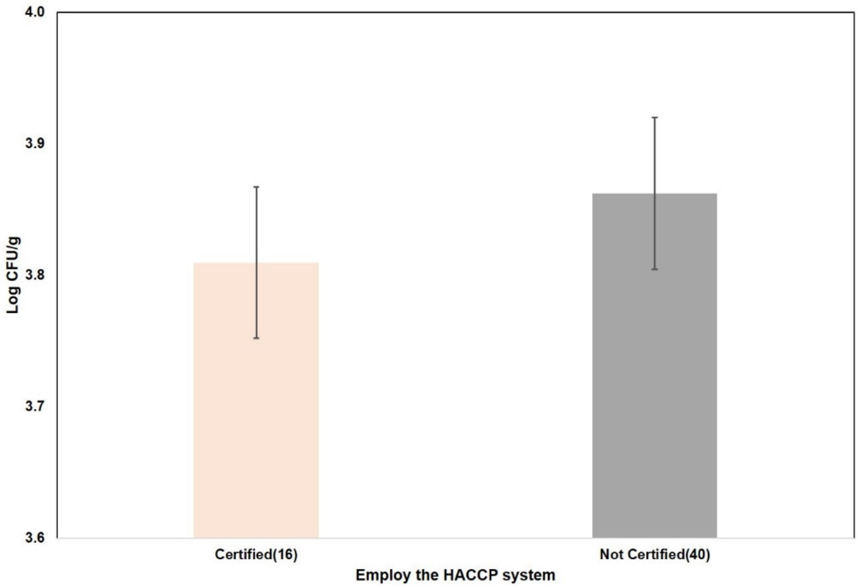
All experiments were performed in triplicate, and the data are expressed as mean ± standard deviation. Statistical analysis was performed using IBM SPSS Statistics (version 20, IBM, Chicago, IL, USA). The significance of the difference between the samples' means was verified using an ANOVA test and Duncan's multiple range test. A p-value < 0.05 (95% confidence interval) was considered statistically significant.

Distribution fitting was performed using the @RISK add-in tool in Microsoft Excel to estimate the possibility of nonconformity due to a contamination of indicator bacteria in the commercially available *Saeu-jeot*, following the application of food-poisoning bacteria reference standards. The fit test for the distribution was analyzed and predicted using the Anderson–Darling test.

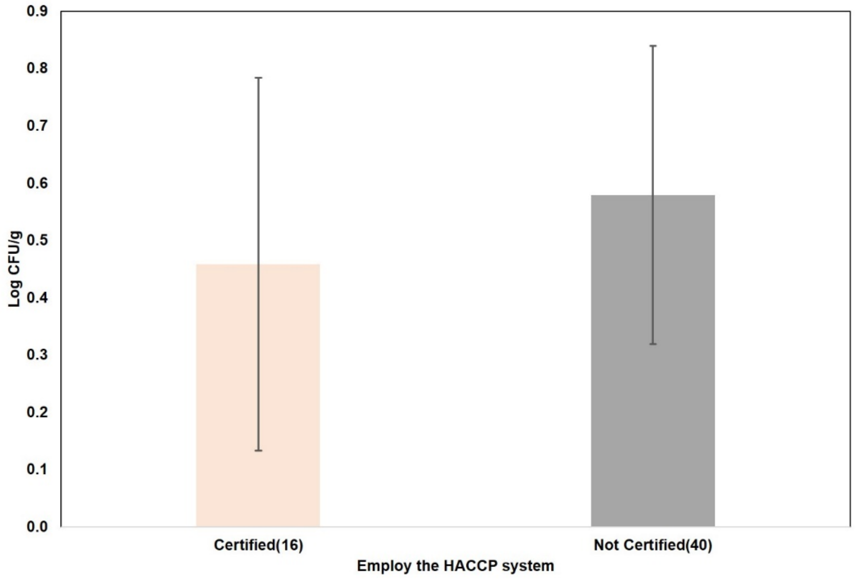
3. Results and Discussion

3.1. Microbial Contamination Analysis of Commercial Saeu-jeot

Figure 2 shows the level of microbial contamination in commercial *Saeu-jeot*. The quantitative test revealed contamination, with a total viable count in all 56 commercial *Saeu-jeot* samples in this study. The average number of the total viable counts in the 56 samples was 3.8 ± 0.4 log CFU/g. The average total viable count contamination in samples manufactured with and without HACCP certification was 3.8 ± 0.1 and 3.9 ± 0.1 log CFU/g, respectively. The maximum of the total viable count was determined as 4.4 ± 0.1 and 4.9 ± 0.0 log CFU/g, respectively. According to a previous study, the total viable counts in *Saeu-jeot* were up to 5.7 log CFU/g [17]. In contrast to the results of a previous study reported in 2004 [18], *E. coli* and coliforms were not detected in any of our samples (detection limit ≤ 1.0 log CFU/g). This difference could be because of the increasing importance of hygiene in recent times, and the fact that most *Saeu-jeot* is produced in established sanitary management systems.



(**a**)

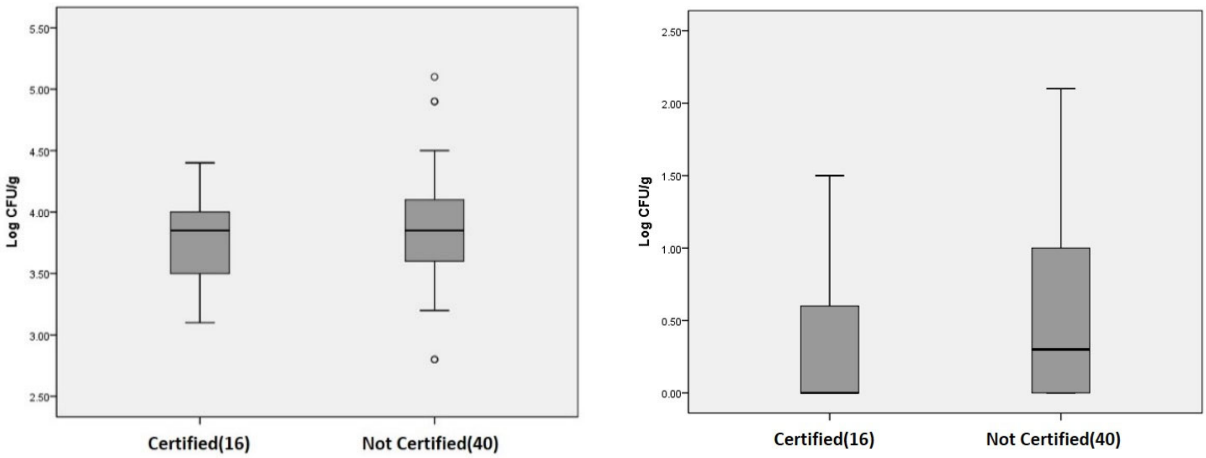


(**b**)

Figure 2. The result of microbial contamination in manufacturer's employing the HACCP system and not employing the HACCP system. (**a**) Total viable count; (**b**) *S. aureus* count. Certified: manufacturer employed the Hazard Analysis Critical Control Point (HACCP) system; Not Certified: manufacturer did not employ the HACCP system.

In commercially available *Saeu-jeot*, *S. aureus* was detected in approximately 70% (38/56) of samples but *V. parahaemolyticus* was not detected in any (detection limit 1.0 log CFU/g or less). The amount of *S. aureus* detected in the samples (detection limit 1.0 log CFU/g or less) varied up to a maximum of 2.5 $\pm$ 0.2 log CFU/g, with an average of 0.6 $\pm$ 0.3 log CFU/g. In the case of the *S. aureus* results, all the average data from the experimental results from all samples include negative samples. Excluding data below the detection limit from the entire sample may result in us obtaining different information from reality. Therefore, we assumed that any data below the detection limit were zero to quantify the entire sample. The maximum amount of *S. aureus* detected in the samples (2.5 $\pm$ 0.2 log CFU/g) was lower than the amount of bacteria required to induce toxicity in foods (5.0 log CFU/g) [19]. Therefore, it could be inferred that the risk of food poisoning due to the direct consumption of *Saeu-jeot* is low.

Figure 3 shows the microbiological data of the 56 samples, represented using box plots. Box plots are commonly used visualization tools that simultaneously display the distribution of the data and outliers, facilitating an easy comparison between different data groups. This figure was used to compare the facilities applying the HACCP system to those that do not.



(**a**) (**b**)

Figure 3. The box plot of the total viable count in salted-fermented shrimp, including microbial contaminants and pathogenic bacteria. (**a**) Total viable counts; (**b**) *S. aureus* counts. Certified: manufacturer employed the Hazard Analysis Critical Control Point (HACCP) system; Not Certified: manufacturer did not employ the HACCP system.

A previous study on the food-derived pathogenic microorganisms in anchovies in the Mediterranean region demonstrated that anchovy sauce tended to show a continuous decline in pathogenic microorganisms, depending on their storage period in salt and the temperature during manufacturing. In addition, it was confirmed that the reduction rate of *S. aureus* was significantly lower than that of other pathogenic microorganisms [20]. Based on these studies, it could be inferred that the lower count of *S. aureus* detected in the tested commercially available *Saeu-jeot* could be due to cross-contamination.

3.2. Prediction of the S. aureus Contamination Level Based on the Contamination Level of Commercial Products

The results of the contamination distribution analysis in the tested commercial *Saeu-jeot* samples are shown in Figure 4. The probability distribution of *S. aureus*-positive samples among the analyzed samples revealed an exponential distribution as the optimal distribution. The predicted contamination for a positive sample was 0.9 $\pm$ 0.7 log CFU/g (Figure 4a). Based on these results, a simulation model was developed for predicting *S. aureus* contaminations in *Saeu-jeot* in their current production and distribution environment. After 10,000 simulations, the predicted contamination level of *S. aureus* in *Saeu-jeot* was 0.2 log CFU/g (Figure 4b). These results indicated that the risk of *S. aureus* in *Saeu-jeot* was low; however, the confirmed contamination with *S. aureus* indicated poor hygiene management in the workplace. In addition, *S. aureus* proliferates if the salt is diluted and, if the product is left unattended for long periods at room temperature, it can also contaminate the product [21]. Therefore, the steps of the manufacturing process should be investigated to identify the causes of and control *S. aureus* contamination.

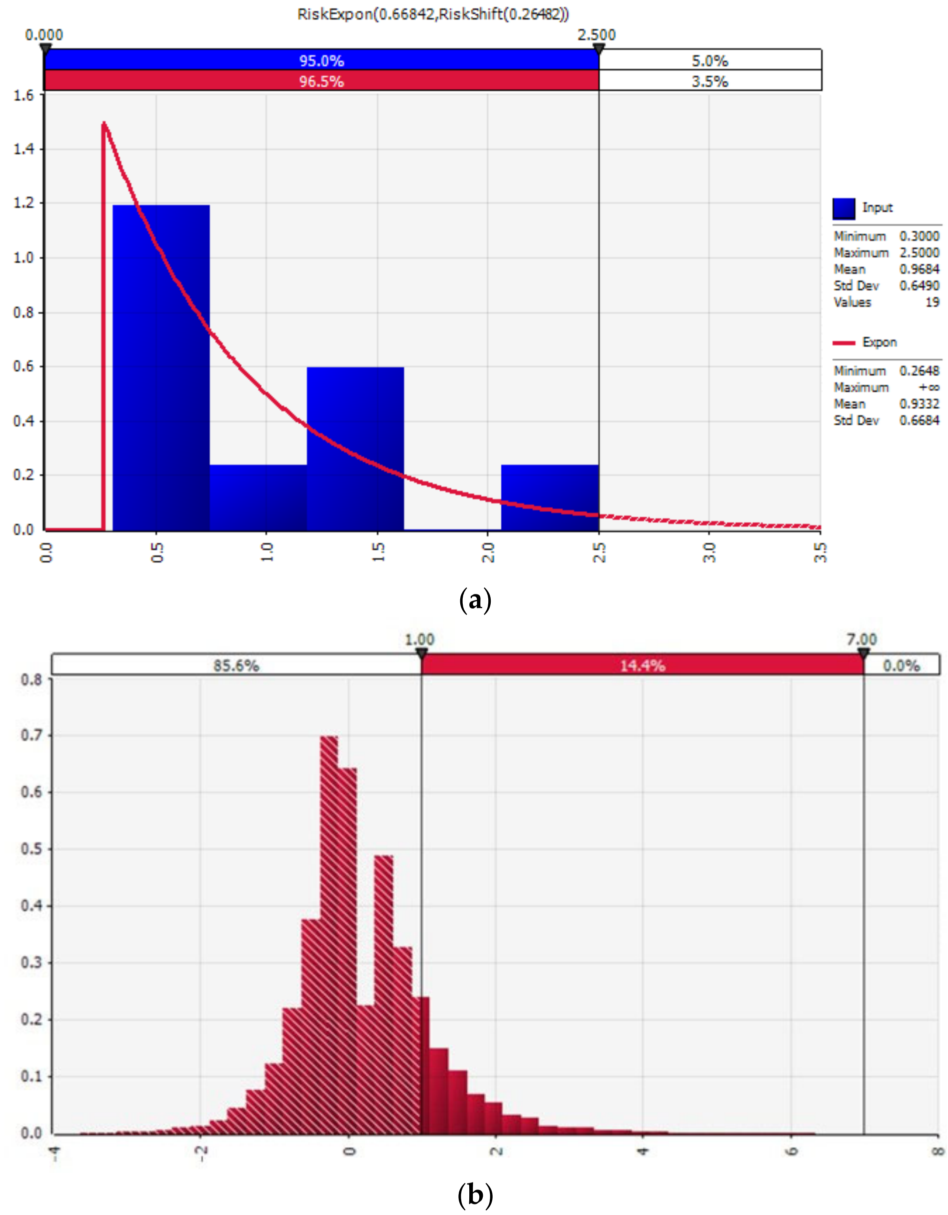


Figure 4. The probability distribution of *S. aureus*-positive samples (**a**). The prediction of *S. aureus* contamination in *Saeu-jeot* in its current production and distribution environment (**b**); *X* axis: contamination level, *Y* axis: probability density.

3.3. Investigation of the Saeu-jeot Manufacturing Process and Analysis of Microbial Hazards

The taste and quality of *Saeu-jeot* depend on the freshness of the shrimp and their aging and fermentation conditions. To maintain the freshness of the shrimp, they are caught on board, salted at 20–30%, fermented, and aged. More recently, after purchasing *Saeu-jeot* from the consignment sales of fishery cooperatives, processing plants perform aging and fermentation for at least 2–3 months and up to 6–12 months under low-temperature conditions (10–15 °C) [22–24].

The traditional method of *Saeu-jeot*'s preparation comprises four simple manufacturing steps in which tiny shrimp are salted, fermented, and aged, and then packaged and transported to the market for sale (Figure 5a). However, currently, *Saeu-jeot* is manufactured in a six-stage process: inspection, saltwater immersion (salting), screening for foreign materials, sterilization, fermentation/aging, packaging, and foreign material detection for hygiene (Figure 5b). To prevent the mixing of foreign marine matter and other fish species during shrimp capture, workers manually sort foreign matter and perform stirring, weighing, and packaging during the fermentation and maturation processes. During the manufacturing process, there is a slight possibility of contamination of the *Saeu-jeot* due to possible unavoidable microbial exposure. Therefore, a hazard analysis was conducted on the suspected contaminants (the workplace, work tools, workers' hands [wearing gloves], and overall working environment), including all steps of the manufacturing process that may be exposed to microorganisms, to ensure microbiological safety.

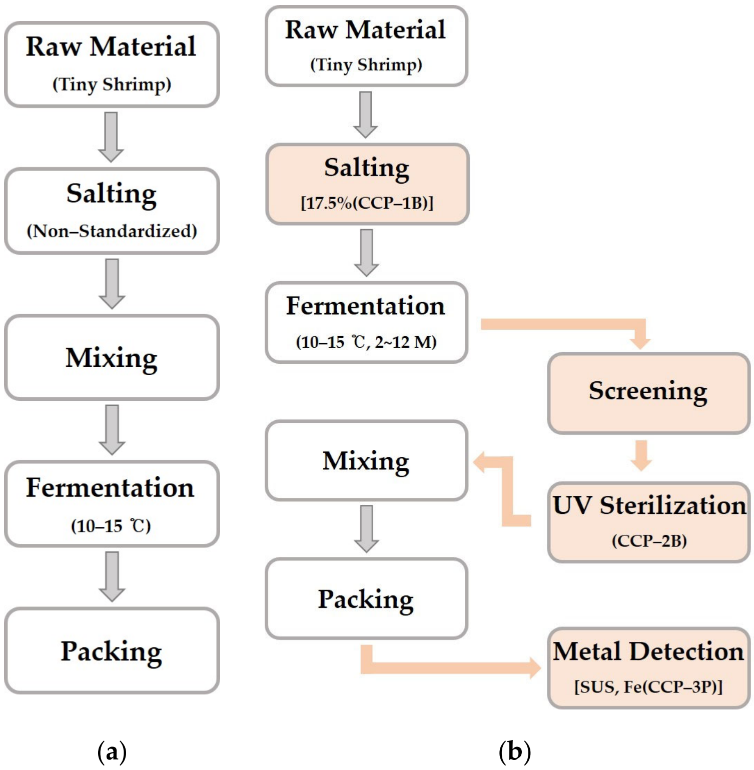


Figure 5. (**a**) Diagram of the traditional *Saeu-jeot* manufacturing process. (**b**) The HACCP system applied to the *Saeu-jeot* manufacturing process. CCP-1B: Saltiness; CCP-2B: Ultraviolet (UV) wavelength and exposure time; CCP 3P: Stainless steel (SUS) and Iron (Fe).

As shown in Table 1, the average total viable counts in the raw material (tiny shrimp) and glass packaging bottles were 4.2 ± 0.0 log CFU/g and 0.7 ± 0.1 log CFU/cm^2, respectively. The levels of contamination on the work table, foreign object sorting knife (work tool), sorting basket, and operator's hand (wearing a glove) were 2.4 ± 0.4, 4.1 ± 0.3, 2.4 ± 0.5, and 1.8 ± 0.2 log CFU/cm^2, respectively. In addition, the level of the total viable count in commercially available *Saeu-jeot* was 3.8 ± 0.3 log CFU/g. These results indicate that microbial contamination was high in the raw material (tiny shrimp). The detected total viable count was high in the absence of a separate process to control microorganisms during the *Saeu-jeot* manufacturing process. Moreover, continuous contamination seemed to occur due to the shrimp's vulnerability to microbial cross-contamination during the screening of mixed fish species and the foreign substances mixed in during capture. A sanitary inspection conducted at a Papua New Guinea fish cannery after a disinfection of the area in contact with food revealed that the total viable count was less than 100 CFU/50 cm^2, and no coliforms or *S. aureus* were detected. In addition, a clean, well-followed hygiene process and an evaluation of spoilage and pathogenic microorganisms are important elements to ensure the safety and quality of food [25,26]. The hygiene of the processing procedure is vital due to the consumption of these shrimp without heat treatment [27]. Therefore, it is necessary to minimize microbial contamination by periodically conducting sanitary assessments of workplaces and workers. Additionally, controlling the migration of microorganisms derived from raw materials, such as tiny shrimp, during the manufacturing process is also an essential step to ensuring the microbial safety of *Saeu-jeot*.

Table 1. Microbial hazard analysis of the *Saeu-jeot* manufacturing process.

Sample Type		**Total Viable Count (log CFU/g or log CFU/cm^2)**	***E. coli***	**Coliforms**	***S. aureus***	***V. parahaemolyticus***
Raw Material	Shrimp	4.2 ± 0.0	ND	ND	ND	ND
	Salt	ND	ND	ND	ND	ND
Packing Material	Glass Bottle	0.7 ± 0.1	ND	ND	ND	ND
Manufacturer	Work Table	2.4 ± 0.4	ND	ND	ND	ND
	Screening Tool	4.1 ± 0.3	ND	ND	ND	ND
	Screening Basket	2.4 ± 0.5	ND	ND	ND	ND
Man	Worker Hands (Gloves)	1.8 ± 0.2	ND	ND	ND	ND
After Wash and UV-C Treatment	Work Table	ND	ND	ND	ND	ND
	Screening Tool	ND	ND	ND	ND	ND
	Screening Basket	ND	ND	ND	ND	ND

ND, not detected.

3.4. Inhibitory Effects of Salting and UV-C Irradiation on S. aureus's Growth

Saeu-jeot is a fermented food ingested without heating, making it impossible to apply heat sterilization. HACCP-certified companies establish and manage salting or UV irradiation standards to manage microbial HACCPs. This study investigated the microbial-growth-inhibitory effect of salting and UV irradiation on managing significant hazards. Salting has been shown to inhibit the growth of microorganisms by controlling water activity or destroying microbial cells via osmotic pressure [24,28]. It has been reported that high-salinity *Saeu-jeot* had a lower number of total viable counts than *Saeu-jeot* with a low salinity [23]. To confirm the effect of the saltwater immersion process, the *Saeu-jeot* samples were inoculated with *S. aureus* strains, and the total viable count in the lower and upper layers of the salting solution were observed separately. The count of *S. aureus* in the upper layer was 6.1 ± 0.0 log CFU/g, and that in the lower layer was 4.7 ± 0.1 log CFU/g. These results demonstrate a reduction in the total viable count by 1.4 log CFU/g in the *Saeu-jeot* immersed in saltwater.

A previous study showed that the UV-C irradiation of drinking water inhibited the growth of both Gram-negative and Gram-positive bacteria [29]. In addition, a UV-C treatment minimized alterations in the quality of semi-salted mackerel fillets and inactivated *S. aureus* [30]. The study also demonstrated that more effective sterilization is possible via longer treatment periods. In this study, to confirm its growth-inhibitory effect on the *S. aureus* in *Saeu-jeot*. *S. aureus* was counted in samples that had undergone UV-C irradiation for 2 min. Its total viable count was reduced from the initial 4.7 ± 0.1 log CFU/g to 4.3 ± 0.0 log CFU/g (Table 2). *S. aureus* was significantly decreased after 2 min of UV-C treatment ($p < 0.05$). Consistent with our study, a previous study reported that the total viable count in *Saeu-jeot* decreased from 4.2 log CFU/g to 3.7 log CFU/g following UV-C irradiation [31]. Nevertheless, a higher rate of reduction in the total viable count has been reported in dried fish (0.82 log CFU/g) and shellfish (1.20 log CFU/g), which could be attributed to the physical properties of the foods and the effect of their surfaces on the irradiation's dose and penetration.

Table 2. Effect of UV-C irradiation on *S. aureus* in *Saeu-jeot*.

Time	*S. aureus* (log CFU/g)
Initial	4.7 ± 0.0^{a}
10 s	4.6 ± 0.1^{ab}
30 s	4.6 ± 0.0^{abc}
1 min	4.6 ± 0.0^{abc}
2 min	4.3 ± 0.0^{d}
5 min	4.5 ± 0.1^{bc}
10 min	4.4 ± 0.0^{cd}

All values are mean ± standard deviation of triplicates; $^{a–d}$ in the same column are significantly different ($p < 0.05$), respectively.

4. Conclusions

In this study, we evaluated the microbiological safety of commercial *Saeu-jeot* to determine the presence of a total viable count, *E. coli*, coliforms, *S. aureus*, and *V. parahaemolyticus*. We also analyzed the microbial hazards in the manufacturing process of *Saeu-jeot.* The commercial *Saeu-jeot* contained a total viable count of 3.8 ± 0.4 log CFU/g and 0.6 ± 0.3 log CFU/g of *S. aureus*. Differences in pathogenic microorganism contamination were observed between companies with HACCP systems and those without. It was observed that non-HACCP-certified companies had higher levels of *S. aureus* compared to those that were HACCP-certified. Additionally, to confirm the microbial hazards of the applied HACCP system on the *Saeu-jeot* manufacturing process, a microbial contamination analysis was performed, which identified the total viable counts in the raw material (tiny shrimp), manufacturing tools (work table, screening tool, screening basket), and on worker's hands (wearing gloves). The results indicated that the contamination originated from the raw material. No microbial contamination was detected upon testing after cleaning and UV treatment between each step in the manufacturing process. During manufacturing, the HACCP system sets the salting and UV-C treatment processes as CCPs to reduce microbial contamination. Depending on the salting layer, the contamination levels of *S. aureus* differed. The upper layer's contamination was 6.1 ± 0.0 log CFU/g, while the lower layer's contamination was 4.7 ± 0.1 log CFU/g. It was observed that the effectiveness of this treatment was reduced when the *Saeu-jeot* was not fully salted. Additionally, it was found that a UV-C treatment for more than 2 min was effective in the reduction of *S. aureus*. Considering that other research findings indicate significant sterilization effects on the surface of objects, it was deemed effective to simultaneously apply salting and UV-C irradiation in the manufacturing process of *Saeu-jeot*. These operations were confirmed to be effective in reducing *S. aureus* contaminations. In summary, salting and UV-C treatment processes can effectively inhibit the growth of microorganisms, without heat treatment, in *Saeu-jeot*. This improved manufacturing process, therefore, produces a non-heat-treated product and can suppress cross-contamination by *S. aureus*. In addition, this study's results suggest that workplace hygiene and the maintenance of cleanliness throughout the manufacturing process have desirable effects on the quality and safety of *Saeu-jeot*.

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References

1. Koo, O.K.; Lee, S.J.; Chung, K.R.; Jang, D.J.; Yang, H.J.; Kwon, D.Y. Korean traditional fermented fish products: Jeotgal. *J. Ethn. Foods* **2016**, *3*, 107–116. [CrossRef]
2. Jung, J.Y.; Lee, S.H.; Lee, H.J.; Jeon, C.O. Microbial succession and metabolite changes during fermentation of Saeu-jeot: Traditional Korean salted seafood. *Food Microbiol.* **2013**, *34*, 360–368. [CrossRef]
3. Cho, H.S.; Kim, K.H. Changes in the physicochemical properties and color values of salted and fermented shrimp. *J. East. Asian Soc. Diet. Life* **2010**, *20*, 69–76.
4. Kim, A.J.; Park, S.Y.; Choi, J.W.; Park, S.H. Assessment of microbial contamination and nutrition of Kwangchun shrimp jeotgal (salt fermented shrimp). *Korean J. Food Sci. Technol.* **2006**, *38*, 121–127.
5. Codex Alimentarius. Standard for Fish Sauce-CODEX STAN 302-2011. Codex Alimentarius. 2011. Available online: https://www.fao.org/fao-who-codexalimentarius/codex-texts/list-standards/en/ (accessed on 27 March 2024).
6. *GB 10133–2014*; National Food Safety Standard Aquatic flavouring. National Health and Family Planning Commission. The People's Republic of China: Beijing, China, 2014.
7. Korea Ministry of Food and Drug Safety (KMFDS). *Food Code*; The Ministry of Food and Drug Safety Notification (No.2021-54, 29 June 2021); The Ministry of Food and Drug Safety: Cheongju-si, Republic of Korea, 2021.
8. Zhao, Y.M.; de Alba, M.; Sun, D.W.; Tiwari, B. Principles and recent applications of novel non-thermal processing technologies for the fish industry—A review. *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 728–742. [CrossRef]
9. Castañeda-López, G.G.; Ulloa, J.A.; Rosas-Ulloa, P.; Ramírez-Ramírez, J.C.; Gutiérrez-Leyva, R.; Silva-Carrillo, Y.; Ulloa-Rangel, B.E. Ultrasound use as a pretreatment for shrimp (*Litopenaeus vannamei*) dehydration and its effect on physicochemical, microbiological, structural, and rehydration Properties. *J. Food Process. Preserv.* **2021**, *45*, e15366. [CrossRef]
10. Mok, C.K.; Song, K.T. High hydrostatic pressure sterilization of putrefactive bacteria in salted and fermented shrimp with different salt content. *Korean J. Food Sci. Technol.* **2000**, *32*, 598–603.
11. Lee, K.H.; Ahn, H.J.; Lee, C.H.; Kim, J.G.; Shin, M.G.; Byun, M.W. Effects of gamma irradiation on quality in the processing of low salted and fermented shrimp. *J. Korean Soc. Food Sci. Nutr.* **2000**, *29*, 430–436.
12. Jung, S.; Choe, J.H.; Kim, B.N.; Yun, H.J.; Kim, Y.J.; Jo, C. Microbiological, physicochemical, and sensory characteristics of Myungran Jeotgal treated by electron beam irradiation. *Korean J. Food Preserv.* **2009**, *16*, 198–203.
13. Lee, J.E.; Xu, X.; Jeong, S.M.; Kang, W.S.; Ryu, S.H.; Kim, Y.S.; Ahn, D.H. Effect of Ultraviolet-C and Organic Acid Treatment on Fungi Isolated from High Carbohydrate Confectionery. *J. Life Sci.* **2021**, *31*, 481–487.
14. Perkins-Veazie, P.; Collins, J.K.; Howard, L. Blueberry fruit response to postharvest application of ultraviolet radiation. *Postharvest Biol. Technol.* **2008**, *47*, 280–285. [CrossRef]
15. Shin, J.Y.; Kim, S.J.; Kim, D.K.; Kang, D.H. Fundamental characteristics of deep-UV light-emitting diodes and their application to control foodborne pathogens. *Appl. Environ. Microbiol.* **2016**, *82*, 2–10. [CrossRef] [PubMed]
16. Cho, M.; Woo-Dong, J.; Je-Yong, Y. Application of UV technology for surface disinfection. *J. Korean Soc. Environ. Eng.* **2007**, *29*, 1020–1026.
17. Shim, K.B.; Park, K.; Yoon, N.Y.; An, B.K.; In, J.J.; Han, H.G.; Lee, W.J. Evaluation of microbiological safety of commercially salt-fermented fishery products by raw materials. *Korean J. Fish. Aquat. Sci.* **2021**, *54*, 1045–1051.
18. Sang-Hee, O.; Ok-Kyun, B.; Hae-Choon, C.; Mee-Ree, K. Microbiological safety of commercial salt-fermented shrimp during storage. *Korean J. Food Sci. Technol.* **2004**, *36*, 507–513.
19. Park, H.J.; Bae, H.J. Hazard analysis of Staphylococcus aureus in ready-to-eat sandwiches. *J. Korean Soc. Food Sci. Nutr.* **2007**, *36*, 938–943. [CrossRef]
20. Jung, M.Y.; Kim, T.W.; Lee, C.; Kim, J.Y.; Song, H.S.; Kim, Y.B.; Ahn, S.W.; Kim, J.S.; Roh, S.W.; Lee, S.H. Role of jeotgal, a Korean traditional fermented fish sauce, in microbial dynamics and metabolite profiles during kimchi fermentation. *Food Chem.* **2018**, *265*, 135–143. [CrossRef] [PubMed]
21. Verdos, G.I.; Makrigiannis, A.; Tsigaras, E.; Boziaris, I.S. Survival of food-borne bacterial pathogens in traditional Mediterranean anchovy products. *J. Food Saf.* **2019**, *39*, e12576. [CrossRef]

22. Song, H.S.; Kim, S.H. Effect of fermentation temperature and salt concentration on changes in quality index of salted shrimp during fermentation. *J. Food Hyg. Saf.* **2017**, *32*, 355–362. [CrossRef]
23. Lee, K.D.; Choi, C.R.; Cho, J.Y.; Kim, H.L.; Ham, K.S. Physicochemical and sensory properties of salt-fermented shrimp prepared with various salts. *J. Korean Soc. Food Sci. Nutr.* **2008**, *37*, 53–59. [CrossRef]
24. Oh, S.H.; Heo, O.S.; Shin, H.S.; Lee, J.W.; Kim, D.H.; Byun, M.W.; Kim, M.R. Effect of salt concentration on the quality of SaewooJeot (Salted shrimp) fermented at room temperature. *J. East. Asian Diet. Soc.* **2005**, *15*, 444–449.
25. Begani, R.K.; Tombe, B.; Polong, T. Effectiveness of cleaning and sanitation of food contact surfaces in the PNG fish canning industry. *Contemp. PNG Stud.* **2012**, *17*, 68–72.
26. Touimi, G.B.; Bennani, L.; Berrada, S.; Benboubker, M.; Bennani, B. Evaluation of hygienic conditions of food contact surfaces in a hospital kitchen in Morocco. *Iran. J. Microbiol.* **2019**, *11*, 527–534. [CrossRef]
27. Um, J.Y.; Jang, H.J.; Choi, Y.J.; Kim, S.Y.; Jo, A.; Kim, M.Y.; Ahn, J.; Kim, J.D. Prevalence of Microbiological Contamination in the Ready-to-Eat Side Dishes Sold in Gyeongsangnam-do, South Korea. *J. Food Hyg. Saf.* **2023**, *38*, 217–227. [CrossRef]
28. Kim, M.H. Microbial management and preservation improvement technology of food. *Bull. Food Technol.* **1994**, *7*, 81–93.
29. Kim, H.J.; Kim, Y.J.; Seo, S.Y.; Lee, C.J. Effect of UV-C irradiation for bacterial disinfection of drinking water. *Korean J. Food Sci. Technol.* **2021**, *53*, 218–222.
30. Song, H.N.; Lee, D.G.; Han, S.W.; Yoon, H.K.; Hwang, I.K. Quality changes of salted and semi-dried mackerel fillets by UV treatment during refrigerated storage. *Korean J. Food Cookery Sci.* **2005**, *21*, 662–668.
31. Lee, H.H.Y. A Study on the Development of Sanitary Salted Shrimp Process. Master's Thesis, Kunsan National University, Gunsan, Republic of Korea, 2013.