Journal of Chemistry and Nutritional Biochemistry
https://jcnb.sabapub.com
E ISSN: 2709-5932

2025 Volume 6, Issue 1: 47–67
DOI: https://doi.org/10.48185/jcnb.v6i1.1433

Utilization of shrimp waste powder as a functional ingredient in fortifying ready-to-eat foods

Shereen I. A. Omar[1], [2], Manar M. A. Farag[1], Rafat A. Taha [2], Ahmed M. Rayan[*2], Amal A. GabAlla [2]

[1]Meat and Fish Technology Research Department, Food Technology Research Institute, Agriculture Research Center, Ministry of Agriculture, Giza, Egypt
[2]Food Technology Department, Faculty of Agriculture, Suez Canal University, Ismailia 41522, Egypt

Received: 21.12.2024 • Accepted: 20.03.2025 • Published: 12.04.2025 • Final Version: 12.04.2026

Abstract: Shrimp waste, a byproduct of seafood processing, is rich in nutrients and bioactive compounds, making it a promising ingredient for sustainable food fortification. This study evaluated the potential of shrimp waste powder (SWP) as a functional ingredient in ready-to-eat shrimp soup and fish fingers. SWP was processed by drying at 60°C for 24 h, grinding, and storing at 4°C ± 1°C. Its chemical composition was analyzed, revealing 42.48% protein, 11.50% fat, 23.6% ash, and a pH of 7.1. SWP was incorporated into food products at levels of 5%, 10%, and 15%. Chemical, physical, microbiological, and sensory analyses were conducted on all samples. Results showed that the 15% SWP fortification in shrimp soup provided the best overall nutritional and sensory properties. Similarly, for fish fingers, 15% SWP fortification level yielded optimal flavor, texture, and microbiological safety. The study confirms that shrimp waste powder can effectively enhance the nutritional value of food products without compromising sensory or safety qualities, offering a sustainable method for utilizing shrimp waste in food production.

Keywords: Shrimp waste, byproduct, shrimp soup, fish fingers, fortification

1. Introduction

The aquaculture sector is among the most rapidly expanding industries globally. Seafood is an essential component of a well-rounded diet, playing a crucial role in maintaining the optimal functioning of the human body. As a result, consumers are increasingly drawn to aquaculture-derived fish products that offer high nutritional value, particularly those that mimic the sensory qualities of wild-caught fish. While aquaculture is generally considered sustainable, there is a pressing need for more research into the potential utilization of shrimp byproducts. Currently, the inadequate processing of shrimp waste undermines the industry's sustainability efforts. It is worth noting that crustacean shells are composed of 20–40% protein, 20–50% calcium carbonate, 15–40% chitin, and minor amounts of lipids (0–14%) (Fotodimas et al., 2024).

The global shrimp processing industry generates approximately 3.8 million tons of waste annually, constituting 50-60% of the total catch weight (Nirmal et al., 2020). This waste primarily consists of shrimp heads, shells, and tails, which, despite being discarded, are rich in valuable nutrients such as proteins, essential minerals (e.g., Ca, Fe, Mg, Na), and bioactive compounds beneficial for both human and animal health. The shrimp head and shell portions alone can represent 45-60% of the total shrimp weight, offering substantial opportunities for sustainable

* Corresponding Author: ahmed_rayan@agr.suez.edu.eg; ammrayan@yahoo.com

resource utilization and environmental conservation. The issue of shrimp waste disposal has significant environmental implications, hindering sustainable development efforts and contributing directly to the phenomenon of environmental change (Fotodimas et al., 2024). Therefore, valorizing shrimp waste by converting it into valuable products could significantly reduce pollution while simultaneously providing economic benefits (Jeyasanta et al., 2017).

Recent studies have highlighted the potential for utilizing shrimp shells to produce bioactive compounds, which can enhance the nutritional and sensory properties of food products. For instance, shrimp shell powder has been shown to significantly boost antioxidant capacity, improve product color, and increase its appeal to the food industry (Maia et al., 2023). It contains abundant proteins (Mizani and Aminlari, 2007), chitin (Ruangwicha et al., 2024), lipids (Ahmadkelayeh and Hawboldt, 2020), and pigments (Jafari et al., 2012), shrimp shell powder holds promise not only as a functional ingredient in food formulations but also as a high-protein component in animal and fish feeds (Pattanaik et al., 2020). The rich concentration of beneficial nutrients in shrimp positions it as a highly valuable resource for researchers, business innovators, and industry leaders to create novel products. Furthermore, repurposing shrimp waste has the potential to alleviate environmental strain and minimize pollution levels (Abuzar et al., 2023).

In certain countries, shrimp heads and shells are now being transformed into petis-udang, a shrimp paste utilized as a seasoning in diverse culinary preparations (Hajeb and Jinap, 2012). This demonstrates the versatility of shrimp waste in food production and the potential for innovative applications such as shrimp flavor powder, shrimp-based soups, and other food formulations. The economic value of shrimp waste, however, remains largely underutilized. With global shrimp shell powder prices as low as $100 per ton (Ray et al., 2021), there is a clear need for sustainable methods to enhance its value. Processing shrimp waste into powders for use in flavoring agents, bouillon cubes, and snacks like shrimp crackers offers an opportunity to not only reduce environmental impact but also create high-demand, value-added products for the food industry (Teerasuntonwat and Raksakulthai, 1995; Essuman, 2005; Khan and Nowsad, 2012).

Shrimp waste powder (SWP) can be effectively utilized as a functional ingredient in food formulations to enhance the nutritional, antioxidant, and sensory properties of food products, while also providing a sustainable method for reducing environmental waste. To evaluate the potential of SWP as a functional ingredient in food products, this study assessing its chemical composition, incorporation into food applications, and its effects on the nutritional, physicochemical, microbiological, and sensory properties of the resulting ready-to-eat products.

2. Materials and methods

2.1. Materials

Raw shrimp wastes (head, shell and tail) namely; Ismalawy shrimp, Port Said shrimp, Jumbo Suez shrimp and Ghlayoun farmed shrimp were collected from local markets located at Ismailia, Port said, Suez and Kafr El-Sheikh cities, respectively. Shrimp wastes were transported to the laboratory in an icebox. The ingredients such as salt, spices, garlic, starch, were purchased from the local market at Ismailia Governorate, Egypt. All chemical used in this study were analytical grade.

2.2. Methods

2.2.1. Preparation of SWP

Shrimp wastes (head, shell, and tail) were segregated and dehydrated in a hot air oven at 60°C for 24 h. The heads, shells, and tails of dried shrimp were coarsely pulverized using a blender for three cycles of 2-3 min each. Ground shrimp wastes were passed through a fine mesh sieve to produce a fine shrimp waste powder. The powder was subsequently enclosed in airtight glass containers and refrigerated at 4°C until use.

2.2.2. Preparing dried shrimp soup

Shrimp soup powder (SSP) was prepared using the method of Suparmi et al. (2020). A spice mixture was prepared for the shrimp soup using the following ingredients and proportions (by weight): onion (5%), garlic (4%), milk powder (25%), white pepper (2.9%), parsley powder (1%), peppermint powder (1%), wheat flour (35%), potato flour (10%), cornstarch (2%), solid vegetable oil (10%), turmeric (0.6%), granular carrot (0.5%), and salt (3%).

The shrimp waste powder (SWP) was incorporated into the prepared spice mixture at three different levels (weight: weight): 5% (5 g SWP + 95 g spices mixture), 10% (10 g SWP + 90 g spices mixture), and 15% (15 g SWP + 85 g spices mixture). The final soup mixture was thoroughly blended to ensure even distribution of all ingredients. The resulting SSP was packed into sterilized glass jars to maintain quality and stored for subsequent analysis. Similar ranges (5 – 20%) were chosen in Khan and Nowsad (2012) study on protein enriched shrimp crackers from shrimp shell wastes. So, we suggested 5–15% as the typical range where nutritional gains are significant without compromising product integrity. Higher doses (>15%) often require masking agents or processing tweaks.

2.2.3. Preparation of fish fingers

Bassaria fish (anchovies) were utilized to prepare fish fingers following the methodology outlined by Izci (2010). Fresh fish was acquired from the Ismailia local market and transported to the laboratory in an icebox. The fish samples were beheaded, eviscerated, and gently rinsed with tap water, followed by manual filleting and skinning. The flesh yield was 53%. The prepared fillets were sliced and ground using a kitchen meat mincer equipped with a 3 mm diameter perforated plate.

The control treatment comprised 93.5% fish flesh mince, 1.5% salt, 1% sugar, 3% wheat flour, and 0.243% each of cumin, onion, garlic powder, and pepper, together with 0.028% thyme (Tokur et al. 2006). All components were combined and homogenized using a meat blender. The mixture was partitioned into four equal portions to formulate the experimental treatments, with SWP utilized at varying concentrations of 0%, 3%, 5%, and 10% (weight/weight) as a substitute for the control treatment.

2.3. Analytical methods

2.3.1. Proximate composition

The shrimp waste samples were analyzed for ash, protein, and fat according to the Official Method of Analysis (AOAC, 2005). The pH of the samples was determined utilizing the methodology of Nirmal and Benjakul (2009) with a pH meter (Sartorius, Göttingen, Germany).

2.3.2. Quality indicators

2.3.2.1. Total volatile basic nitrogen (TVB–N) and Trimethylamine (TMA)

The extracts were obtained by homogenizing 100 g of materials with 200 ml of 7.5% trichloroacetic acid solution using a laboratory homogenizer at high speed for 1 min. The homogenate was centrifuged at 3000 rpm for 5 min. The supernatant was further filtered using double rings filter paper No. 102.

The total volatile basic nitrogen (TVB-N) was quantified using steam distillation of the TCA-fish filtrate, following the modified procedure of Malle and Poumeyrol (1989). Twenty-five mL of the filtrate were introduced into a Kjeldahl distillation tube, subsequently followed by 5 mL of a 10% (w/v) aqueous sodium hydroxide solution. Steam distillation was conducted utilizing a vertical apparatus, with the distillate collected in a beaker containing 15 mL of 4% aqueous boric acid solution, achieving a final volume of 50 mL. The titration was performed with a 0.05 M sulfuric acid solution until the endpoint was reached, utilizing methyl red and bromocresol green as indicators.

The measurement of trimethylamine (TMA) was conducted following the same experimental protocol as TVB-N (Malle and Poumeyrol, 1989), with the exception that 20 mL of 35% formaldehyde was introduced into the distillation tube to inhibit the reaction of primary and secondary amines, allowing only tertiary amines to react. The amount of TVB-N and TMA

in milligrams was ascertained from the volume of 0.1N sulfuric acid utilized for titration. The data were presented as mg of nitrogen per 100 g of sample.

2.3.2.2. Thiobarbituric acid reactive substances (TBARS)

The TBARS values were quantitatively assessed using colorimetric analysis as outlined by Tarladgis et al. (1960). A homogenized 10 g sample of fish muscle was placed in a Kjeldahl flask and combined with 97.5 ml of distilled water and 2.5 ml of 6 N HCl. The mixture underwent steam distillation until 200 mL of distillate was obtained. Five mL of each distillate were combined with five mL of 0.02 M thiobarbituric acid reagent and incubated in boiling water for 35 min. The absorbance of the pink solution was recorded at 538 nm utilizing a Jenway spectrophotometer (6505 UV/Vis, UK) following cooling with running tap water. The reading was multiplied by a factor of 7.8 to convert it to mg of malondialdehyde, expressed as mg malondialdehyde equivalent (MDA eq) per kg of sample.

2.3.3. Microbiological evaluation

2.3.3.1. Total aerobic plate count (TAPC)

Agar plate method was used for determination of total aerobic bacterial counts on nutrient agar according to Difco (1985). A 10 g sample was blended in a high-speed blender under sterile conditions for 3 min in 90 mL buffered peptone water. Decimal dilutions were prepared for the determination of various bacterial groups. Plates were incubated at 37±2 ºC for 48 h.

2.3.3.2. Coliform group count

Violet red bile (VRB) agar was utilized as the medium for total coliform count, using the following approximate formula per liter: 3 g yeast extract, 7 g peptone, 1.5 g bile salts, 10 g lactose, 5 g sodium chloride, 0.03 g neutral red, 2.0 mg crystal violet, and 15 g agar. Plates were incubated at 35°C for 18 to 24 h. Following incubation, the characteristic purple, spherical bacterial colonies were counted. Fecal coliform and *E. coli* were identified by counting typical purple colonies, which were further validated through cultivation on eosin methylene blue (EMB) agar plates. Presumptive colonies (blue-black colonies exhibiting a green metallic sheen and dark cores) on EMB agar were streaked onto slant agar. The outcomes are presented as log CFU per gram of sample.

2.3.3.3. Detection of *Vibro cholera*

Thiosulfate Citrate Bile Sucrose Agar (TCBS Agar) was employed for the isolation of *Vibrio cholerae* (*V. cholerae*). Samples underwent serial tenfold dilutions and were thereafter spread plated on TCBS agar, followed by incubation at 37°C for 24 h. The sucrose-fermenting colonies on the TCBS plates were purified by streak dilution and identified at the species level using the identification scheme of Noguerola and Blanch (2008). The *V. cholerae* isolates identified by the aforementioned methods were validated by the tests outlined for *V. cholerae* species identification (Bergey's Manual of Systematic Bacteriology, 2005).

2.4. Sensory evaluation

Sensory evaluation was conducted on shrimp wastes immediately after processing and at the end of storage. Ten members of semi-trained staff members, of the Food Technology Department, Suez Canal University, evaluated the samples to find out the products that have more palatability by evaluating color, aroma, texture and overall acceptability of these products were evaluated according to Ojagh et al. (2010).

2.5. Statistical analysis

The data were evaluated with the Analysis of Variance (ANOVA) test, conducted with SPSS software (version 16.0 for Windows, SPSS Inc., Chicago). Duncan's multiple range tests were employed to ascertain significance among treatment means at $P < 0.05$.

3. Results and discussion

3.1. Shrimp waste powder (SWP)

3.1.1. Physiochemical properties of SWP

The proximate composition of SWP reveals its strong nutritional profile, with high protein content (41.48%), fat (14.60%) and ash (17.96%) levels, making it a valuable resource for fortifying food products (Table 1). The moderate moisture content (25.96%) suggests that drying is essential for preserving its shelf life. The pH of 7.1 indicates a neutral character, suitable for incorporation into various food formulations without altering their properties. The low TBA (0.29) and TMA (1.76) values indicate minimal lipid oxidation and protein degradation, reflecting good preservation during processing. The TVN value (12.54) suggests some protein breakdown, possibly due to slight microbial activity, though this does not appear

to significantly affect the powder's overall quality. These findings suggest that SWP is not only a sustainable ingredient, reducing shrimp waste, but also offers significant nutritional benefits, making it suitable for use in food products like soups, snacks, or animal feeds, with appropriate storage and handling practices to maintain its quality over time.

Table 1. **Proximate composition of shrimp waste powder SWP**

Compounds	values
Protein (%)	41.48 ± 0.64
Moisture (%)	25.96± 0.45
Fat (%)	14.60 ± 0.71
Ash (%)	17.96 ± 0.34
pH	7.1 ± 0.05
TBA (mg MDA eq/kg)	0.29±0.032
TVN (mg/100 g)	12.54±0.61
TMA (mg/100 g)	1.76±0.39

Each value represent mean ±SD: standard deviation of triplicate determinations

The proximate composition values of shrimp waste powder (SWP) align with the results of Shiv et al. (2018), who indicated that the protein percentage in SWP (32.06±1.072 %) was markedly greater than that of fresh waste protein (22.85±1.535 %). Jeyasanta et al. (2017) indicated that the crude protein content in fresh heads and waste of *Penaeus* spp. was 18.4% and 16.08%, respectively. The markedly elevated crude protein in SWP compared to fresh waste is ascribed to the increased protein concentration resulting from moisture loss during the drying process. The results closely align with Shahidi (1994), who reported 44.12% crude protein in shrimp discards, highlighting their potential as a viable protein source for the food industry. The fat content of the SWP aligns with the findings of Jeyasanta et al. (2017) and Shiv et al. (2018). The elevated ash level (17.96±0.34%) closely resembles the findings of Fernandes et al. (2013), who reported an ash percentage of 20.97% in shrimp cephalothorax flour. Additionally, dietary supplements derived from crustacean byproducts can serve as an effective source of calcium, aiding human metabolism and promoting bone health (Xu et al., 2020). The spoiling indicator TVB content in SWP was low (0.29±0.032 %), consistent with Shiv et al. (2018), who reported a TVB level of 0.37±0.085 mg MDA eq/kg in SWP.

While SWP offers a sustainable protein source, addressing the health and scalability challenges through interdisciplinary collaboration (food technologists, regulators, and supply chain experts) will determine its commercial viability.

3.1.2. Microbial quality of the SWP

The microbial quality of SWP during storage at 4°C shows a gradual increase in total plate count (TPC) over time (Table 2). Initially, at zero time, the TPC was relatively low (1.36 ± 0.56 Log CFU/g), indicating minimal microbial contamination immediately after preparation. However, over the next three months, there was a consistent increase in TPC, reaching 7.11 ± 0.23 log CFU/g by the end of the storage period. This increase suggests microbial growth during storage, likely due to the natural moisture content and the conditions under which the powder was stored. Despite the rising TPC, the absence of *Vibrio cholerae* and Coliform group bacteria at all storage time points indicates that the SWP remained free from significant foodborne pathogens, maintaining its safety for consumption. The increase in TPC could be attributed to the proliferation of non-pathogenic bacteria, which may be part of the natural microbiota of the shrimp waste. This trend highlights the importance of monitoring microbial quality during storage to ensure the product's safety, and it emphasizes the need for proper storage and potential preservatives to maintain the quality of SWP over longer durations. the microbiological quality parameter of 10^5 CFU/g (5 Log CFU/g) in sea foods (Surendran et al., 2006). By implementing appropriate quality controls, manufacturers can develop value-added food products within their current processing infrastructure, enabling both local and export market opportunities.

Table 2. Microbial quality of the shrimp waste powder during storage period at 4°C.

Microbial analysis (Log CFU/g)	Storage time (Month)			
	Zero time	One	Two	Three
TPC	1.36±0.56	2.1±0.32	4.5 ±0.48	7.11±0.23
Vibro cholerae	Nil	Nil	Nil	Nil
Coliform group	Nil	Nil	Nil	Nil

Each value represent mean ±SD: standard deviation of triplicate determinations

3.1.3. Sensory evaluation of shrimp soup

The distinct sensory properties of shrimp by-products make them particularly suitable for the creation of innovative products. A wide range of items, including fortified biscuits, bread, peach-flavored tea, acid-curd cheese, extruded snacks, yogurt, margarine, and shrimp powder, have been developed using these by-products (Abuzar et al. 2023). The sensory evaluation results indicate that the incorporation of SWP into the shrimp soup formulae significantly enhanced the sensory attributes, especially in treatments B and D (Fig. 1).

Treatment D, with the highest concentration of SWP, exhibited superior scores in appearance (7.0±0.45), color (8.0±0.5), odor (7.0±0.29), texture (7.5±0.55), taste (7.0±0.65), and overall acceptability (7.5±0.65), suggesting a noticeable improvement in the soup's appearance, aroma, flavor, and mouthfeel. Treatment B also showed positive results, particularly in texture (7.0±0.46) and taste (6.0±0.5), while the control group (C) had the lowest scores across all attributes, confirming that the addition of SWP notably improved the product's sensory quality. These findings highlight that SWP can be an effective ingredient for enhancing the organoleptic properties of shrimp-based food products, offering a sustainable method for utilizing shrimp waste to produce more attractive and acceptable food items.

Suparmi et al. (2020) identified glutamic acid as the predominant non-essential amino acid contributing to the flavor of shrimp powder, as it activates the mouth's umami taste receptors. Ghorban et al. (2019) discovered that the sensory evaluation outcomes (color, odor, flavor, taste, and texture) of the soup powders in the first month were substantially superior to those at the conclusion of storage ($P<0.05$). The findings of this investigation were analogous to those of Chacko et al. (2005).

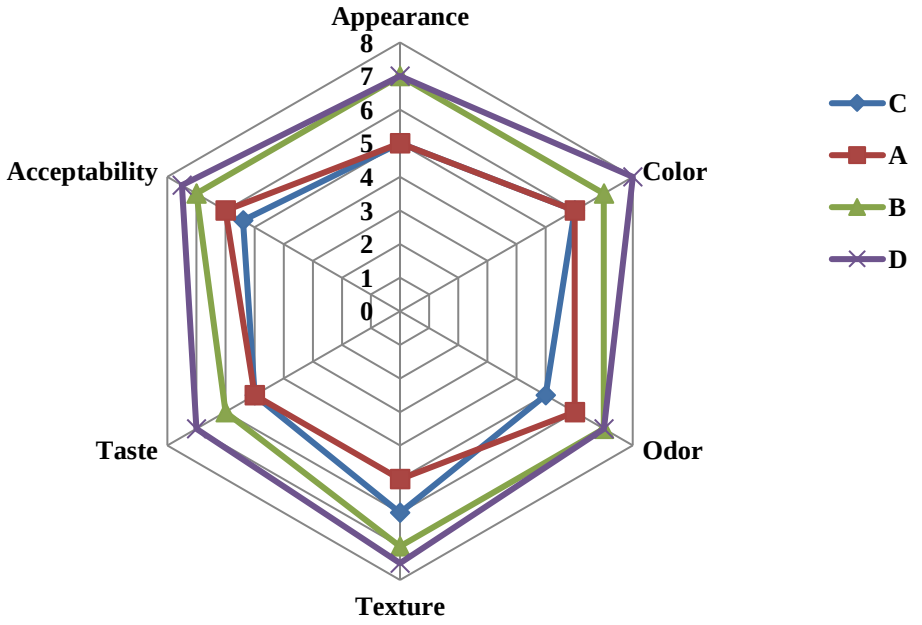

Fig. 1. Sensory evaluation of shrimp soup prepared from SWP. Treatment C: control, treatment A: shrimp soup 5% SWP, treatment B: shrimp soup with 10% SWP, treatment D: shrimp soup with 15% SWP.

3.2. Fish finger prepared from Anchova fish supplemented with SWP

3.2.1. Proximate composition of fish finger

The results in Table 3 indicates that the incorporation of SWP into Anchova fish fingers significantly enhanced their proximate composition, with increases in protein, fat, and ash content as the SWP percentage rises. Treatment D (15% SWP) showed the highest levels of all three components, particularly protein (36.75%), fat (5.54%), and ash (4.98%), suggesting that higher SWP supplementation improves the nutritional quality of the fish fingers. These findings demonstrate that SWP can be an effective supplement to boost the protein and fat content of fish products, potentially offering a more nutrient-dense alternative for consumers. The significant differences in composition across the treatments (P <0.05) highlight the positive impact of SWP on the nutritional profile, making it a promising ingredient for enhancing the quality of processed fish products. Osibona et al. (2009) indicated that the nutritional composition of deep-fried fish cake derived from shrimp consisted of 60.12% moisture, 21.01% protein, 8.50% fat, 6.30% ash, and 4.07% carbohydrate. Ayse et al. (2011) determined that the proximate composition of anchovy cakes was 4.23% protein, 2.58% fat, and 0.45% ash, based on wet weight. Aref et al. (2016) mentioned that chemical composition for Catfish fingers was protein 19.32, fat 1.37, ash 2.98%.

Table 3. Proximate composition of fish finger prepared from Anchova fish supplemented with SWP.

Treatments	Proximate composition in dry weight basis (%)		
	Protein	Fat	Ash
C	18.89±0.72^{d}	2.12 ± 0.17^{d}	2.45 ± 0.30^{c}
A	25.65±0.93^{c}	3.47±0.33^{c}	3.09±0.78^{b}
B	30.13±0.44^{b}	4.61±0.64^{b}	4.13±0.85^{ab}
D	36.75±0.64^{a}	5.54±0.56^{a}	4.98±0.47^{a}

Results are expressed as mean ± SD of triplicate determinations. Treatment C: fish finger control; Treatment A: fish finger with 5% SWP; Treatment B: fish finger with 10% SWP; Treatment D: fish finger with 15% SWP. a-d Value in the same columns with different superscript letters are significantly different (P<0.05).

3.2.2. Changes in chemical quality indicators of fish finger during storage

TBA is a critical measure for assessing lipid deterioration during storage periods. Results in Table 4 revealed that TBA values (lipid oxidation) increased over the 15-day storage period for all treatments, but the rate of oxidation is slower in samples supplemented with shrimp waste powder (SWP). The control (Treatment C) showed the highest TBA values, starting at 0.438 mg MDA/kg and reaching 2.41 mg MDA/kg by day 15, indicating rapid oxidation. In contrast, treatments with SWP (5%, 10%, and 15%) exhibited lower TBA values, with Treatment D (15% SWP) showing the best results, starting at 0.268 mg MDA/kg and reaching only 0.96 mg MDA/kg by day 15. This suggests that SWP supplementation helps to

reduce lipid oxidation, with higher levels (15% SWP) providing the most effective protection against spoilage, improving the shelf life and quality stability of the fish fingers. The results indicate that the TBA levels across all formulations and storage durations remained below the permissible limits, not exceeding 4.5 mg malonaldehyde/kg, as per the Egyptian Standard (2005). Furthermore, Rossi et al. (2024) indicated that TBA readings exceeding 3 to 4 mg malondialdehyde per 1 kg of fish flesh signify a decline in quality (Bassig et al., 2021; Suparmi et al., 2020). Bassig et al. (2021) mentioned that the inhibition of lipid peroxidation, measured with thiobarbituric-acid-reacting compounds, varied from 11.7% to 51.63%, 17.24% to 63.52%, and 29.31% to 77.39% throughout a concentration range of 250 to 1000 μg/mL. The increasing trend of TBA levels during refrigerated storage signifies a relationship between this index, time, and the temperature of fish finger storage. Numerous investigations have indicated elevated levels of TBA at the conclusion of a storage period (Bassig et al., 2021; Suparmi et al., 2020).

Table 4. Changes in TBA, TVN, TMA and pH values of fish finger supplemented with SWP during storage at 4°C.

Treatments	Storage period (day)					
	0	**3**	**6**	**9**	**12**	**15**
	TBA values (mg MDA/kg)					
C	0.438±0.04^{a}	0.593±0.02^{a}	0.732±0.03^{a}	0.951±0.04^{a}	1.83±0.02^{a}	2.41±0.02^{a}
A	0.369±0.06^{b}	0.483±0.03^{b}	0.632±0.01^{b}	0.751±0.01^{b}	0.93±0.04^{b}	1.63±0.05^{b}
B	0.307±0.03^{c}	0.441±0.04^{c}	0.580±0.03^{c}	0.685±0.05^{c}	0.88±0.04^{b}	1.16±0.03^{c}
D	0.268±0.02^{d}	0.392±0.04^{d}	0.483±0.04^{d}	0.532±0.03^{d}	0.76±0.06^{c}	0.96±0.04^{d}
	TVN values (mg/100 g)					
C	11.23±0.02^{a}	14.51±0.02^{a}	18.73±0.04^{a}	22.34±0.04^{a}	29.42±0.02^{a}	37.41±0.05a
A	9.64±0.06^{b}	12.32±0.04^{b}	15.53±0.03^{b}	19.39±0.02^{b}	24.37±0.04^{b}	31.22±0.05^{b}
B	9.11±0.07^{b}	11.85±0.04^{c}	14.69±0.02^{c}	18.1±0.04^{c}	21.33±0.04^{c}	29.74±0.02^{c}
D	8.53±0.02^{c}	10.34±0.06^{d}	13.85±0.05^{d}	15.37±0.04^{d}	19.11±0.02^{d}	26.54±0.04^{d}
	TMA (mg/100 g)					
C	1.23±0.03^{a}	1.71±0.03^{a}	3.73±0.03^{a}	5.66±0.03^{a}	7.62±0.06^{a}	9.51±0.08^{a}
A	0.92±0.03^{b}	1.32±0.06^{b}	2.93±0.06^{b}	4.04±0.03^{b}	5.41±0.07^{b}	7.43±0.07^{b}
B	0.88±0.04^{b}	1.15±0.03^{c}	2.61±0.04^{b}	3.79±0.04^{c}	4.22±0.05^{c}	6.14±0.07^{c}
D	0.76±0.05^{c}	0.93±0.04^{d}	1.85±0.05^{c}	3.33±0.05^{d}	4.19±0.06^{c}	5.54±0.04^{d}
	pH values					
C	6.9±0.45^{a}	7.2±0.93^{a}	7.4±0.48^{a}	7.5±0.54^{a}	7.1±0.62^{a}	7.4±0.53^{a}

A	6.8±0.39[a]	6.9±0.72[a]	7.2±0.76[a]	7.4±0.32[a]	7.2±0.58[a]	7.2±0.88[a]
B	7.1±0.53[a]	7.3±0.57[a]	7.3±0.31[a]	7.4±0.19[a]	7.2±0.56[a]	7.3±0.21[a]
D	7.1±0.46[a]	7.2±0.21[a]	7.3±0.22[a]	7.5±0.26[a]	7.1±0.84[a]	7.2±0.61[a]

Results are expressed as mean ± SD of triplicate determinations. Treatment C: fish finger control; Treatment A: fish finger with 5% SWP; Treatment B: fish finger with 10% SWP; Treatment D: fish finger with 15% SWP.
a-d Value in the same columns with different superscript letters are significantly different ($P<0.05$).

Table 4 also shows the changes in Total Volatile Nitrogen (TVN) values, a key indicator of fish spoilage, in fish fingers supplemented with SWP over a 15-day storage period at 4°C. TVN values significantly increase over time for all treatments, reflecting the gradual degradation of proteins. The control (Treatment C) has the highest TVN values at all time points, starting at 11.23 mg/100g on day 0 and reaching 37.41 mg/100g by day 15, indicating rapid spoilage. Treatments with SWP (A, B, and D) show lower TVN values, with Treatment D (15% SWP) having the lowest values throughout, starting at 8.53 mg/100g and reaching 26.54 mg/100g by day 15. This suggests that increasing the SWP content helps in reducing the formation of volatile nitrogen compounds, likely due to its antioxidant properties, and thereby slows down the spoilage process. The significant differences in TVN values across the treatments ($P < 0.05$) highlight the protective effect of SWP against fish finger spoilage. Ojagh et al. (2010) discovered that the pretreatment of rainbow trout with 2% chitosan could inhibit the rise in total volatile nitrogen (TVN). Moreover, Fan et al. (2009) discovered that chitosan coating significantly reduced TVN values, hence decelerating the rotting of silver carp. Nanochitosan coating shown superior efficacy compared to chitosan coating in suppressing the rise of TVN concentration in silver carp fillets during cold storage (Ghorabi and Khodanazary, 2020). The data indicate a modest increase ($P <0.05$) in TVN during storage for all samples.

The concentration of trimethylamine (TMA) in muscle is the primary biomarker of fish deterioration (Shahidi and Hossain, 2022; Rossi, 2024). Table 4 presents the changes in TMA values of fish fingers supplemented with SWP over a 15-day storage period at 4°C. TMA values increase with time for all treatments, reflecting the growing spoilage of the fish fingers. The control (Treatment C) shows the highest TMA values at all time points, starting at 1.23 mg/100g on day 0 and reaching 9.51 mg/100g by day 15, indicating rapid spoilage. Treatments with SWP (A, B, and D) demonstrate lower TMA values, with Treatment D (15% SWP) exhibiting the lowest values throughout the storage period, starting at 0.76 mg/100g and increasing to 5.54 mg/100g by day 15. This suggests that higher SWP supplementation helps reduce the production of TMA, likely due to its antioxidant properties, which help slow down the microbial degradation of the fish. The significant differences in TMA values across

treatments **(**$P < 0.05$**)** highlight the protective effect of SWP in preserving the quality of fish fingers during storage (Ozogul et al., 2004; Nirmal et al., 2020).

The natural pH of live fish is slightly above 7.0, generally around 7.3; however, this value significantly decreases post-mortem as the fish undergoes rigor mortis and glycogen is metabolized into lactic acid. In the majority of species, the post-mortem pH ranges from 6.0 to 6.8. The pH value is associated with the post-mortem changes in flesh and is affected by species, food, seasonal variations, activity levels or stress during capture, and muscle category (Rossi et al., 2024; Bassig et al., 2021; Suparmi et al., 2020; Periago et al., 2005). Low pH and moisture levels in seafood items create unfavorable conditions that promote microbial proliferation (Bassig et al., 2021; Suparmi et al., 2020; Rostamzad et al., 2011). Results in Table 4 shows the changes in pH values of fish fingers supplemented with SWP over a 15-day storage period at 4°C. The pH values slightly increase or remain stable throughout the storage period for all treatments, suggesting that the fish fingers do not undergo significant acidification, which is typical in spoilage processes. The control (Treatment C) starts at 6.9 and fluctuates slightly, reaching 7.4 by day 15. Similarly, treatments with SWP (A, B, and D) show minimal changes in pH, remaining around 7.0 to 7.4. Treatment B (10% SWP) has the highest pH values, starting at 7.1 and ending at 7.3, which suggests a relatively stable pH throughout the storage period. Overall, the pH values do not show significant variation across treatments, indicating that SWP supplementation does not substantially affect the pH of the fish fingers, and the changes observed are likely within the normal range for fish product storage. The absence of significant pH changes suggests that spoilage processes like lactic acid production are not accelerating, which is a good indicator of overall product stability during storage. The slight increase in pH values during storage may be due to hydrolysis by microbial enzymes and increase in volatile bases produced (Rossi et al., 2024; Bassig et al., 2021; Mohan et al., 2012).

3.2.3. Microbial quality of fish finger prepared from Anchova fish and supplemented with SWP

The microbiological load of fish fingers is contingent upon the microbial load of the raw fish, the seafood processing environment, sanitary conditions, storage duration and temperature, as well as additional components utilized in their preparation. Table 5 show the total bacterial counts (TBC) of fish fingers in zero time then every 3 days for 2 weeks at refrigerator temperature ($4^oC \pm 1$). The result indicated that TBC in control showed the highest level and increased till storage period end and opposite in treatment D (fish finger with 15%

SWP) the microbial load was low and gradually increased towards till the end of storage period, this may be due to the addition of 15% shrimp waste powder (SWP) was reduce microbial growth These result due to the inhibitory effect of bioactive compound in SWP, which suppressing the growth of microorganisms as well. According to Campo et al. (2000) who mentioned that components such as chitosan and phenolics had antimicrobial effects. The observed levels did not above the maximum threshold (7 log CFU/g) established for fresh and frozen fish by the International Commission on Microbiological Specifications for Foods (ICMSF) (2005). Suparmi et al. (2020) and Bassig et al. (2021) indicated that bacterial proliferation in shrimp croquettes stored at room temperature escalated with prolonged storage duration, reaching a bacterial load of 4.46×10^5 CFU/g after 1 day and 5.1×10^8 CFU/g after 3 days.

Table 5 additionally presents the quantification of coliform bacteria in fish finger samples subjected to cold storage. The coliform bacteria count in fish finger samples varied from 1.53 to 5.87 log CFU/g. A statistically significant ($p < 0.05$) increase in coliform bacteria was noted in control samples relative to treated samples. Treatments containing 15% SWP exhibited the lowest coliform counts due to their antibacterial capabilities. Petrou et al. (2012) reported that chitosan shows antibacterial activity on oysters. According to Tsai and Su (1999) who reported that chitosan from shrimp had antibacterial activity against *E. coli.* Bassig et al. (2021) demonstrated that the product remains microbiologically safe during seven months of storage. Shamshina et al. (2020) noted that the bactericidal, fungicidal, and other intrinsic features of chitin and its derivatives render them very suitable for agricultural uses.

Vibrios are significant emerging food and waterborne diseases in both developing and industrialized countries, attributable to the growth of worldwide food trade. The transmission routes of certain Vibrio species, such as *V. cholerae*, *V. parahaemolyticus*, and *V. vulnificus*, can be specifically attributed to fish items (Espineria et al., 2009). The results of this study demonstrated that *Vibro cholira* was not detected in investigated samples. Rossi et al. (2024) and Bassig et al. (2021) observed that the *Vibro cholerae* in shrimp waste product is not detected**.**

Table 5. Total bacterial and coliform counts (log CFU/g) during cold storage at 4ºC±1.

Treatments	Storage period (day)					
	0	**3**	**6**	**9**	**12**	**15**
	Total bacterial count (TBC)					
C	3.78±0.52^{a}	5.23±0.46^{a}	6.7±0.65^{a}	8.32±0.45^{a}	9.280.66±^{a}	9.63±00.43^{a}
A	2.74±0.64^{b}	4.73±0.22^{bc}	5.54±0.33^{b}	6.65±0.45^{b}	7.21±0.66^{b}	7.45±0.66^{b}
B	2.63±0.33^{b}	3.52±0.44^{c}	4.31±0.54^{c}	5.22±0.53^{c}	5.66±0.85^{c}	5.83±0.58^{c}

D	2.11±0.26^{c}	2.84±0.45^{d}	3.64±0.73^{d}	4.84±0.07^{c}	5.13±0.75^{c}	5.23±0.62^{c}
			Coliform count			
C	2.11±0.23^{a}	2.83±0.17^{a}	4.02±0.34^{a}	4.83±0.44^{a}	5.85±0.66^{a}	5.87±0.66^{a}
A	1.79±0.12^{b}	1.94±0.13^{b}	2.34±0.26^{b}	2.96±0.23^{b}	3.73±0.35^{b}	4.65±0.34^{b}
B	1.56±0.14^{c}	1.87±0.14^{bc}	2.21±0.45^{b}	2.42±0.13^{c}	3.67±0.42^{b}	4.15±0.31^{c}
D	1.53±0.22^{c}	1.66±0.19^{c}	1.75±0.18^{c}	2.17±0.11^{d}	2.87±0.27^{c}	3.42±0.29^{c}
			***Vibro cholerae* count**			
C	ND	ND	ND	ND	ND	ND
A	ND	ND	ND	ND	ND	ND
B	ND	ND	ND	ND	ND	ND
D	ND	ND	ND	ND	ND	ND

Results are expressed as mean ± SD of triplicate determinations. Treatment C: fish finger control; Treatment A: fish finger with 5% SWP; Treatment B: fish finger with 10% SWP; Treatment D: fish finger with 15% SWP. a-d Value in the same columns with different superscript letters are significantly different (P<0.05). ND: not detected.

3.3. Sensory evaluation of fish finger prepared from Anchova fish and supplemented with SWP.

Sensory evaluation is employed to determine the quality of fish based on organoleptic attributes, including color, odor, flavor, texture, and overall acceptability of the product. Sensory evaluation is a straightforward, rapid, and effective technique for assessing product quality. Haq and Hasnain (2013) and Rossi et al. (2024) reported that the sensory evaluation of shrimp waste applications was affected by raw material and storage time. The results revealed that the scores of sensory attributes decreased by increasing storage time. Control sample had significantly lower scores than treated samples ($P < 0.05$). As expected, some quality loss would occur as a result of increasing the time of storage.

The acceptability of fish and fisheries products after preservation is contingent upon alterations in their sensory characteristics. Ojagh et al. (2010) said that samples were deemed safe for human eating till the sensory value attained 4. Fig. 2 illustrates the variations in overall acceptability of fish finger samples during cold storage. The scores of control samples decreased significantly with prolonged storage period, potentially due to lipid oxidation. Rossi et al. (2024) and Haq and Hasnain (2013) mentioned that lipid oxidation during storage of products can affect the sensory properties. However, treatments improved the acceptability score with the samples with 10% SWP having the highest score (7.5). The general acceptability value consistently decreased with storage time increase. Regardless of the treatment, and with statistically significant differences ($p < 0.05$) between the treatments throughout the storage time. Li *et al.* (2012) found a significant decline in general acceptance after 8 days of storage of uncoated large yellow croaker, which corresponded well with a

concomitant increase in bacterial counts. Similarly, in this study, sensory evaluation results appeared to be in consistent with microbial and chemical value analyses. The higher rate of lipid oxidation causes rancidity, which consequently affects the flavor and general acceptability.

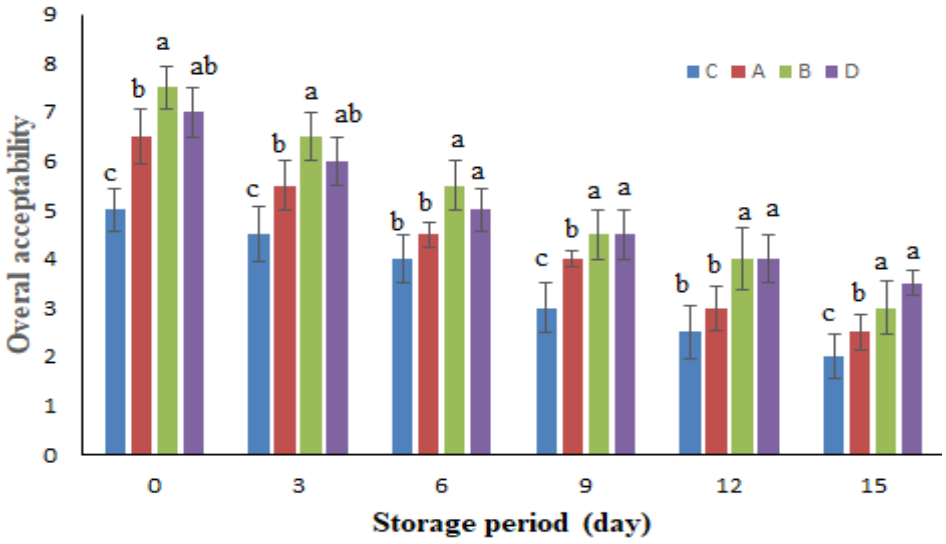

Fig. 2. Overall acceptability scores of fish finger samples during storage at 4°C ±1. Treatment C: fish finger control; Treatment A: fish finger with 5% SWP; Treatment B: fish finger with 10% SWP; Treatment D: fish finger with 15% SWP. a-d Value in the same columns with different superscript letters are significantly different ($P<0.05$). Error bars indicate ±SD.

Conclusion

The shelf life of fish fingers stored under refrigeration can be significantly extended by incorporating shrimp waste powder (SWP)**,** with the optimal percentage being 15% SWP. This enhancement is likely due to the antioxidant properties of SWP, which help slow down the oxidation process. Additionally, sensory evaluation showed that fish fingers containing 15% SWP were more favorable in terms of flavor, taste, texture, and overall acceptability, making them a preferred choice among panelists. Also, 15% SWP fortification in shrimp soup provided the best overall nutritional and sensory properties. This study demonstrates the strong potential of value-added products in the market, offering significant economic benefits to producers. The use of shrimp waste not only provides a cost-effective solution to waste disposal but also results in protein-fortified products, such as shrimp croquettes, which can serve as a high-quality protein source for those suffering from malnutrition. Given its abundance, low cost, and rich protein content, SWP could become a valuable ingredient in the food industry for protein enrichment in various products. However, further research is needed to explore its broader applications and optimize its potential.

Funding

No funding was received for this study.

Declaration of competing interest

The authors declared that they have no conflict of interest.

References

Abuzar, Sharif, H. R., Sharif, M. K., Arshad, R., Rehman, A., Ashraf, W., & Al-Sameen, M. A. (2023). Potential industrial and nutritional applications of shrimp by-products: a review. *International Journal of Food Properties*, 26(2), 3407–3432. https://doi.org/10.1080/10942912.2023.2283378

Ahmadkelayeh, S., & Hawboldt, K. (2020). Extraction of lipids and astaxanthin from crustacean by-products: A review on supercritical CO_2 extraction. Trends in Food Science & Technology 103(5). https://doi.org/10.1016/j.tifs.2020.07.016

AOAC. (2005). Official method of Analysis. 18th Edition, Association of Officiating Analytical Chemists, Washington DC.

Aref, S., Morsy, N., Habiba, R.A., & Zayat, F. M. (2016). Effect of Transglutaminase Enzyme and some Natural Antioxidants on the Quality of Ready to Eat Catfish Fingers during Frozen Storage. *Journal of Food Sciences; Suez Canal University*, 3 (1), 45-55. https://doi.org/10.21608/SCUJ.2016.6664

Ayse, G.I., Nermin, K., & Ozlem, E.C. (2011). Sensorial, chemical and microbiological quality of anchovy cake. *African Journal of Biotechnology*, 10(48), 9870-9874. https://doi.org/10.5897/AJB11.903

Bassig, R. A., Obinque, A. V., Nebres, V. T., Delos Santos, V. H., Peralta, D. M., & Madrid, A. J. J. (2021). Utilization of shrimp head wastes into powder form as raw material for value-added products. *The Philippine Journal of Fisheries*, *28*(1), 181-190. https://doi.org/10.31398/tpjf/28.2.2020A0010.

Bergey's Manual of Systematic Bacteriology (2005). Volume Two The Proteobacteria Part B The Gammaproteo bacteria. ISBN: 978-0. https://doi.org/10.1007/0-387-28022-7

Campo, J. D., Amiot, M., & Nguyen-The, C. (2000). Antimicrobial effect of rosemary extracts. *Journal of Food Protection*, 63, 1359–1368. https://doi.org/10.4315/0362-028x-63.10.1359

Chacko, A., Hyland, P.L., McDade, S.S., Hamilton, P., Russell, S.E.H., & Hall, P.A. (2005). SEPT9_v4 expression induces morphological change, increased motility and disturbed polarity. *Journal of Pathology*, 206, 458–467. https://doi.org/10.1038/sj.bjc.6602753

Difco Manual, (1985). Dehydrated culture media and reagents for microbiology. Laboratories incorporated Detriot. Michigan, 48232 USA. PP 621.

Egyptian Standard Specifications (2005). Quick frozen fish products breaded or in batter. ES 3495/2005.

Espineria, M., Atanassova, M., Vieites, J.M., Santaclara, F.J. (2009). Validation of a method for the detection of five species, serogroups, biotypes and virulence factors of Vibrio

by multiplex PCR in fish and seafood. *Food Microbiology*, 27, 122–131. https://doi.org/10.1016/j.fm.2009.09.004

Essuman, K.M. (2005). Development of Local Smoke Dried Shrimp For Production of Royco Bouillon Cube. In: FAO Fisheries Report No.712. Ndenn J, Teutscher F, Diei-Ouadi Y, editors. Report and papers presented at the seventh FAO Expert Consultation on Fish Technology in Africa. Saly-Mbour, Republic of Senegal. 10-13 Dec 2001. FAO, Rome. 170 p.

Fan, J., Gu, X.S., Guise, K.G., Liu, X., Fossella, J., Wang, H.B., & Posner, M.I. (2009). Testing the behavioral interaction and integration of attentional networks. *Brain Cognition*, 70, 209–220. https://doi.org/10.1016/j.bandc.2009.02.002.

Fernandes, T.M., Jada, S., Ahada, S., Jmdao, C., & Mjda, C. (2013) Flour production from shrimp by-products and sensory evaluation of flour-based products. *Pesquisa Agropecuária Brasileira*, 48(8), 962-967. https://doi.org/10.1590/S0100-204X2013000800022.

Fotodimas, I., Ioannou, Z., & Kanlis, G. A. (2024). Review of the Benefits of the Sustainable Utilization of Shrimp Waste to Produce Novel Foods and the Impact on Human Health. *Sustainability*, 16(16), 6909. https://doi.org/10.3390/su16166909

Ghorabi, R. S., & Khodanazary, A. (2020). Effects of chitosan and nano-chitosan as coating materials on the quality properties of large scale tongue sole *Cynoglossus arel* during super-chilling storage. *Iranian Journal of Fisheries Sciences*, *19*(5), 2242-2257.

Ghorban, K., Ezzeddini, R., Eslami, M., Yousefi, B., Sadighi Moghaddam, B., & Tahoori, M.T., (2019). "PTPN22 1858 C/T polymorphism is associated with alteration of cytokine profiles as a potential pathogenic mechanism in rheumatoid arthritis". *Immunology Letters*, 216(13), 106–113. https://doi.org/10.1016/j.imlet.2019.10.010

Hajeb, P., & Jinap, S. (2012). Fermented Shrimp Paste Products as Source of Umami in Southeast Asia. *Journal of Nutrition and Food Science*, S10, 006. https://doi.org/10.4172/2155-9600.S10-006

Haq, M. A., & Hasnain, A. (2013). Studies on shelf life extension of chilgoza (Pinus gerardiana). *Asian Journal of Chemistry*, 25(1), 343 - 348. https://doi.org/10.4172/2155-9600.S10-006

ICMSF. (2005). Microorganisms in Foods 6: Microbial ecology of food commodities, 2nd edition. New York: Kluwer Academic/Plenum Publishers

Izci, L. (2010). Utilization and quality of fish fingers from Prussian carp (*Carassius gibelio* Bloch, 1782), 207-210.

Jafari, A. M., Gharibi,S.; Farjadmand, F, & Sadighara, P. (2012). Extraction of shrimp waste pigments by enzymatic and alkaline treatment: evaluation by inhibition of lipid peroxidation. *Journal of Material Cycles and Waste Management*, 14, 411–413. http://dx.doi.org/10.1007/s10163-012-0077-6

Jeyasanta, I.K., Jeyanth Allwin, S.I., & Patterson, J. (2017). Development of nutritious chutney powder from shrimp head waste for better utilization to reduce environmental pollution. *Research Journal of Animal, Veterinary and Fishery Sciences*, 5(3), 1-8.

Khan, M., & Nowsad, A. K. M. A. (2012). Development of protein enriched shrimp crackers from shrimp shell wastes. *Journal Bangladesh Agricultural University*, 10(2), 367–374. http://dx.doi.org/10.3329/jbau.v10i2.14930

Li, M., Yeung, J. M. Y., Cherny, S. S., & Sham, P. C. (2012). Evaluating the effective numbers of independent tests and significant p-value thresholds in commercial genotyping arrays and public imputation reference datasets. *Human Genetics*, 131, 747–756. https://doi.org/10.1007/s00439-011-1118-2

Maia, M.L., Grosso, C., Barroso, M.F., Silva, A., Delerue-Matos, C., & Domingues, V.F. (2023). Bioactive Compounds of Shrimp Shell Waste from Palaemon Serratus and Palaemon Varians from Portuguese Coast. *Antioxidants*, 12, 435. https://doi.org/10.3390/antiox12020435

Malle, P., & Poumeyrol, M. (1989). A New Chemical criterion for the Quality Control of Fish: Trimetylamine/Total Volatile Basic Nitrogen (%). *Journal of Food Protection*, 52, 419-423. https://doi.org/10.4315/0362-028X-52.6.419

Mizani, A. M., & Aminlari, B. M. (2007). A new process for deproteinization of chitin from shrimp head waste. In Proceedings of European Congress of Chemical Engineering (ECCE-6) (pp. 16-20). September Copenhagen.

Mohan, V., Deepa, M., Pradeepa, R., Prathiba, V., Datta, M., Ravikumar, S., & Anjana, R. M. (2012). Prevention of diabetes in rural India with a telemedicine intervention. Journal of Diabetes Science and Technology, 6(6), 1355-1364. https://doi.org/10.1177/193229681200600614

Nirmal, N.P., & Benjakul, S. (2009). Melanosis and quality changes of Pacific white shrimp (*Litopenaeus vannamei*) treated with catechin during iced storage. *Journal of Agriculture and Food Chemistry*, 57 (9), 3578-3586. http://dx.doi.org/10.1021/jf900051e

Nirmal, N.P., Santivarangkna, C., Rajput, M.S., & Benjakul, S. (2020). Trends in shrimp processing waste utilization: An Industrial Prospective. *Trends in Food Science and Technology*, 103, 20–35. http://dx.doi.org/10.1016/j.tifs.2020.07.001

Noguerola, A.R., & Blanch, (2008). Identification of *Vibrio* spp. with a set of dichotomous keys. *Journal of Applied Microbiology*, 105(1), 175-185. https://doi.org/10.1111/j.1365-2672.2008.03730.x

Ojagh, S.M., Rezaei, M., & Razavi, S.H. (2010). Effect of chitosan coatings enriched with cinnamon oil on the quality of refrigerated rainbow trout. *Food Chemistry*, 120(1), 193-198. https://doi.org/10.1016/j.foodchem.2009.10.006

Osibona, A. O., Kusemiju, K., & Akande, G. R. (2009). Fatty Acid Composition and Amino Acid Profile of Two Freshwater Species, African Catfish (*Clarias Gariepinus*) and Tilapia (*Tilapia Zillii*). *African Journal of Food, Agriculture, Nutrition and Development*, 9(1), 608-621.

Ozogul, F., Polat,A., & Özogul,Y.(2004). The effects of modified atmosphere packaging and vacuum packaging on chemical, sensory and microbiological changes of sardines (*Sardina pilchardus*). *Food Chemistry*, 85(1), 49-57. https://doi.org/10.1016/j.foodchem.2003.05.006

Pattanaik, S.S., Sawant, P.B., Xavier, K.A.M., Dube, K., Srivastava, P.P., Dhanabalan, V., & Chadha, N.K. (2020). Characterization of carotenoprotein from different shrimp shell waste for possible use as supplementary nutritive feed ingredient in animal diets. *Aquaculture*, 515, 734594. http://dx.doi.org/10.1016/j.aquaculture.2019.734594

Periago, M.J., Ayala, M.D., López-Albors, O., Abdel, I., Martínez, C., García -Alcázar, A., Ros, G., & Gil, G. (2005). Muscle cellularity and flesh quality of wild and farmed sea bass, *Dicentrarchus labrax* L. *Aquaculture*, 249, 175 - 188. https://doi.org/10.1016/j.aquaculture.2005.02.047

Petrou, S., Tsiraki, M., Giatrakou, V., & Savvaidis, I. N. (2012). Chitosan dipping or oregano oil treatments, singly or combined on modified atmosphere packaged chicken breast meat. *International Journal of Food Microbiology*, 156(3), 264-271. https://doi.org/10.1016/j.ijfoodmicro.2012.04.002

Ray, S., Mondal, P., & Paul, A. (2021). Role of shrimp farming in socio-economic elevation and professional satisfaction in coastal communities. *Aquaculture Reports*, 20, 100708. https://doi.org/10.1016/j.aqrep.2021.100708

Rossi, N., Grosso, C., & Delerue-Matos, C. (2024). Shrimp waste upcycling: unveiling the potential of polysaccharides, proteins, carotenoids, and fatty acids with emphasis on extraction techniques and bioactive properties. Mar. *Drugs*, 22, 153. https://doi.org/10.3390/md22040153

Rostamzad, H., Shabanpour, B., Shabani, A. & Shahiri, H. (2011). Enhancement of the storage quality of frozen Persian sturgeon fillets by using of ascorbic acid. *International Food Research Journal*, 18, 109-116.

Ruangwicha, J., Cheirsilp, B., & Suyotha, W. (2024). Green biorefinery of shrimp shell waste for α-chitin and high-value co-products through successive fermentation by co-lactic acid bacteria and proteolytic fungus. *Bioresource Technology*, 393, 130106. https://doi.org/10.1016/j.biortech.2023.130106

Shahidi, F. (1994). In: Sea Foods: Chemistry, processing, technology and quality, Ed. by F. Shahidi and J. R. Botta. Blackie Academic and Professional, London, New York.. 320–333 pp.

Shahidi, F., & Hossain, A. (2022). Preservation of aquatic food using edible films and coatings containing essential oils: A review. *Critical Reviews in Food Science and Nutrition*, 62, 1–40. https://doi.org/10.1080/10408398.2020.1812048

Shamshina, J.L., Kelly, A., Oldham, T., & Rogers, R.D. (2020). Agricultural uses of chitin polymers. *Environmental Chemistry Letters*, 18 (1), 53-60. https://doi.org/10.1080/10408398.2020.1812048

Shiv, M.S., Siddhnath, Ravikant B., Abdul A., Narendra V., & Bhogeshwar B. C. (2018). Shrimp waste powder – potential as protein supplement . *International Journal of Pure Applied Biosciences*, 6 (6): 401-406. http://dx.doi.org/10.18782/2320-7051.7141

Suparmi, Edison, Sari, N.I., Sumarto, & Rusilo R. (2020). Study on the quality of natural flavor powder made from shrimp waste. Proceedings of the 8th International and National Seminar on Fisheries and Marine Science, IOP Conference Series Earth and Environmental Science. 430:012007. Pekanburu: IOP Publishing. p.1-5. http://dx.doi.org/10.1088/1755-1315/430/1/012007

Surendran, P.K., Thampuran N., Nambiar, V., & Lalitha, K.V. (2006). Laboratory manual on microbiological examination of seafood. Central Institute of Fisheries Technology (CIFT), 2nd Edition. https://doi.org/10.1007/978-981-32-9574-2_2

Tarladgis, B.G., Watts, B.M., Younathan, M.T., & Dugan, L.R. Jr. (1960). A distillation method for quantitative determination of malonaldehyde in rancid foods. *Journal of American Oil Chemist Society*, 37, 44-48.

Teerasuntonwat, P., & Raksakulthai, N. (1995). Production of flavouring agent from shrimp heads. *ASEAN Food Journal* (Malaysia).

Tokur, B., Özkutuk, A.S., Atici, E., & Ozyurt, C.E. (2006). Chemical and sensory quality changes of fish fingers, made from mirror carp (*Cyprinus carpio* L., 1758), during frozen storage (−18°C). *Food Chemistry*, 99(2), 335-341. http://dx.doi.org/10.1016/j.foodchem.2005.07.044

Tsai, G. J., & Su, W. H. (1999). Antibacterial activity of shrimp chitosan against *Escherichia coli*. *Journal of Food Protection*, 62(3), 239-243. https://doi.org/10.4315/0362-028x-62.3.239

Xu, Y., Ye, J., Zhou, D., & Su, L. (2020). Research progress on applications of calcium derived from marine organisms. *Scientific Reports*, *10*(1), 18425. https://doi.org/10.1038/s41598-020-75575-8