Saudi Journal of Biological Sciences 29 (2022) 640–649

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Evaluating the effects of different processing methods on the nutritional composition of shrimp and the antioxidant activity of shrimp powder

Nora A. AlFaris [a], Ghedeir M. Alshammari [b], Jozaa Z. AlTamimi [a], Lujain A. AlMousa [a], Reham I. Alagal [a], Nora M. AlKehayez [a], Dalal H. Aljabryn [a,*], Muneer M. Alsayadi [c], Mohammed Abdo Yahya [b]

[a] Department of Physical Sport Science, Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia
[b] Department of Food Science and Nutrition, College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia
[c] Department of Food Science and Technology, Faculty of Agriculture and Food Science, Ibb University, Ibb, Yemen

ARTICLE INFO

Article history:
Received 15 July 2021
Revised 9 September 2021
Accepted 12 September 2021
Available online 20 September 2021

Keyword:
Shrimp
Nutritional composition
Antioxidant activity
Macronutrients
Cooking processes

ABSTRACT

Shrimp is a prevalent food in the Arabian Gulf that is known for its good sensory properties and high nutritional value. The aim of the present work was to assess the effects of diverse processing methods on the nutritional composition of shrimp and the antioxidant activity of shrimp powder. Shrimp (*Penaeus semisulcatus*) flesh was treated using four processes (salting, frying, grilling, and boiling), following which its macronutrient content, fatty acid profile, vitamins and mineral contents were measured. Also, the antioxidant activity of all shrimp powder extracts was assessed using the 2, 2 diphenyl 1 picrylhydrazyl (DPPH), linoleic acid oxidation inhibition, and reducing power methods. The results revealed that the fresh and processed shrimp flesh had significant nutritional value and the fresh and treated shrimp powders have high antioxidant activity, but the cooking processes have significant effects on the nutritional value and antioxidant activity of shrimp flesh. These effects were greater significantly in grilled shrimp followed by boiled shrimp and then fried shrimp. It is concluded that the high nutritional value and antioxidant activity of shrimp flesh make it an important food for nutritional health promotion for the community.

1. Introduction

Shrimps belong to the class Crustacea and are considered from the utmost economically significant seafood worldwide (Oosterveer, 2006). Nutritionally, shrimp protein has high bioavailability because it is more easily digested (85digestibility) than proteins from different sources. The Rubian or green tiger shrimp (*Penaeus semisulcatus*) comprises a portion of the regular diet in the Arabian Gulf and is reported to be a useful food due to its high contents of protein and minerals such as copper (Cu), magnesium (Mg), calcium (Ca) zinc (Zn) and phosphorus (P) (Musaiger and D'Souza, 2008). For instance, the flesh of shrimps in the genus *Parapenaeus* has an average content of 76.74% water, 0.91% fat, 1.71% ash, and 0.49% P, as well as 22.07% crude protein, which comprises 76.5% pure protein. The protein in shrimp flesh includes large quantities of the amino acids histidine, proline, and arginine and low amounts of the amino acids valine, threonine, lysine, tryptophan, and methionine (Teofil et al., 1969). It has also been shown that *Penaeus monodon* (tiger shrimp), *Fenneropenaeus indicus* (Indian white shrimp), and *Litopenaeus vannamei* (Pacific white leg shrimp) have higher amounts of crude protein (23.60% ± 1.63%, 22.87% ± 1.63%, and 19.80% ± 0.04%, respectively) in the edible portions but higher amounts of ash content (7.94% ± 0.17%, 9.03% ± 0.17%, 6.75% ± 0.47%, respectively) and total fiber (1.54% ± 0.13%, 1.56% ± 0.08%, 3.31% ± 0.06%, respectively) in inedible slices (Ali et al., 2017).

Pink shrimp (*P. notialis*) originating from three different water sources (sea, river, and lagoon) contained 25.93%–34.42% protein, 11.85%–18.25% ash, 0.76%–1.83% fat, and 9.22%–12.72% moisture (Akuamoa et al., 2018). The flesh of *P. notialis* had a proximate composition of 15.4% moisture, 19.9% total ash, 44.7% protein, 8.9% fiber, 8.5% fat, and 2.6% carbohydrate (% dry weight), and contains 1119.5 kJ energy. Shrimp have been shown to contain 865 mg/g protein in the flesh and 740 mg/g protein in the shell (Adeyeye

* Corresponding author at: Riyadh 11451, P.O. Box 2460, Saudi Arabia.
E-mail address: dhaljabryn@pnu.edu.sa (D.H. Aljabryn).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.09.029
1319-562X/

et al., 2008). Cultured and wild *Penaeus semisulcatus* contain 22.76% and 23.53% protein, 1.44% and 0.76% lipid, 75.10%, and 75.18% moisture, and 1.36% and 1.62% ash, respectively, and mainly contained the saturated fatty acids (SFAs) palmitic acid (C16) and stearic acid (C18), the monounsaturated fatty acid (MUFA) oleic acid (C18:1 cis9), and the polyunsaturated fatty acids PUFAs, docosahexaenoic acid (DHA; C22:6n-3) and eicosapentaenoic acid (EPA; C20:5n-3) (YANAR et al., 2011).

P. monodon has been found to contain 24.58% protein, 8.32% lipid, 3.65% sugar, and 3.04% ash (Jeyasanta and Patterson, 2017). The protein content includes the essential amino acids threonine, valine, arginine, methionine, isoleucine, leucine, lysine, phenylalanine, and histidine were 2.75, 3.78, 6.49, 5.04, 6.21, 2.57, 6.54, 5.58 and 3.31 (mg/100 g) and the nonessential amino acids aspartic acid, glutamic acid, cysteine, tyrosine, alanine, glycine, proline and serine were 4.93, 5.42, 1.49, 2.44, 1.09, 2.73, 2.97 and 3.73 (mg/100 g) (Jeyasanta and Patterson, 2017). The lipid content includes the fatty acids Lauric, myristic, palmitic, stearic, behenic, palmitoleic, oleic, nervonic, linoleic, linolenic, arachidonic acid were 2.5, 0.95, 2.7, 0.78, 1.67, 2.28, 6.10, 4.71, 11.64, 2.85, and 3.38 (mg/100 g) while EPA and DHA were 11.13 and 8.85 (mg/100 g) (Jeyasanta and Patterson, 2017).

Shrimp *L. vannamei* processing waste possesses antioxidative and antimicrobial activity (Arancibia et al., 2014). Furthermore, the shrimp byproduct liquid hydrolysate has been shown to have high essential amino acid and ash contents, indicating a high nutritional value (Bueno-Solano et al., 2009). Peralta et al. (2005), showed antioxidant activity for salt-fermented shrimp, which they considered to have resulted from shrimp original antioxidants rather than the fermentation process. Other findings found that a sufficiently long fermentation period may increase the antioxidant ability and nutritional contents of the paste of salted and fermented shrimp (Peralta et al., 2008).

Shrimp flesh is processed using several different methods and consumed in several different forms in a range of recipes, and these processes alter the micronutrient and macronutrient contents and the bioactivity of the flesh (Yamamoto and Imose, 1989; Castrillon et al., 1999). However, there is currently a lack of data on the effects of different processing methods on the nutritional quality of shrimp flesh in Saudi Arabia and Arabian countries. Consequently, the aim of the current work was to assess the effects of salting, grilling, frying, and boiling on the macronutrient and micronutrient contents of shrimp flesh, as well as the antioxidant activity of shrimp powder resulting from each of these processing methods.

2. Materials and methods

2.1. Shrimp flesh collection

Fresh shrimp (*Penaeus semisulcatus*) (20 kg; average length, 8 cm) were provided by a certified supplier at Riyadh fish market, Kingdom of Saudi Arabia. The shrimp were reserved in a box filled with ice from the time of fishing until the time of purchase and were used immediately after purchase.

2.2. Shrimp processing

Prior to processing, each shrimp was cleaned, then the legs, shell, and tail were removed carefully. The flesh was then processed by using four different ways, as described below. Salted shrimp was prepared by adding 1 teaspoon of salt per 500 g of flesh. The samples were then placed in sealed packages and kept in the refrigerator until use. The salted samples were used for all following processes. Grilled shrimp was prepared by grilling on a flat grill for 10 min. Fried shrimp was prepared frying in 750 mL of sunflower oil for 7 min, and wrapped in special cooking filter paper. Boiled shrimp was prepared by boiling in 3 cups of water for 15 min in a stainless steel pan. Samples from all processes were then cooled, weighed, placed in sealed packages, and stored in the refrigerator until use.

The flesh of all of the shrimp in each treatment was homogenized by blender and then analyzed to assess the macronutrient, vitamin, lipid, and mineral contents and compositions. All assessments were done in triplicate.

2.3. Determination of the macronutrients content

The protein, moisture, carbohydrate fat, and ash contents of the salted, grilled, fried, and boiled shrimp samples were determined. The moisture was determined by drying shrimp flesh samples at 105 °C to a perpetual weight using the oven. The protein amount was determined by determining the nitrogen (N) using the Kjeldahl method, protein value was calculated using the 6.25 factor. The soxhlet method was used to determined fat. The ash rate was measured by a gravimetric method by heating the samples in a muffle furnace at 525 °C for 24 h. Finally, carbohydrate concentration was calculated as the sum of all previous contents minus 100 (AOAC, 2002).

2.4. Determination of the lipid composition

For determination of Fatty acids profiles of the fresh and processed shrimp. First, fatty acid methyl esters (FAMEs) were generated by *trans*-esterification of the oils extracts of methanol (MeOH), as described before (Choo et al., 2020). Briefly, the extracted fats of each process (50 mg) were drenched in 5 mL of 0.5 M NaOH (in MeOH) and boiled for 5 min. then it was cooled and added to 4 mL of 12% boron trifluoride diethyl etherate (BF3) (in MeOH). This mixture was boiled for a second time for 25 min, following by adding 2 mL of isocantane for separation. FAME analysis was undertaken using a capillary gas chromatography system (model 7890A; Agilent Technologies, CA, USA) equipped with a 5975C Inert Mass Selective Detector. A special column was used for the separation of FAMEs (Supelco SPTM 2560; 0.2 lm film thickness, 0.25 mm inner diameter, 100 m length; (Germany). The samples were dissolved in dichloromethane (CH_2Cl_2) prior to injection, and the following analysis conditions were used: injection volume, 1 mL; initial temperature, 140 °C; final temperature, 240 °C; and heating rate, 4 °C/min. All fatty acids were recognized by their retention time comparing with a standard mixture of fatty acids37 (FAME Mix 47 885-U; Supelco, Germany). The fatty acids, SFAs, MUFAs, and PUFAs levels were then quantified using the calibration curve of the standard or based on their peak areas in relation to all eluted fatty acids in the sample the results were presented as % of total fat or mg/100 g.

2.5. Determination of the vitamins content

Vitamins contents of the fresh and processes shrimp were determined as follows. The contents of vitamin B1, vitamin B2, vitamin B3, vitamin B6, and vitamin B12 were measured by high-performance liquid chromatography (HPLC) (Eitenmiller and Landen, 1999; Ersoy and Özeren, 2009). Using a KNUAER system (Germany) with the following conditions: wavelength, 245 nm; injection volume, 20 L; flow rate, 1.0 mL/min; mobile phase, 1000 mL of phosphate solvent and 360 mL of methanol; pressure, 150–160 bar and running time, 22 min. Ascorbic acid was determined using a 2, 4-dinitrophenyl hydrazine (DNPH) method with an ultraviolet (UV)-visible spectrophotometer (Ben Mussa and El Sharaa, 2014). Vitamin E was measured by the spectrophotometric

method, as early described (Rutkowski and Grzegorczyk, 2007). The vitamin K content was determined by HPLC (Eitenmiller and Landen, 1999)., while the vitamin A content was assessed by HPLC using a Thermo Scientific™ Specta system (Thermo Fisher Scientific Inc., Waltham MA, USA) that equipped with a Hypersil™ ODS-2 reversed-phase analytical column (250 × 4.6 mm, 5 μm; Thermo Fisher Scientific Inc.). Finally, the vitamin A content was measured by using UV detection at 325 nm (Stancheva and Dobreva, 2013).

2.6. Determination of minerals content

Contents of the minerals Iron (Fe), Magnesium (Mg), Potassium (K), Calcium (Ca), Sodium (Na), Copper (Cu), and Zinc (Zn)were determined by digesting the samples in nitric acid (HNO_3) and measuring the absorbance of the resulting solution with an atomic absorption spectrophotometer (Savant A; GBC Scientific Equipment, Australia) (AOAC, 2002). The phosphorus (P) content was estimated by using Barton's reagent and spectrophotometric method (Uran and Gokoglu, 2014). The absorbance at 430 nm was taken as the result, and standard curves were utilized to assess all element content.

2.7. Determination of the antioxidant activity

2.7.1. Preparation of the shrimp powder

Shrimp powder was prepared for each treatment group by drying the flesh at 50 °C for 72 h, and then cooling and crushing the dried samples. Each shrimp powder was then retained in a sealed package and saved in a refrigerator until analysis.

2.7.2. Shrimp powder extraction

Each shrimp powder sample was extracted as formerly described (BENJAKUL et al., 2009). Briefly, 1 g of each shrimp powder was solved in 100 mL of distilled water, stirred at room temperature for 30 min, it then centrifuged at 3000*g* at room temperature for 30 min to remove any undissolved remains. The supernatant was stowed in a capped bottle at − 20 °C until using for assessment of the antioxidant activity.

2.7.3. Determination of DPPH scavenging activity

$$\text{DPPH radical scavenging activity } (\%) = \frac{A_{\text{control517}} - A_{\text{sample517}}}{A_{\text{control517}}} \times 100 \quad (1)$$

The DPPH radical scavenging effects of each shrimp powder extract were evaluated by (DPPH) Scavenging Activity method (BinMowyna and Alsayadi, 2020). The absorbance of solutions was then taken at 517 nm, and the antioxidant activity against DPPH (%) was calculated as follows:

Where $A_{\text{control517}}$ and $A_{\text{sample517}}$ are the absorbance at 517 nm of the control and sample respectively.

2.7.4. Determination of linoleic acid system antioxidant activity

The antioxidant activities of the shrimp powder extracts were determined using the linoleic acid and thiocyanate system as described by Osawa and Namiki, (1981). The antioxidant activity (%) was then calculated by the following equation:

$$\text{Antioxidant activity } (\%) = \frac{A_{\text{control500}} - A_{\text{sample500}}}{A_{\text{control500}}} \times 100 \quad (2)$$

where $A_{\text{control500}}$ and $A_{\text{sample500}}$ are the absorbance of the control and sample at 500 nm, respectively.

2.7.5. Determination of the reducing power

The reducing power of each shrimp powder extract was determined following the method reported by Yen and Duh, (1993), absorbance was measured at 700 nm.

2.8. Statistical analysis

The differences between the obtained values (means ± standard deviations) were analyzed by one-way analysis of variance followed by Newman-Keuls test using SPSS V. 21 (SPSS Inc., Chicago, IL, USA). Differences were considered significant statistically at $p < 0.05$.

3. Results

3.1. Macronutrients content

The macronutrient contents of the shrimp flesh samples treated with different processing ways are exposed in Table 1. The fresh and salted shrimp moisture was significantly higher than those of the grilled, fried, and boiled shrimp ($p \leq 0.05$). The grilled shrimp protein was significantly higher than that in the fried, boiled, salted, and fresh shrimp ($p \leq 0.05$). Fat concentration was also significantly increased in all different cooking processing methods ($p \leq 0.05$), being uppermost in the fried shrimp, followed by boiled and grilled shrimp, and lowermost in the salted and fresh shrimp. There was no significant difference in the carbohydrate among treatments ($p > 0.05$). Finally, the ash content was developed significantly in the fried shrimp than in all other treatment groups and in the grilled and salted shrimp than in the fresh and boiled shrimp ($p \leq 0.05$).

3.2. Lipid composition

The lipid contents {MUFAs, PUFAs, SFAs, cholesterol, total omega 6 fatty acids (Σω6), and omega 3 fatty acids (Σω3)} total and compositions (PUFA/SFA and Σω6/Σωn3) of the shrimp flesh samples treated with different processing methods are shown in Table 3. The concentration of PUFAs was maximum in fried shrimp, followed by the fresh, salted, boiled, and grilled shrimp, respectively. Similarly, the concentration of MUFAs was highest in the fried shrimp and lowest in the boiled shrimp, whereas the concentration of SFAs was highest in the fresh shrimp and lowest in the fried shrimp, and the concentration of cholesterol was uppermost in the fresh shrimp and last in the grilled shrimp. The Σω6 concentration was highest in the fried shrimp and lowest in the boiled shrimp, while the Σω3 concentration was highest in the salted shrimp and lowest in the boiled shrimp. The PUFA/SFA ratio was highest in the fried shrimp and lowest in the grilled shrimp, while the Σω6/Σω3 ratio was highest in fried shrimp and lowermost in boiled shrimp.

Statistically, PUFA and MUFA were higher in the fried shrimp and lower in the grilled and boiled shrimp than in the fresh and salted shrimp ($p \leq 0.05$). By contrast, the SFA was lower with significant differences in the fried shrimp than that of all other treatments ($p \leq 0.05$), while grilling caused a moderate reduction and boiling caused the least reduction in SFAs. While, no significant difference in cholesterol between fresh, salted, and fried shrimp ($p > 0.05$). However, both grilled and boiled shrimp had significantly lower cholesterol. The Σω6 content was significantly higher in fried shrimp and lower in both grilled and boiled shrimp ($p \leq 0.05$). By contrast, Σω3 was significantly lower in fried, grilled, and boiled shrimp. Both PUFA/SFA and Σω6/Σω3 ratios were elevated significantly in fried shrimp ($p \leq 0.05$). However, the PUFA/SFA ratio was significantly greater in the boiled shrimp than in the

Table 1
Macronutrients content % in the fresh and treated shrimp flesh.

Nutrient	Fresh	Salted	Fried	Grilled	Boiled
Moisture (%)	73.77 ± 0.33[a]	73.20 ± 0.43[a]	68.27 ± 1.43[c]	67.51 ± 1.87[b]	66.61 ± 1.59[d]
Protein (%)	18.39 ± 0.25[c]	18.88 ± 0.26[c]	20.95 ± 1.15[b]	25.65 ± 1.07[a]	20.02 ± 1.21[b]
Fat (%)	3.75 ± 0.01[d]	3.29 ± 0.02[d]	6.32 ± 0.98[a]	4.84 ± 0.88[c]	5.12 ± 0.67[b]
Carbohydrate (%)	1.28 ± 0.03	1.42 ± 0.04	1.1 ± 0.03	1.16 ± 0.02	1.56 ± 0.03
Ash (%)	2.81 ± 0.22[c]	3.21 ± 0.18[b]	4.26 ± 0.06[a]	3.51 ± 0.05[b]	2.64 ± 0.20[c]

Values are the means ± St.D. the different letters in same row indicate the significant different ($p < 0.05$).

grilled shrimp, whereas the Σω6/Σω3 ratio showed the reverse pattern.

3.3. Vitamins content

The vitamin contents of the shrimp flesh samples treated with different processing methods are shown in Table 2 of Vitamins A, K, and E concentrations were generally upper in the fried shrimp and lower in the grilled and boiled shrimp than in the fresh and salted shrimp. By contrast, the concentrations of vitamin C and all types of vitamin B were generally lower in the salted and cooked shrimp than in the fresh shrimp, with the grilling process followed by the frying process having the smallest effects and the boiling process having the greatest effect.

Statistical analysis showed that the vitamin A and E content was higher significantly in both the salted and fried shrimp than in the fresh, grilled, and boiled shrimp ($p \leq 0.05$). The vitamin K was lowered significantly in both the grilled and boiled shrimp than in all other treatment groups ($p \leq 0.05$). Vitamin C decreased to half in grilled and fried shrimp and by three-quarters in boiled shrimp significantly ($p \leq 0.05$). Vitamins B1 and B2 were lowered significantly in all of the treated shrimp than in the fresh shrimp ($p \leq 0.05$). The vitamin B3 and B6 content was also significantly reduced in the grilled shrimp, followed by the salted, fried, and boiled shrimp ($p \leq 0.05$). Finally, vitamin B12 was significantly lowered in all treated shrimp ($p \leq 0.05$), without significant differences between different processing methods.

3.4. Minerals content

The mineral contents of the shrimp flesh treated with different processing methods are shown in Table 4. The Ca content of the fried shrimp was uppermost and it was little in boiled shrimp, while the Fe concentration was the highest in the grilled shrimp and the lowest in the boiled shrimp, the Mg amount of the fried shrimp was the highest and in the fresh shrimp it was lowest, the P quantity was highest in fried shrimp and lowest in the boiled shrimp, and the K, Na, Zn, and Cu concentrations were found to be high in the grilled shrimp and low in boiled shrimp.

Statistical analysis showed that the mineral contents were high with significant differences in grilled and fried shrimp and significantly lower in the boiled shrimp than in the fresh and salted shrimp ($p \leq 0.05$).

3.5. Antioxidant activities of the shrimp powder extracts

The antioxidant effects of methanolic extracts of the shrimp powders obtained from the different processing methods were determined using the DPPH, linoleic acid oxidation inhibition, and reducing power activity methods.

3.5.1. DPPH scavenging activity

The scavenging activities of the different shrimp powder extracts against DPPH expressed as percentages of antioxidant activity are presented in Table 5. It was highest in the grilled shrimp powder extract, followed by the boiled, fresh, salted, and fried shrimp powder extracts, respectively. Both the grilled and boiled shrimp powder extracts had greater DPPH scavenging actions than that of the other shrimp powder extracts, while the fried shrimp powder extract had the lower scavenging activity against DPPH than all of the other shrimp powder extracts ($p \leq 0.05$).

3.5.2. Inhibition activity of linoleic acid oxidation

The Inhibition activity of Linoleic Acid oxidation of the different shrimp powder extracts expressed as percentages of antioxidant activity is shown in Table 5. The inhibition effects of linoleic acid oxidation were highest in the grilled shrimp powder extract, followed by the boiled, salted, fresh, and fried shrimp powder extracts, respectively. Both the grilled and boiled shrimp powder extracts exhibited significantly higher inhibition of linoleic acid oxidation than the fresh and salted shrimp powder extracts, while the fried shrimp powder extract had a significantly lower value ($p \leq 0.05$).

3.5.3. Reducing power

Table 5 display the results of reducing powers of the different shrimp powder extracts. It was highest in the grilled shrimp pow-

Table 2
Vitamins content % in the fresh and treated shrimp flesh.

Vitamins	Fresh	Salted	Fried	Grilled	Boiled
A (IU)	0.30 ± 0.02[b]	0.34 ± 0.02[a]	0.34 ± 0.03[a]	0.31 ± 0.06[b]	0.26 ± 0.01[c]
K (mg)	4.73 ± 0.20[a]	4.63 ± 0.16[a]	4.87 ± 0.62[a]	3.64 ± 0.43[b]	3.23 ± 0.76[b]
E (mg)	10.30 ± 0.33[b]	12.19 ± 0.35[a]	12.74 ± 0.51[a]	9.43 ± 1.02[b]	8.73 ± 1.4[c]
C (mg)	8.33 ± 0.53[a]	8.16 ± 0.19[a]	4.37 ± 0.65[b]	5.22 ± 0.13[b]	2.32 ± 0.82[c]
B1 (μg)	18.55 ± 2.95[a]	9.63 ± 2.50[b]	4.42 ± 1.4[d]	7.83 ± 1.73[c]	6.28 ± 0.65[c]
B2 (μg)	34.57 ± 1.44[a]	19.11 ± 1.59[b]	14.66 ± 2.4[c]	15.32 ± 3.7[c]	10.02 ± 1.87[d]
B3 (μg)	1864.67 ± 102.55 [a]	1192.78 ± 70.88[c]	1092.6 ± 87.3[d]	1489.28 ± 93.6[b]	983.32 ± 102.3[e]
B6 (μg)	39.23 ± 2.58[a]	20.12 ± 1.83[b]	15.91 ± 2.07[d]	17.86 ± 3.2[c]	8.78 ± 2.5[e]
B12 (μg)	2.41 ± 0.42[a]	1.87 ± 0.61[b]	1.53 ± 0.6[b]	1.12 ± 0.21[b]	1.04 ± 0.8[b]

Values are the means ± St.D. the different letters in same row indicate the significant different ($p < 0.05$).

Table 3
Lipids compositions content (mg/100 g) in the fresh and treated shrimp flesh.

Lipids	Fresh	Salted	Fried	Grilled	Boiled
PUFAs	351.79 ± 2.61^{b}	351.1 ± 2.45^{b}	372.11 ± 1.95^{a}	334.46 ± 3.76^{d}	342.08 ± 5.12^{c}
MUFAs	152.84 ± 10.24^{b}	153.45 ± 8.43^{b}	157.78 ± 3.23^{a}	135.10 ± 3.26^{c}	127.43 ± 2.58^{d}
SFAs	243.91 ± 12.26^{a}	242.52 ± 14.02^{a}	228.42 ± 4.64^{d}	235.09 ± 1.89^{c}	237.30 ± 6.2^{b}
Ch	167.34 ± 2.19^{a}	165.22 ± 1.21^{a}	167.23 ± 3.89^{a}	158.40 ± 2.73^{b}	161.02 ± 5.43^{b}
Σω6	98.81 ± 13.39^{b}	101.32 ± 18.65^{b}	143.83 ± 2.04^{a}	93.71 ± 3.5^{c}	87.54 ± 1.59^{c}
Σω3	239.34 ± 15.67^{a}	241.73 ± 11.69^{a}	235.65 ± 3.36^{b}	224.85 ± 2.03^{c}	217.65 ± 4.07^{d}
PUFA/SFA	1.45 ± 0.03^{b}	1.45 ± 0.05^{b}	1.63 ± 0.45^{a}	1.42 ± 0.56^{c}	1.44 ± 0.41^{b}
Σω6/Σω3	0.41 ± 0.08^{b}	0.42 ± 0.02^{b}	0.61 ± 0.05^{a}	0.42 ± 0.01^{b}	0.40 ± 0.08^{c}

Values are the means ± St.D. the different letters in same row indicate the significant different ($p < 0.05$).

Table 4
Minerals content (mg/100 g) in the fresh and treated shrimp flesh.

Mineral	Fresh	Salted	Fried	Grilled	Boiled
Ca	291·00 ± 2.65^{c}	294.67 ± 1.53^{c}	313.64 ± 1.73^{b}	324.71 ± 1.53^{a}	273.26 ± 3.21^{d}
Fe	512.00 ± 7.81^{c}	517.67 ± 4.04^{c}	525.9 ± 4.16^{b}	541.5 ± 4.04^{a}	416.03 ± 1.31^{d}
Mg	31.23 ± 2.35^{b}	32.7 ± 0.85^{b}	35.21 ± 0.55^{a}	35.1 ± 0.85^{a}	33.01 ± 0.7^{b}
P	151.67 ± 0.58^{c}	148.13 ± 0.15	163.42 ± 0.25^{a}	157.3 ± 0.15^{b}	127.37 ± 0.58^{d}
K	425.33 ± 0.58^{c}	412.67 ± 0.58$^{c\ d}$	447.2 ± 1.15^{b}	453.41 ± 0.58^{a}	397.31 ± 1.53^{e}
Na	162.5 ± 0.5^{c}	165.5 ± 0.5^{c}	176.4 ± 1.53^{b}	181.24 ± 0.5^{a}	154.63 ± 0.58^{d}
Zn	152.67 ± 1.53^{c}	156.33 ± 1.53^{c}	171.76 ± 0.42^{b}	181.78 ± 1.53^{a}	90.43 ± 1.11^{d}
Cu	91.33 ± 1.97^{c}	114.67 ± 2.52^{a}	111.58 ± 1.53^{b}	116.12 ± 2.52^{a}	70.23 ± 2.08^{d}

Values are the means ± St.D. the different letters in same row indicate the significant different ($p < 0.05$).

Table 5
Antioxidant activities of shrimp powder obtained from different processing methods.

Shrimp sample	DPPH scavenging activity (%)	Antioxidant activity (%)	Reducing power (absorbance at 700 nm)
Fresh	79.29 ± 2.26^{b}	43.11 ± 2.04^{b}	0.352 ± 0.233^{d}
Salted	78.94 ± 3.34^{b}	44.62 ± 1.44^{b}	0.368 ± 0.061^{c}
Fried	66.92 ± 2.07^{c}	37.09 ± 3.30^{c}	0.372 ± 0.036^{b}
Grilled	83.20 ± 1.64^{a}	57.04 ± 2.52^{a}	0.395 ± 0.021^{a}
Boiled	81.32 ± 2.84^{a}	54.72 ± 1.43^{a}	0.350 ± 0.045^{d}

Values are the means ± St.D. the different letters in same row indicate the significant different ($p < 0.05$).

der extract and lowest in the boiled shrimp powder extract. The grilled shrimp powder extract had a significantly higher reducing power than all other shrimp powder extracts, and then fried and salted shrimp powder extracts also had significantly higher reducing powers than the fresh and boiled shrimp powder extracts ($p \leq 0.05$). No significant differences were appeared in reducing power between the fresh and boiled shrimp powder extracts.

4. Discussion

4.1. Macronutrients content

A range of low-moderate and high-temperature processing methods are used to generate attractive and fresh fish products with a prolonged storage life, including salting, chilling, freezing, drying, smoking, canning, sun-drying, fermenting, frying, and grilling in various combinations. All these processing methods, use different techniques and have varying applications, have a significant influence on the organoleptic, physical, chemical, and nutritional attributes of fish, due to freezing, heating, oxidation, and exposure to high salt concentrations cause physical and chemical alterations (Abraha et al., 2018).

The present study results showed that the cooking processing methods increased the fat, protein, and ash rates and reduced the moisture in *Penaeus semisulcatus* flesh. Similar results were reported for the proximate composition of *L. vannamei* from Indramayu (Rostini and Pratama, 2018). Likewise, a loss of water was observed in sardine (*Clupea pilchardus*) through all processes (Castrillon et al., 1999), silver carp (*Hypophthalmichthys molitrix*) fillets (Hakimeh et al., 2010), and carp (*Cyprinus carpio*) cutlets (Talab, 2014). A comparable to our results, increasing the temperature during cooking also decreased the water content and increased the protein, fat, and ash contents of shrimp flesh (Benjakul et al., 2008).

Three-quarters of the edible part of shrimp meat in the water, while approximately 80% of dry matter consists of protein. The fresh shrimp protein mean is 19.4 g/100 g, it donates 87% of total energy, while the average lipid content is approximately 1.15 g/100 g (Dayal et al., 2013). The fresh *P. semisulcatus* in the present study had lower water content but similar protein content. In contrast to the results of this study, Musaiger and D'Souza (Musaiger and D'Souza, 2008), found that no significant difference between different cooked fishes varieties in moisture but that was lesser following the frying process.

No significant difference appeared in the crude protein (9.21%) in *P. monodon* and (6.09%) in *P. notialis* ($p > 0.05$) (Bernard and Bolatito, 2016). However, in the present study, *P. semisulcatus* had higher water and protein than that of *P. monodon* and similar water content to *P. notialis*. The high protein amount in fish and shrimps is significant from a dietary perspective, as the protein of fish is very high quality due to its composition of essential amino acids (Beklevik et al., 2005). A reduction in water through cooking has been shown to cause the protein and fat contents to increase significantly (Alipour et al., 2010). However, heating at 130 °C for 10 min caused protein digestibility of hake (*Merluccius merluccius*) to decrease by 1.5% (Seidler, 1987).

Lower than the that in this study, the lipid content of shrimp has been ranged from 1.04 g/100 g in shallow-water species to 2.46 g/100 g in deep-water species (Yerlikaya et al., 2013), and range from 0.9% to 1.6% in shrimp and prawn species (Ayas et al., 2013). Saglik and Imre (2001), found that lipids in pink shrimp of deep-water (*Parapenaeus longirostris*) and *Penaeus semisulcatus* were 0.93% and 0.58%, respectively, while Oksuz et al. (Oksuz

et al., 2009), reported 2.61% and 1.1% in red shrimp (*Plesionika martia*) and *Parapenaeus longirostris* respectively. Dinakaran and Soundarapandian (Dinakaran and Soundarapandian, 2009) indicated that male (*Macrobrachium idella*) lipid was highest in the 96–105 mm size group (5.60%) and lowest in the 46–55 mm size group (3.53%), while that of females was highest in the 76.85 mm size (5.88%) and lowest in the 66–75 mm size group (3.98%), these are similar to those in the current study.

The higher fat in fried shrimp in this study can be explained by oil absorption by the meats and supports the findings of Echarte et al. (Echarte et al., 2001). By contrast, the fat was lower in grilled shrimp because of the depletion of fat in cooking drip, which is in accordance with the findings of Pena and Samperio (Pena and Samperio, 1994), who showed that grilling decreases the fat content of salmon (*Salmo salar*) by 11.7%. The protein content of raw Bata fish (*Labeo bata*) and take fish (*Channa punctata*) was decreased after conventional cooking but less decreased after microwave cooking, also fat and sugar contents were significantly changed by both methods (Rashid et al., 2016).

4.2. Vitamins content

During grilling, the fat tends to melt out of shrimp flesh, reducing not only its content of fat but also its contents of the fat-soluble vitamins E, A, and K. Shrimp are described as a good source of protein, PUFAs (e.g., DHA and EPA), vitamins D and A, and the minerals Ca and Fe, and is also considered to be rich in cholesterol (Feliz et al., 2002, Heu et al., 2003, Luzia et al., 2003). In contrast with the results of the present study, vitamin B1 (thiamin) amount was not significantly affected by frying and microwave cooking however it was significantly reduced by baking and boiling (Karimian-Khosroshahi et al., 2016). A reduction in vitamin B1 during cooking has been attributed to its thermal breakdown (Lynch and Young, 2000). In particular, it appears that boiling causes discharge of vitamin B1 into the water leading to a significant decreasing.

Shellfishes, including shrimps, are good sources of B-complex vitamins, mainly vitamin B12, which helps to protect blood vessels from damage, with 100 g of shrimp providing 0.3–7 μg of vitamin B12, 1 mg of vitamin B3 (niacin), and 9 μg of vitamin B9 (folic acid) (Venugopal, 2020). Shrimps also contain other important vitamins, such as vitamins A, D, and E (180 IU, 2I U, and 1.32 μg) respectively (USDA, 2012). Shrimps are principally rich in vitamin A, with steamed meat of shrimp giving 240 IU/100 g of vitamin A, and many shrimp species have high quantities of vitamin D, which benefits blood vessels protection from damage which may lead to stroke occurrence and also assists in dietary Ca and P absorption, for example, vitamin D3content is 0.6 mg% (Venugopal, 2006).

Shrimp that has been cooked under moist heat (76% moisture) contain significant percent daily values for essential amino acids, selenium (Se), and vitamin B12 (Dayal et al., 2013). However, the cooking process can cause a loss of B-complex vitamins, which is a significant issue because meat supplies approximately 20% of vitamin B1 in the diet. The loss of B-complex vitamins is proportional to cooking temperature, with 30%–60% potentially being lost during roasting. Consequently, the processing method often affects vitamin content and availability. Water-soluble vitamins can be affected by heat, acid, and other cooking methods, regardless of the type of dish. However, fat-soluble vitamins are also affected by cooking as although they will not leach into the cooking water, they can leach into fats, such as olive oil or butter. Thus, these vitamins can also degrade with cooking, but not as easily as water-soluble vitamins.

4.3. Profile of fatty acids

The amount of PUFA in the fresh and salted shrimp in this study is comparable to the previously recorded for this species (33.44% ± 2.55%) and similar to that recorded for several shrimp species, *Aristeus antennatus* (29.68%±2.84%), *Aristaeomorpha foliacea* (33.88%±0.50%), *Plesionika martia* (32.20%±1.56%), *Parapenaeus longirostris* (33.95%±2.19%), *Plesionika edwardsii* (31.53%±2.11%), *Penaeus kerathurus* (41.57%±0.40%), *Penaeus japonicus* (38.25 ± 3.35%), and *Metapenaeus monoceros* (42.77%±2.79%) (Yerlikaya et al., 2013). Fats of salted shrimp paste ranges from 1.41% to 3.67%, and the oil of shrimp was stated to be rich in PUFAs, with linoleic acid (C18:2n-6) being the main FA in oil of *Litopenaeus vannamei* (Takeungwongtrakul et al., 2012). PUFA in this study is agreed with those of *Penaeus semisulcatus* in fall (321.9 mg/100gmuscle tissue), winter (374.9 mg/100 g), spring (380.7 mg/100 g), and summer (324.8 mg/100 g), with an average of 350.575 mg/100 g (Ayas et al., 2013). Total PUFA of females and males (*Metapenaeus affinis*) was 25.48% and 24.21% respectively (DİNÇER and AYDIN, 2014). Heu et al. (2003), revealed that *Penaeus monodon* and (*Penaeus* vannamei) have C18:1n-9 at the highest concentration, followed by C16:1 for *P. monodon* and C18:1n-7 for *P. vannamei*, while C17:1 was also detected in both species.

The MUFA in fresh and cooked shrimp in this experiment were lesser than that found in this species previously (30.85 ± 1.80%/total lipids) and other shrimp species, including *Aristeus antennatus* (37.59 ± 2.30%), *Aristaeomorpha foliacea* (34.92%±1.52%), *Plesionika martia* (37.87%±1.44%), *Parapenaeus longirostris* (30.32 ± 2.34%), *Plesionika edwardsii* (38.89 ± 1.11%), *Penaeus kerathurus* (24.84%±0.12%), *Penaeus japonicus* (29.82%±1.52%), and *Metapenaeus monoceros* (23.97%±3.62%) (Yerlikaya et al., 2013). However, Ayas et al. (2013) found similar MUFA contents as the present study in fall (224.6 mg/100 g muscle), winter (153.1 mg/100 g), spring (226.7 mg/100 g), and summer (170.3 mg/100 g), with an average of 193.675 mg/100 g. The total MUFA in female and male *Metapenaeus affinis* were 19.90% and 15.47% respectively (DİNÇER and AYDIN, 2014).

All cooking methods in this research reduced shrimp SFA significantly, frying leading the greatest reduction, followed by grilling and boiling. *Metapenaeus affinis* males and females are rich in the fatty acids n-3 containing 53.64% and 60.31%/SFAs respectively (DİNÇER and AYDIN, 2014). By contrast, Yerlikaya et al. (2013) found that *Plesionika edwardsii* and *Penaeus semisulcatus* contained 29.58%±2.21% and 35.71%±2.43% SFAs of total lipids respectively, both are higher than of fresh and salted *P. semisulcatus* in this work. Furthermore, Ayas et al. (2013) found that *P. semisulcatus* had SFA contents of 257.1 mg/100 g muscle in fall, 226.8 mg/100 g in winter, 269.5 mg/100 g in spring, and 261.9 mg/100 g in summer, with a mean of 253.825 mg/100. In agreement with our results, the saturated (SFA) and polyunsaturated fatty acids (PUFA) were lost and the percentage of MUFA increased in sardine by pan-frying (Castrillon et al., 1999).

The Σω6 concentration in the fresh and salted shrimp examined in the present study was 98.81 and 101.32 mg/100 g, which are similar to the values previously reported for *Penaeus semisulcatus* in winter (100.8 mg/100 g) and spring (100.8 mg/100 g) (Ayas et al.). However, all of the cooked shrimp in this study had higher Σω6 than that for spring (76.3 mg/100 g muscle tissue), summer (64.6 mg/100 g), and overall (85.625 mg/100 g) (Ayas et al., 2013). Similarly, Σn6 in *Penaeus semisulcatus* was (9.89%±0.08%), *Aristaeomorpha foliacea* (4.48%±0.07%) and *Metapenaeus monoceros* (18.95%±1.09%) (Yerlikaya et al., 2013). Σω3 concentrations in fresh and salted shrimp in the present study are parallel to that of *P. semisulcatus* (23.55%±0.04%) and *A. foliacea* (29.41% ±0.38%) (Yerlikaya et al., 2013). In arrangement with the findings of the current study, deep-frying significantly increased Σn-6 and ΣPUFA and lowered SFA and Σn-3 of frozen shrimp, octopus, and squid (Czech et al., 2015). Boiling has no effect on Σn-3, whereas other cooking methods, frying, cooking, microwaving, and boiling with

salt, cause a significant decrease in Σn-3 due to the increased UFAs auto-oxidizing at a much faster rate than other lipids in the presence of small quantities of natural antioxidants (Domiszewski et al., 2011).

The PUFA/SFA ratio in fresh shrimp in the present study was higher than the previously reported 0.94% (Yerlikaya et al., 2013) and 1.39% (Ayas et al., 2013) for this species. All treated shrimp had higher PUFA/SFA ratios than the minimum recommended value for essential fatty acids 0.45 (Sargent et al., 1995). Low PUFA/SFA ratios (0.40 and 0.48) have been observed in the males and females of *Metapenaeus affinis* respectively (DİNÇER and AYDIN, 2014). In agreeable with this study results, frying causes the highest rising in UFA/SFA, PUFA/SFA, and PUFA/(SFA-stearic acid) ratios (Karimian-Khosroshahi et al., 2016).

The Σω6/Σω3 ratio for the fresh shrimp samples in the present study was 0.42 was similar to that for *Penaeus semisulcatus* (0.419) but higher than that of other shrimp which were 0.151% in *Aristaeomorpha foliacea* and 0.795% in *Metapenaeus monoceros*, while the DHA + EPA ranged from 29.06% in *P. kerathurus* to 23.45% in *P. semisulcatus* (Yerlikaya et al., 2013). However, higher DHA + EPA was observed in *Penaeus monodon* (0.76) and *Penaeus vannemai* (1.00) (Sriket et al., 2007), and a lower in *P. semisulcatus* 0.34 (Ayas et al., 2013).

The n6/n3 ratio was 0.576 and 0.235 in wild marine shrimp (Bragagnolo and Rodriguez-Amaya, 2001), while a 0.241 was recorded for seabob shrimp (Luzia et al., 2003). The Σω6/Σω3 ratio of shrimp in the present study was inferior to the optimum recommended ratio 4.0 of the Department of Health of UK (Sargent et al., 1995).

In the existing research, frying increase the MUFA PUFA, Σω3, and Σω6 contents and the PUFA/SFA and Σω6/ Σω3 ratios, decreased the SFA content, and had no effect on the cholesterol content. The increases in these lipid components and indexes can be attributed to the frying oil absorption by shrimp flesh. All of the other cooking processing methods decreased the PUFA, MUFA, Σω6, Σω3, SAF, and cholesterol contents and the PUFA/SFA and Σω6/Σω3 ratios, boiling resulting most significant reductions, while grilling has the smallest effect on the lipid. Marine shrimp that nourished by microalgae might contain faintly higher omega n-3 PUFAs, and their proximate composition can also change depending on the treatment used to like cooking, drying, chilling, and freezing also extended storage period (Bono et al., 2012; Sriket et al., 2007; Venugopal and Gopakumar, 2017). Most shellfishes, including shrimps, have crude fat contents below 2%, comprise cholesterol, phospholipids, and acylglycerols 15% – 20%, 65% – 70%, and 10% – 20% respectively with greater USFA quantity (Venugopal and Gopakumar, 2017).

In accordance with this study findings, baking, boiling, microwaving, and frying reduced ΣSFA, ΣMUFA, Σn3, and PUFAs in (*Oncorhynchus mykiss*) (Karimian-Khosroshahi et al., 2016). Marine shrimp contains upper n-3 PUFAs than n-6 PUFAs, and shallow-water shrimp are commonly more rich in n-3 PUFAs than their counterparts in deep-water because of their consumption of microalgae that are rich in PUFA. The lipid of the brown shrimp comprises approximately 30% PUFAs (32% DHA and41% EPA), 33% SFAs, and 22% MUFAs. The n-3 PUFAs of *Penaeus vannamei* and *Penaeus monodon* comprise 42% – 44% lipids, *P. monodon* having a higher DHA/EPA ratio than *P. vannamei* (2.15 and 1.05 respectively) (Sriket et al., 2007).

4.4. Minerals content

Penaeus semisulcatus has high contents of Mg, Zn, Ca, Cu, P, and protein (Musaiger and D'Souza, 2008), which this supported by the findings of the present study. It has also been shown that the mineral contents of fish flesh are most greatly increased by baking, followed by microwaving and frying, and are decreased by boiling compared with the raw fish (Karimian-Khosroshahi et al., 2016). Similarly, the mineral of cooked grass carp fillets significantly increased by microwaving, deep-frying, pan-frying, and steaming, respectively, whereas Na, K, Mg, P, and Zn significantly decreased by boiling (Golgolipour et al., 2019). Furthermore, the K of grass carp fillets decreased with poaching but was not affected by other cooking methods (Hosseini et al., 2014). Additional study on kutum roach (Rutilus frisii kutum) showed that microwaving increased the contents of Mg and K, but had no significant effect on Mn, Ca, Zn, and Na, and diminished P concentration; baking augmented Ca, Na, K, and Mg with significant differences but not effect on Zn and P, while Cu was decreased significantly; frying increased K, Mn, Zn, P and Ca, and Mg, Cu and Na not effected; Mg and Ca were increased by boiling significantly, but K, Cu, Zn, and Mn were not affected and decreased Na and P significantly (Hosseini et al., 2014). Similarly, *P. semisulcatus* have higher contents of Mg and Ca when cooked in rice, reflecting the great amount of these salts in different species of prawn (Abulude et al., 2006).

The mineral contents of shrimp in this study were higher than that of *Penaeus monodon* edible flesh and *F. indicus*, (Dayal et al., 2013). It also reported that both *Penaeus notialis* and *P. monodon* had high contents of all of the micro-and macrominerals, but *P. monodon* had higher Ca and Zn levels ($p < 0.05$) (Bernard and Bolatito, 2016). The species of raw shellfish, together with shrimps, have about 2% of ash contain Na, K, Ca, Mg, and P, as well as some microelements like Se, F, I, Co, Mn, and Mo (Venugopal, 2020). Shrimps contain Na, K, Ca, Mg, P, and Fe (1270, 130, 110, 35, 89, and 0.6 mg respectively (Venugopal, 2020). Musaiger and D'Souza (2008), found that Na of fish is generally lower when cooked in rice, but *P. semisulcatus* had higher Na after this treatment (500 mg/100 g), and *P. semisulcatus* had low K compared with the other fish species but higher in Ca (92 mg/100 g for curried and 100 mg/100 g for cooked in rice), Mg (49 mg/100 g for curried and 54 mg/100 g for cooked in rice), and Zn (1.8 mg/100 g for curried and 2.0 mg/100 g for cooked in rice). Furthermore, DİNÇER and AYDIN (2014) found that while male and female *Metapenaeus affinis* had similar Na contents, females significantly lowered in Ca and increased K and Mg than males. By contrast, Karakoltsidis et al. (1995) reported that the *Aristeus antennatus* has 1210 mg/kg of Ca, while Adeyeye et al. (2008) found that an even higher Ca quantity in *P. notobilis* but a similar Mg content to that of *Metapenaeus affinis*. The latter species has been shown to contain sufficient essential microelements (Zn, Mn, and Cu) as well as the nonessential microelements aluminum (Al) and nickel (Ni) 0.58–0.70 mg/kg in males and 0.04–0.05 mg/kg in females (DİNÇER and AYDIN, 2014). The cooking method effect the mineral contents of fishes and shrimps considerably (Musaiger and D'Souza, 2008).

In this study, fresh *P. semisulcatus* had high contents of Ca, K, Cu, Fe, P, Mg, Zn, and Na. Furthermore, the contents of these minerals were significantly increased by grilling, frying, and salting and significantly decreased by boiling, which can be attributed to the addition of salt and loss of water from the flesh at an increased temperature.

4.5. Antioxidant activity

The present study showed that shrimp powder extract of fresh shrimp had high antioxidant activity, this activity was significantly increased by the grilling and boiling processes and significantly decreased by the frying process. The antioxidant activity of shrimp originates from the presence of antioxidants such as astaxanthin, carotenoids, vitamin A, vitamin E, vitamin C, ω6 fatty acids, ω3 fatty acids, PUFAs, and minerals such as Se (Luzia et al., 2003;

SEABRA and PEDROSA, 2010; Dayal et al., 2013; Yerlikaya et al., 2013; Karimian-Khosroshahi et al., 2016; Ekpe et al., 2018; Venugopal, 2020).

It has previously been reported that the antioxidant potential of isolated chitosan and chitin from cultured *Penaeus monodon* has a maximum inhibitory activity of 89.56% at a concentration of 1000 μg/mL (Shabna et al., 2015). However, Trung and Bao (2015) showed that the scavenging activity of chitosan against DPPH was lower than that of butylated hydroxytoluene (BHT) significantly at equal concentration, it was ranged from 3.7% to 16.8%, in corresponding with1.0–2.0 mg/mL of chitosan. Chitosan act as a scavenger for several free radicals by the N action on the position C-2 of chitosan and its total reducing power was shown to be dose-dependent among 1.0 and 2.0 mg/mL (Trung and Bao, 2015). Similarly, chitosan peroxidation inhibition activity was also lowered than that of equal concentration of the standard BHT significantly ($p < 0.05$) and was 1.7%-15.1%, which corresponds to 1.0–2.0 mg/mL chitosan (Trung and Bao, 2015).

In the present study, the grilled and boiled shrimp powder extracts had higher antioxidant activity, which related to the increased contents of protein, ash, and antioxidant vitamins, as well as the formation of peptides and polypeptides by protein hydrolysis throughout heating. However, the antioxidant activity of shrimp was decreased by frying, likely due to the formation of free radicals during the frying process as a result of the increased temperature and exposure of oil to the light and oxygen, and also the existence of some oxidizing agent in the frying materials or the oxidation of the used oil during storage and exposure. The potential use of the carotenoid extract of shrimp as a natural antioxidant for biomedical and food applications has previously been noted (Sowmya and Sachindra, 2012). Furthermore, Rajesh et al. (2021) found that both cultured and wild shrimps are rich in antioxidants, as indicated by their DPPH scavenging ability.

A previous study on the antioxidant and antihemolytic activities of the wild shrimp muscle fractions showed that one fraction produced significantly higher μM Trolox equivalent (TE)/g values of 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS; 21.4 ± 2.4), DPPH (25.2 ± 1.5), and ferric reducing power (FRAP;166.8 ± 7.2) (García-Romo et al., 2020). A separate study reported that the peel of fresh shrimp and the peel of fresh and ground shrimp of *Litopenaeus vannamai* was possessed greater antioxidant efficacy (Ratanasiriwat and Pienchob, 2018).

The DPPH scavenging activities of protein hydrolysates of shrimp (*P. indicus* and *P. monodon*) waste have been shown to increase in a linear manner by the increasing of protein hydrolysate concentration to 5 mg/mL (Dey and Dora, 2014), which agreeing to the findings of this research. The ethyl acetate extract of *P. vannamei* shells also possesses good scavenging activity and a significant inhibitory effect, with an IC_{50} rate equal to 15.03 μg/mL (Muniyappan et al., 2019).

The DPPH scavenger activity of "Vila Franca" shrimp (*L. schmitti*) was decreased in the cooked fillets at zero time (8%) and (6.9%) after frozen storage for 90 days (Lira et al., 2017). Consequently, the authors concluded that heat treatment caused declining in the antioxidant activity and the total carotenoid concentration in the cooked shells (Lira et al., 2017). A previous study found that both purified and crude extracts at rates of 0.2%–0.5% were reduced the thiobarbituric acid (TBA) and peroxide number significantly (Li and Morrissey, 1995). The high antioxidant activity was also reported for salt-fermented shrimp paste and suggested that this antioxidant ability developed throughout the fermentation (Peralta et al., 2008). Moreover, Sila et al. (2014), suggested that carotenoproteins peptidic fraction is a worthy provider for the peptides and natural antioxidants with remarkable functionalities. Arctic shrimp (*Pandalus borealis*) has been reported to contain 1200 ppm of astaxanthin (Ekpe et al., 2018), which may have protective effects against immune, inflammatory, and neurodegenerative diseases and is believed to play an important prevention role in atherosclerosis as a result of its anti-inflammatory and antioxidant activities in endothelial cells (Ekpe et al., 2018). Thus, the antioxidant and anti-inflammatory activities of shrimp powder extracts examined in this present study may partly have resulted from the presence of astaxanthin. Treatment with crude extract (0.5%) and antioxidant components that are partly purified from the waste of shrimp lowers the TBA and peroxide number significantly (Li, 1994). Water extracts from fermented shrimp paste (Kapi) products also showed strong antioxidative effects and angiotensin I-converting enzyme inhibitory (AIEI) activity (Kleekayai et al., 2015).

The current research results indicated that the flesh and powders of *Penaeus semisulcatus* were rich in macronutrients, vitamins, minerals, ω3, ω6, and PUFAs, as well as possessing high antioxidant activity, which corresponds with the findings of shrimp fermented paste products from Klongkone, Thailand (Prapasuwannakul and Suwannahong, 2015).

5. Conclusions

The results of this experiment work displayed that the shrimp *Penaeus semisulcatus* contains high concentrations of macronutrients, protein, vitamins, and the minerals P, Ca, Mg, K, Cu, Fe, Zn, and Na and low concentrations of fat, albeit with high concentrations of ω3 and ω6 fatty acids. The different processing methods examined had considerable effects on the nutrient content and composition of the shrimp flesh. In addition, all of the shrimp powder extracts tested (from both the fresh and processed flesh) had high antioxidant activities, with the grilled shrimp powder extracts having the highest activity. Thus, grilling considered the best method for shrimp treatment, as the shrimp maintain a high nutritional value while exhibiting an elevated antioxidant activity, which would be beneficial for improving health and nutrition when consumed as part of a regular diet. This study results maybe help in the areas of pharmaceutical and food manufacturing like: in the development of new functional products with therapeutic nutritional properties including shrimp meat in its composition, used in therapeutic nutrition to treat chronic diseases and malnutrition diseases and extract some bioactive compounds from shrimp meat (vitamins, minerals, fatty acids, and amino acids) for uses in the pharmaceutical industries and develop shrimp product preservation and cooking process techniques to meet consumer nutritional needs and contribute to improving community health.

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.

Acknowledgements

The authors are grateful to the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the Fast-track Research Funding Program for funding this work.

References

Abraha, B., Admassu, H., Mahmud, A. et al., 2018. Effect of processing methods on nutritional and physico-chemical composition of fish: a review. MOJ Food Process Technol. 6, 376–382.

Abulude, F., Lawal, L., Ehikhamen, G., Adesanya, W., Ashafa, S., 2006. Chemical composition and functional properties of some prawns from the coastal area of Ondo state, Nigeria. Electronic J. Environ., Agric. Food Chem. 5, 1235–1240.
Adeyeye, E.I., Adubiaro, H.O., Awodola, O.J., 2008. Comparability of Chemical Composition and Functional Properties of Shell and Flesh of Penaeus notabilis. Pakistan J. Nutrition 7, 741–747.
Akuamoa, F., Odamtten, G.T., Korley, K.N., 2018. Nutritional and shelf-life studies of dry smoked and gamma irradiated shrimps (Penaeus notialis) from three different water sources in Ghana, Felicia. Cogent Food Agric. 4, 1–9.
Ali, S.S.R., Ramachandran, M., Chakma, S.K., Sheriff, M.A., 2017. Proximate composition of commercially important marine fishes and shrimps from the Chennai coast, India. Int. J. Fisheries Aquatic Stud. 5, 113–119.
Alipour, H.J., Shabanpoor, B., Shabani, A., Mahoonak, A.S., 2010. Effects of cooking methods on physico-chemical and nutritional properties of Persian sturgeon Acipenser persicus fillet. Int. Aquat. Res, 16, 15–23.
AOAC 2002. International Official Methods of Analysis, Association of Official Analytical Chemists AOAC, Washington DC, USA.
Arancibia, M.Y., Alemán, A., Calvo, M.M., López-Caballero, M.E., Montero, P., Gómez-Guillén, M.C., 2014. Antimicrobial and antioxidant chitosan solutions enriched with active shrimp (Litopenaeus vannamei) waste materials. Food Hydrocolloids 35, 710–717.
Ayas, D., Ozogul, Y., Yazgan, H., 2013. The effects of season on fat and fatty acids contents of shrimp and prawn species. Eur. J. Lipid Sci. Technol. 115, 356–362.
Beklevik, G., Polat, A., Ozogul, F., 2005. Nutritional value of Sea Bass (Dicentrarchus labrax) fillets during frozen (-18°C) storage. Turkish J. Veterinary Animal Sci. 29, 891–895.
El Ben Mussa, S., Sharaa, I., 2014. Analysis of Vitamin C (ascorbic acid) Contents packed fruit juice by UV-spectrophotometry and Redox Titration Methods *IOSR*. J. Appl. Phys. 6, 46–52.
Benjakul, S., Visessanguan, W., Kijroongrojana, K., Sriket, P., 2008. Effect of heating on physical properties and microstructure of balck tiger shrimp (Penaeus monodon) and white shrimp (Penaeus vannamei) meats. Int. J. Food Sci. Technol. 43, 1066–1072.
Benjakul, S.W., Binsan, W., Visessanguan, K., Osako Tanaka, M., 2009. Effects of Flavourzyme on Yield and Some Biological Activities ofMungoong, an Extract Paste from the Cephalothorax of White Shrimp. J. Food Sci. 74, S73-S80.
Bernard, E., Bolatito, A., 2016. Comparative study on the nutritional composition of the pink shrimp (Penaeus notialis) and tiger shrimp (Penaeus monodon) from Lagos lagoon, Southwest Nigeria. Cogent Food Agric. 2, 1201891.
BinMowyna, M.N., Alsayadi, M.M., 2020. Assessment of the antioxidant and antimicrobial activities of Caralluma deflersiana growing in the South of Saudi Arabia. African J. Pharmacy Pharmacologyonline 14, 331–338.
Bono, G., Gai, F., Peiretti, P.G., Badalucco, C., Brugiapagli, A., Siragusa, G., Palmegiano, G.B., 2012. Chemical and nutritional characterisation of the Central Mediterranean Giant red shrimp (Aristaeomorpha foliacea): Influence of trophic and geographical factors on flesh quality. Food Chem. 130, 104–110.
Bragagnolo, N., Rodriguez-Amaya, D.B., 2001. Total lipid, cholesterol, and fatty acids of farmed freshwater prawn (Macrobrachium rosenbergii) and wild marine shrimp (Penaeus brasiliensis, Penaeus schimitti, Xiphopenaeus kroyeri). J. Food Compos. Anal. 14, 359–369.
Bueno-Solano, C., López-Cervantes, J., Campas Baypoli, O.N., Lauterio-García, R.N.P., Adan-Bante a, D.I.S.-M., 2009. Chemical and biological characteristics of protein hydrolysates from fermented shrimp by-products. Food Chem. 112, 671–675.
Castrillon, A., Navarro, P., Alvarez-Pontes, E., 1999. Changes in chemical composition and nutritional quality of fried sardine (Clupea pilchardus) produced by frozen storage and microwave reheating. J. Sci. Food Agric. 75, 125–132.
Choo, P.Y., Azlan, A., Khoo, H.E., 2020. Cooking methods affect total fatty acid composition and retention of DHA and EPA in selected fish fillets. ScienceAsia. 44, 92–101.
Czech, A., Grela, E.R., Ognik, K., 2015. Effect of Frying on Nutrients Content and Fatty Acid Composition of Muscles of Selected Freezing Seafoods. J. Food Nutr. Res-Slov. 3, 9–14.
Dayal, J.S., Ponniah, A.G., Imran Khan, H.E., Madhu Babu, P., Ambasankar, K., Vasagam, K.P.K., 2013. Shrimps – a nutritional perspective. Curr. Sci. 104, 1487–1491.
Dey, S.S., Dora, K.C., 2014. Antioxidative activity of protein hydrolysate produced by alcalase hydrolysis from shrimp waste (Penaeus monodon and Penaeus indicus). J. Food Sci. Technol. 51, 449–457.
Dinakaran, G.K., Soundarapandian, P., 2009. Biochemical status of edible palaemonid prawn Macrobrachium idella idella (Hilgendorf, 1898). Adv. J. Food Sci. Technol. 1, 19–26.
Dinçer, M.T., Aydin, İ., 2014. Proximate composition and mineral and fatty acid profiles of male and female jinga shrimps (Metapenaeus affinis, H. Milne Edwards, 1837). Turkish J. Veterinary Animal Sci. 8, 92–103.
Domiszewski, Z., Bienkiewicz, G., Plust, D., 2011. Effects of Different Heat Treatments on Lipid Quality of Striped Catfish (Pangasius Hypophthalmus). ACTA Scientiarum Polonorum Technologia Alimentaria. 10, 359–373.
Echarte, M., Zulet, M., Astiasaran, I., 2001. Oxidation process affecting fatty acids and cholesterol in fried and roasted salmon. J. Agric. Food Chem. 49, 5662–5667.
Eitenmiller, R.R., Landen, J.W.O., 1999. Vitamin analysis for the health and food sciences. CRC Press LLC, US.
Ekpe, L., Inaku, K., Ekpe, V., 2018. Antioxidant effects of astaxanthin in various diseases-a review. J. Mol. Pathophysiol. 7, 1–6.
Ersoy, B., Özeren, A., 2009. The effects of cooking methods on mineral and vitamin contents of African catfish. Food Chem. 115, 419–422.
Feliz, G.L.A., Gatlin, M.D., Lawrence, L.A., Velazquez, P.M., 2002. Effect of dietary phospholipid on essential fatty acid requirements and tissue lipid composition of Litopenaeus vannamei juveniles. Aquaculture 207, 151–167.
García-Romo, J.S., Noguera-Artiaga, L., Gálvez-Iriqui, Alma Carolina, Hernández-Zazueta, Martin Samuel, Valenzuela-Cota, Daniel Fernando, González-Vega, Ricardo Iván, Plascencia-Jatomea, Maribel, Burboa-Zazueta, María Guadalupe, Sandoval-Petris, Edgar, Robles-Sánchez, Rosario Maribel, Juárez, Josué, Hernández-Martínez, Javier, del Carmen, Hisila, Burgos-Hernández, Santacruz-Ortega Armando, 2020. Antioxidant, antihemolysis, and retinoprotective potentials of bioactive lipidic compounds from wild shrimp (Litopenaeus stylirostris) muscle. CyTA –J. Food. 18, 153–163.
Golgolipour, S., Khodanazary, A., Ghanemi, K., 2019. Effects of different cooking methods on minerals, vitamins and nutritional quality indices of grass carp (Ctenopharyngodon idella). Iranian J. Fisheries Sci. 18, 110–123.
Hakimeh, J.A., Akram, A.A., Bahareh, S., Alireza, S.M., 2010. Physicochemical and sensory properties of silver carp (Hypophthalmichthys molitrix) fillets as affected by cooking methods. Int. Food Res. J. 17, 921–926.
Heu, M., Kim, J., Shahidi, F., 2003. Components and nutritional quality of shrimp processing by-products. Food Chem. 82, 235–242.
Hosseini, H., Mahmoudzadeh, M., Rezaei, M., Mahmoudzadeh, L., Khaksar, R., Karimian Khosroshahi, N., Babakhani, A., 2014. Effect of different cooking methods on mineral, vitamins and nutritional quality on Kutum roach (Rutilus kutum). Food Chem. 148, 86–91.
Jeyasanta, I.K., Patterson, J., 2017. Effect of formulated feed on the biochemical composition of cultured shrimp, Penaeus monodon (Fabricius, 1798). Int. J. Fisheries Aquatic Res. 2, 15–22.
Karakoltsidis, P., Zotos, A., Constantinides, S., 1995. Composition of the commercially important Mediterranean finfish, crustaceans, and mollusks. J. Food Comp. Anal. 8, 258–273.
Karimian-Khosroshahi, N., Hosseini, H., Rezaei, M., Khaksar, R., Mahmoudzadeh, M., 2016. Effect of Different Cooking Methods on Minerals, Vitamins, and Nutritional Quality Indices of Rainbow Trout Oncorhynchus mykiss). Int. J. Food Prop. 19, 2471–2480.
Kleekayai, T., Saetae, D., Wattanachaiyingyong, O., Tachibana, S., Yasuda, M., Suntornsuk, W., 2015. Characterization and in vitro biological activities of Thai traditional fermented shrimp pastes. J. Food Sci. Technol. 52, 1839–1848.
Li, S.J., 1994. Isolation of a Natural Antioxidant from Shrimp Waste. Doctor of Philosophy, Oregon State University.
Li, S.J., Morrissey, M.T., 1995. The effect of natural antioxidant from shrimp waste on lipid oxidation and color stability of fish. IFT Annual Meeting 1995. Davis, CA 95616, USA.: Dep. of Avian Sei., Univ. of Califomia.
Lira, G. M., Lopez, A.M.Q., Firmino, G.O., Santos, S.D., Bezerra, R.d.S., 2017. Total carotenoids and antioxidant activity of fillets and shells (in natura or cooked) of "Vila Franca" shrimp (Litopenaeus Schmitti) in different intervals of storage under freezing. Ciência e Agrotecnologia. 41, 94-103.
Luzia, L.A., Sampaio, G.R., Castellucci, C.M.N., Torres, E.A.F.S., 2003. The influence of season on the lipid profiles of five commercially important species of Brazilian fish. Food Chem. 83, 93–97.
Lynch, P.L.M., Young, I.S., 2000. Determination of Thiamine by High Performance Liquid Chromatography. J. Chromatogr. A 881, 267–284.
Muniyappan, J., Varadharajan, V., Namadevan, P., 2019. Biochemical screening and determination of bioactive components of commercially cultured pacific white shrimp Penaeus vannamei. Pharmacognosy Res. 11, 140–146.
Musaiger, A.O., D'Souza, R., 2008. The effects of different methods of cooking on proximate, mineral and heavy metal composition of fish and shrimps consumed in the Arabian Gulf. Arch. Latinoam. Nutr. 85, 103–109.
Oksuz, A., Ozyilmaz, A., Aktas, M., Gercek, G., Motte, J., 2009. A comparative study on proximate, mineral and fatty acid compositions of deep seawater rose shrimp (Parapenaeus longirostris, Lucas 1846) and red shrimp (Plesioni martia, A. Milne- Edwards, 1883). J. Anim. Veterinary Adv. 8, 183–189.
Oosterveer, P., 2006. Globalization and sustainable consumption of shrimp: Consumers and governance in the global space of flows. Int. J. Consumer Stud. 30, 465–476.
Osawa, T., Namiki, M., 1981. A novel type of antioxidant isolated from leaf wax of eucalyptus leaves. Agric. Biol. Chem. 45, 735–739.
Pena, M., Samperio, M., 1994. The effects of frying and grilling on the fat content of common foods (salmon, hake and beefsteak). Rev Clin Esp. 194, 966–969.
Peralta, E., Hatate, H., Watanabe, D., Kawabe, D., Murata, H., Hama, Y., 2005. Antioxidative activity of Philippine salt-fermented shrimp paste and variation of its contents during fermentation. J. Oleo Sci. 54, 553–558.
Peralta, E.M., Hatate, H., Kawabe, D., Kuwahara, R., Wakamatsu, S., Yuki, T., Murata, H., 2008. Improving antioxidant activity and nutritional components of Philippine salt-fermented shrimp paste through prolonged fermentation. Food Chem. 111, 72–77.
Prapasuwannakul, N., Suwannahong, K., 2015. Chemical composition and antioxidant activity of Klongkone shrimp paste. Procedia - Social and Behavioral Sciences. 197, 1095–1100.
Rajesh, M., Dhanaraj, T.S., Noorjahan, A., 2021. Comparative studies on antioxidant properties of wild and cultured shrimps. J. Survey Fisheries Sci. 7, 199–208.
Rashid, M.A., Saifullah, M., Habib, M.A., Iqbal Hussain, M., Sattar, M.A., 2016. The Effect of Different Cooking Methods on Nutrient Content of Selected Bangladeshi Fish. Int. J. Adv. Res. Chem. Sci. 3, 9–14.
Ratanasiriwat, P., Pienchob, P., 2018. Effect of extraction conditions on the yield and antioxidant activity of crude extracts from shrimp peel. J. Thai Interdisciplinary Res. 13, 10–14.

Rostini, I., Pratama, R.I., 2018. Effect of steaming on physical and chemical characteristics White Shrimp (Litopenaeus vannamei) from Indramayu Waters. IOP Conf. Ser.: Earth Environ. Sci. 176, 012–046.
Rutkowski, M., Grzegorczyk, K., 2007. Modifications of spectrophotometric methods for antioxidative vitamins determination convenient in analytic practice. Acta Sci. Pol. Technol. Aliment. 6, 17–28.
Saglik, S., Imre, S., 2001. n-3-Fatty acids in some fish species from Turkey. J. Food Sci. 66, 210–212.
Sargent, J.R., Bell, J.G., Bell, M.V., Henderson, R.J., Tocher, D.R., 1995. Requirements criteria for essential fatty acids. J. Appl. Ichthyol. 11, 183–198.
Seabra, L.M.J., Pedrosa, L.F., 2010. Astaxanthin: Structural and functional aspects. Revista de Nutrição. 23, 1041–1050.
Seidler, T., 1987. Effects of additives and thermal treatment on the content of nitrogen compounds and the nutritive value of hake meat. Die Nahrung. 31, 959–970.
Shabna, R.M., Manasa, D., Medikonda, D., Chitra, D.K., 2015. Isolation Characterisation and Evaluation of Antioxidant and In-Vitro Anticancer activity f Chitin and Chitosan from carapace of cultured Penaeus monodon species. World J. Pharm. Res. 4, 986–993.
Sila, A., Sayari, N., Balti, R., Martinez-Alvarez, O., Nedjar-Arroume, N., Moncef, N., Bougatef, A., 2014. Biochemical and antioxidant properties of peptidic fraction of carotenoproteins generated from shrimp by-products by enzymatic hydrolysis. Food Chem. 148, 445–452.
Sowmya, R., Sachindra, N., 2012. Evaluation of antioxidant activity of carotenoid extract from shrimp processing byproducts by in vitro assays and in membrane model system. Food Chem. 134, 308–314.
Sriket, P., Benjakul, S., Visessanguan, W., Kijroongrojana, K., 2007. Comparative studies on the effect of the freeze–thawing process on the physicochemical properties and microstructures of black tiger shrimp (Penaeus monodon) and white shrimp (Penaeus vannamei) muscle. Food Chem. 104, 113–121.
Stancheva, M., Dobreva, D.A., 2013. Bulgarian marine and freshwater fishes as a source of fat- soluble vitamin foe a healthy human diet. Foods. 2, 332–337.
Takeungwongtrakul, S., Benjakul, S. H-Kittikun, A. 2012. Lipids from cephalothorax and hepatopancreas of Pacific white shrimp (Litopenaeus vannamei): compositions and deterioration as affected by iced storage. Food Chem 134, 2066-2074.
Talab, S., 2014. Effect of cooking methods and freezing storage on the quality characteristics of fish cutlets. J Food Sci Technol. 6, 468–479.
Teofil, D., Edward, K., Barbara, K., 1969. Chemical Composition of Shrimp Flesh (Parapenaeus spp.) and its Nutritive Value. J. Fish. Res. Board Can. 26, 2969–2974.
Trung, T.S., Bao, H.N.D., 2015. Physicochemical Properties and Antioxidant Activity of Chitin and Chitosan Prepared from Pacific White Shrimp Waste. Int. J. Carbohydrate Chem.. 2015, 1–6.
Uran, H., Gokoglu, N., 2014. Effects of cooking methods and temperatures on nutritional and quality characteristics of anchovy (Engraulis encrasicholus). J. Food Sci. Technol. 51, 722–728.
USDA, 2012. National Nutrient Database for Standard Reference Release. Nutrient Data Laboratory, Beltsville, MD, p. 24.
Venugopal, V., 2006. Seafood Processing: Adding Value Through Quick Freezing, Retortable Packaging, And Cook-Chilling. CRC Press,Boca Raton, Florida, USA.
Venugopal, V., 2020. Nutritional Value of Shrimp the Popular Shellfish. EC Nutrition SI. 02, 01–09.
Venugopal, V., Gopakumar, K., 2017. Shellfish: Nutritive value, health benefits, and consumer safety. Compr. Rev. Food Sci. Food Saf. 16, 1219–1242.
Yamamoto, Y., Imose, K., 1989. Changes in fatty acid composition in sardines (Sardinops melanosticta) with cooking and refrigerated storage. J Nutr Sci Vitaminol. 35, 39–47.
Yanar, Y., Göçer, M., Yanar, M., Kücükgülmez, A., 2011. Differences in nutritional composition between cultured and wild green tiger shrimp (Penaeus Semisulcatus). Ital. J. Food Sci. 23, 1–7.
Yen, G.C., Duh, P.D., 1993. Antioxidative properties of methanolic extracts from peanut hulls. J. Am. Oil Chem. Soc. 70, 383–386.
Yerlikaya, P., Topuz, O.K., Buyukbenli, H.A., Gokoglu, N., 2013. Fatty Acid Profiles of Different Shrimp Species: Effects of Depth of Catching. J. Aquat. Food Prod. Technol. 22, 290–297.