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ORIGINAL ARTICLE

Changes in the fatty acid composition of brown shrimp, *Crangon crangon*, after boiling

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Abstract

Brown shrimp, *Crangon crangon* (L.), is the most valuable target of coastal fisheries in the southern North Sea. Annual landings exceeded 30,000 tons in the last decade, yielding up to 100 Mio Euro. The shrimp are boiled immediately after capture onboard the fishing vessel for preservation and easy peeling. After landing, the shrimp are collected by traders and exported for manual peeling. Only the muscle of the pleon is returned and sold as regional delicacy. The remains, comprising the cephalothorax, the shell of the pleon, and, in case, adhering eggs, account for up to 70% of the total body mass. This potential resource, for example as aquaculture feed, has not yet been considered for exploitation. In this respect, the fatty acid (FA) profile and the share of essential FAs are crucial quality factors. Since boiling alters the quality of shrimp, this study evaluates changes in the FA composition of shrimp muscle and remains by comparing frozen and boiled samples. Major FAs in *C. crangon* were the saturated palmitic acid (PA, 16:0), accounting for 16.6%–19.1% of total fatty acids (TFAs), and the long-chain polyunsaturated FAs (LC-PUFAs) eicosapentaenoic acid (EPA, 20:5(n-3), 16.1–21.6%$_{TFA}$) and docosahexaenoic acid (DHA, 22:6(n-3), 11.5–13.6%$_{TFA}$). Frozen muscle and frozen remains showed similar FA profiles. Boiling changed the FA profile. PA, EPA, and DHA decreased by up to 25%, whereas palmitoleic acid 16:1(n-7) and oleic acid 18:1(n-9) increased by 2% to 3% each. Boiled muscle and boiled remains showed similar FA profiles. Despite the loss of FAs, the boiled shrimp remains are suggested to be a suitable PUFA supplement for aquaculture feeds, deserving further investigation.

KEYWORDS
aquaculture feeds, DHA, EPA, lipids, North Sea, processing remains

1 | INTRODUCTION

The term 'shrimp' comprises approximately 3000 species of natant decapod crustaceans. Approximately 300 species are of economic interest worldwide, of which 100 represent the major annual world catch (Gillet, 2008). The brown shrimp *Crangon crangon* (L.), belonging to the taxonomic group Caridea, shows a wide latitudinal distribution in the northeast Atlantic between approximately 34 and 67°N. It occurs from the Atlantic coast off Morocco, the Mediterranean, and the Black Sea in the South, to the White Sea in the North, including the North Sea and Baltic Sea (Luttikhuizen et al., 2008). The highest densities of brown shrimp are present in the southern North Sea, where it has been harvested in coastal waters for human consumption for centuries. An intensive fishery evolved in the 20th century with the introduction of steam vessels and mechanized bottom trawling.

The lifespan of *C. crangon* is 1–3 years (Campos & van der Veer, 2008). Females may reach a total length of up to 85 mm, whereas males rarely reach the commercial size of 50 mm (Meixner, 1996; Tiews, 1970). Onboard the ship, the catch is sorted mechanically, and the shrimp are cooked for 10 min in seawater and stored on ice. Further processing of the shrimp, that is, peeling, sorting, and packing, is usually done manually in low working-cost countries (Aviat et al., 2011). The products are shipped back and offered as regional seafood delicacy. In the last decade, brown shrimp have gained high economic relevance, with annual catches of more than 30,000 tons and a market value exceeding 100 Mio Euro (BLE, 2019; ICES, 2019, 2022).

After peeling, only the meat of the tail is sold as a high-value product. The remains, constituting up to 70% of the shrimp body mass, are only marginally exploited. However, shrimp remains have a high nutritional and economic potential as a source of valuable biomolecules, such as proteins (Synowiecki & Al-Khateeb, 2000), chitin, chitosan (Bajaj et al., 2011; Kumari et al., 2016; Xu et al., 2008), and pigments (Czerpak & Czeczuga, 1969; Snauwaert et al., 1973). Nevertheless, the biochemical composition and properties of brown shrimp remains have not been sufficiently investigated. In particular, information about their lipid content and fatty acid (FA) composition is lacking.

The current study evaluates the biochemical composition of shrimp meat and shrimp remains with emphasis on the FA composition. Specifically, the effect of heat processing, that is, boiling after capture, was determined by comparing frozen and cooked shrimp muscle tissue and shrimp remains. The suitability of brown shrimp remains as feedstock for shrimp aquaculture (e.g., *Litopenaus vannamei* and related species) is discussed.

2 | MATERIALS AND METHODS

2.1 | Sampling and treatment of shrimp

Brown shrimp, *C. crangon*, were sampled in May 2012 in the Weser estuary (53°49.40 N, 008°08.50 E) by bottom trawling with R/V *Uthörn*. The net was towed for 15 min at 6 m depth with a speed of 3–4 knots. The water temperature was 12°C. The animals were immediately transferred to basins, which were continuously supplied with running seawater. Shrimp of commercial size (50–75 mm, 1.5–2.5 g) were randomly selected for analysis. The shrimp were briefly rinsed with demineralized water to clear the bodies from attached particles and seawater. The shrimp were pooled into groups of 12 individuals each and immediately frozen at −20°C (referred to as 'frozen'). Another share of approximately 200 shrimp was cooked in boiling seawater for 10 min (referred to as 'boiled'), resembling the procedure onboard commercial shrimp trawlers. The boiled shrimp were randomly pooled into groups of 12 individuals, wrapped in aluminium foil, and stored on ice. Each pool of animals was considered one sample. The samples were transported on ice to the laboratories of the Alfred Wegener Institute in Bremerhaven, where they arrived approximately 3 h after catch. The frozen samples were defrosted, stored on ice, and peeled to separate the shrimp muscle (pleon) and the shrimp remains. The peeling remains accounted for 66%–70% of the body mass. Thereafter, the samples were frozen at −80°C and lyophilized for 90 h. The samples were pulverized in liquid nitrogen using a porcelain mortar and a pestle. The resulting fine powder was transferred into glass vials and stored in a desiccator.

2.2 | Lipid extraction and fatty acid analysis

The total lipid content of the shrimp muscle and shrimp remains was determined gravimetrically after Hagen (2000), and the FA composition was analyzed after Peters et al. (2006). Subsamples containing 1 mg of lipid were taken from the extracted lipids for transesterification. The resulting fatty acid methyl esters (FAMEs) were subsequently analyzed by gas chromatography (7890A, Agilent Technologies). Details are listed in the Supporting Information (S1). In brief, 20 μl of dissolved FAMEs was mixed with 980 μl of hexane in a newly annealed glass vial. The samples were loaded into the autosampler of the instrument. Ten microliters of the FAME sample were injected using a cold-injection system (programmable temperature vaporizer injector). The helium gas carried the sample through the 30 m capillary column (DB-FFAP), where the separation of the FAMEs took place. The column was heated in a column oven from 80 to 240°C. The separated FAMEs were detected and quantified by a flame ionization detector. FAs were identified based on the retention times of a known standard (fish oil Marinol, Solvay Pharmaceuticals). The chromatographic data were recorded and analyzed with the program Kroma System 2000.

2.3 | Statistics

Calculation of the data, including the processing of data recorded by instrument software, was performed with Microsoft Excel. Cluster analysis and principal component analysis (PCA) of the 19 major FAs listed in Table 1 were performed with the Primer 7 software. Percent data of FAs were arcsine square root transformed for analysis. The resemblance measure was the Euclidean distance, and the cluster

TABLE 1 Fatty acid (FA) composition ($\%_{TFA}$) of lipids extracted from frozen muscle and remains and boiled muscle and remains of *Crangon crangon*. The nine most common FAs, comprising 85% of TFAs, are termed. The sums (Σ) of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) are listed (Means ± SD of $n = 12$ in each frozen sample and $n = 11$ in each boiled sample)

			Frozen		Boiled		*p*-Value		
Fatty acid	**Name**	**Abbreviation**	**Muscle**	**Remains**	**Muscle**	**Remains**	**Tissue**	**Treatm.**	**Interact.**
14:0			1.3 ± 0.3	1.3 ± 0.2	1.6 ± 0.3	1.7 ± 0.2			
15:0			1.0 ± 0.1	0.9 ± 0.0	0.9 ± 0.1	0.9 ± 0.1			
16:0	Palmitic acid	PA	19.0 ± 0.7^{a}	19.1 ± 0.7^{a}	16.6 ± 0.5^{b}	16.9 ± 0.4^{b}	0.2770	<0.0001	0.5798
Iso 17			0.8 ± 0.1	0.8 ± 0.1	1.0 ± 0.1	1.0 ± 0.1			
17:0			0.9 ± 0.0	0.9 ± 0.1	0.8 ± 0.1	0.8 ± 0.1			
18:0	Stearic acid	SA	4.2 ± 0.2	4.2 ± 0.2	4.0 ± 0.5	4.1 ± 0.3	0.7616	0.2510	0.8124
Σ Saturated fatty acids		**SFAs**	**27.3 ± 1.0^{a}**	**27.4 ± 0.8^{a}**	**24.9 ± 0.8^{b}**	**25.4 ± 0.5^{b}**	**0.2026**	**<0.0001**	**0.4109**
16:1(n-7)	Palmitoleic acid	POA	6.1 ± 0.7^{a}	6.3 ± 0.7^{a}	8.9 ± 1.0^{b}	8.7 ± 0.9^{b}	0.9912	<0.0001	0.4349
18:1(n-9)	Oleic acid	OA	10.6 ± 0.4^{a}	10.5 ± 0.4^{a}	12.5 ± 0.8^{b}	12.3 ± 0.5^{b}	0.3883	<0.0001	0.6511
18:1(n-7)	Vaccenic acid	VA	5.4 ± 0.2^{a}	5.4 ± 0.1^{a}	5.7 ± 0.2^{b}	5.8 ± 0.2^{b}	0.4612	<0.0001	0.9464
20:1(n-11)			0.4 ± 0.2	0.4 ± 0.1	0.7 ± 0.4	0.5 ± 0.4			
20:1(n-9)			0.3 ± 0.2	0.2 ± 0.2	0.5 ± 0.2	0.6 ± 0.0			
20:1(n-7)			0.6 ± 0.1	0.6 ± 0.2	1.3 ± 0.1	1.2 ± 0.1			
22:1(n-7)			0.8 ± 0.1	0.7 ± 0.2	0.7 ± 0.1	0.7 ± 0.1			
Σ Monounsaturated fatty acids		**MUFAs**	**24.1 ± 1.1^{a}**	**24.2 ± 1.2^{a}**	**30.3 ± 1.2^{b}**	**29.7 ± 1.0^{b}**	**0.4068**	**<0.0001**	**0.3588**
16:3(n-4)			0.8 ± 0.2	0.9 ± 0.2	0.9 ± 0.1	0.8 ± 0.3			
18:2(n-6)			0.7 ± 0.0	0.7 ± 0.1	0.7 ± 0.0	0.7 ± 0.0			
20:4(n-6)	Arachidonic acid	ARA	2.7 ± 0.1^{a,b}	2.5 ± 0.1^{b}	2.8 ± 0.2^{a}	2.7 ± 0.2^{a}	0.0100	0.0007	0.6123
20:5(n-3)	Eicosapentaenoic acid	EPA	21.6 ± 1.3^{a}	21.0 ± 1.1^{a}	16.2 ± 0.7^{b}	16.1 ± 0.8^{b}	0.2624	<0.0001	0.4440
22:5(n-3)	Docosapentaenoic acid	DPA	2.5 ± 0.2	2.6 ± 0.2	2.5 ± 0.3	2.7 ± 0.4	0.1148	0.8439	0.9690
22:6(n-3)	Docosahexaenoic acid	DHA	13.6 ± 0.8^{a}	13.6 ± 0.6^{a}	11.7 ± 0.6^{b}	11.5 ± 0.9^{b}	0.4531	<0.0001	0.5832
Σ Polyunsaturated fatty acids		**PUFAs**	**41.9 ± 1.9^{a}**	**41.3 ± 1.5^{a}**	**34.9 ± 1.1^{b}**	**34.5 ± 1.4^{b}**	**0.3814**	**<0.0001**	**0.9621**
FAs < 0.5%			2.4 ± 0.9	2.3 ± 0.9	3.8 ± 0.7	4.2 ± 0.7			
FAs unknown			4.4 ± 1.0	4.8 ± 0.9	6.1 ± 1.0	6.2 ± 0.9			

Note: Means in a row with different superscript letters indicate significant differences ($p < 0.05$) as analyzed by two-way ANOVA and Tukey's multiple comparisons test on arcsin-sqrt-transformed data. Tissue = muscle and remains, treatm. = treatment (frozen and boiled), Interact. = interaction (tissue × treatment).

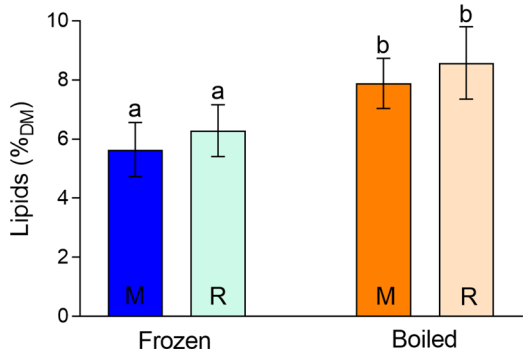

FIGURE 1 Total lipid content of frozen and boiled shrimp (*C. crangon*) muscle (M) and remains (R) in relation to dry mass (DM). Means ± SD of $n = 7–9$. Two-way analysis of variance (ANOVA) of arcsin sqrt-transformed data revealed a significant difference between treatments ($p < 0.0001$) but not between tissues. There was no significant interaction between the two factors. Different lowercase letters indicate significant differences between data sets

mode was the group average. Data sets of frozen and boiled samples (muscle and remains) were compared by two-way analysis of variance (ANOVA) and Tukey's multiple comparison test on arcsin sqrt-transformed data with a significance level of $p \leq 0.05$. ANOVA and graphical presentation were performed with GraphPad Prism ver. 7.05.

3 | RESULTS

3.1 | Lipids

The total lipid content of the frozen muscle tissue was 5.6 ± 0.9%$_{DM}$ and that of the frozen remains was 6.3 ± 0.9%$_{DM}$. The lipid content of the boiled samples was 7.9 ± 0.8%$_{DM}$ in the muscle tissue and 8.6 ± 1.2%$_{DM}$ in the remains (Figure 1). The lipid contents of the samples (arcsin sqrt transformed data) differed significantly between treatments ($F_{(1,28)} = 41.27$, $p < 0.0001$) but not between tissues ($F_{(1,28)} = 3.47$, $p = 0.0731$). There was no significant interaction between treatments and tissues ($F_{(1,28)} = 0.014$, $p = 0.9081$). Tukey's multiple comparison test confirmed significant differences between treatments and no significant differences between tissues.

3.2 | Fatty acids

Nineteen FAs, each comprising more than 0.5% of the total fatty acids (%$_{TFA}$), are listed in Table 1. FAs accounting on average for less than 0.5%$_{TFA}$ were combined into one group (FAs < 0.5%). Similarly, unknown and unidentified FAs were pooled. The share of unknown FAs accounted for 2.8–7.9%$_{TFA}$ in individual samples. The share of FAs < 0.5% and the share of unknown FAs increased in the boiled samples.

The major saturated fatty acids (SFAs) were palmitic acid 16:0 and stearic acid 18:0. The monounsaturated fatty acids (MUFAs) were dominated by oleic acid 18:1(n-9), palmitoleic acid 16:1(n-7), and vaccenic acid 18:1(n-7). The main polyunsaturated fatty acids (PUFAs) were eicosapentaenoic acid (EPA, 20:5(n-3)) and docosahexaenoic acid (DHA, 22:6(n-3)). Minor contributions to the PUFA pool were provided by arachidonic acid 20:4(n-6) and docosapentaenoic acid (DPA, 22:5(n-3)). These nine FAs make up ca. 85%$_{TFA}$ in frozen shrimp and ca. 80%$_{TFA}$ in boiled shrimp (Table 1).

Boiling significantly affected the composition of FAs. The cluster analysis clearly separated between the frozen and boiled samples (Figure 2) but not between the muscle tissue and the remains within each treatment. Likewise, the PCA clearly separated frozen samples from boiled samples. No distinction was evident between muscle tissue and remains in the frozen samples or in the boiled samples (Figure 3). PC1 explained 60.2% of the variation, and the eigenvectors were primarily determined by EPA (20:5(n-3)) and palmitoleic acid (16:1(n-7)). PC2 covered another 16.5% of the variation.

The shares of three of the nine most common FAs decreased after boiling (Table 1, Figure 4a). The major saturated palmitic acid (16:0) decreased by 2.2–2.4 percentage points (pp) in the boiled samples compared to the frozen samples. Likewise, the shares of the PUFAs EPA and DHA decreased by 4.9 and 5.2 pp and 1.9 and 2.1 pp, respectively. In contrast, the shares of the three major MUFAs were significantly higher in all boiled samples: 16:1(n-7) increased by 2.4 and 2.8 pp, 18:1(n-9) by 1.8 and 1.9 pp, and 18:1(n-7) by 0.3 and 0.4 pp. The three other major FAs, 18:0, 20:4(n-6), and 22:5(n-3), showed only slight variation between frozen and cooked samples.

In summary, the share of SFAs decreased by 2.0 and 2.4 pp in the boiled shrimp, the sum of MUFAs increased by 5.5 and 6.2 pp, and the PUFAs decreased by 6 pp, particularly due to EPA and DHA (Table 1, Figure 4b).

4 | DISCUSSION

Immediate boiling of brown shrimp after the catch is necessary to preserve the delicate meat from spoilage (Roskam, 1958; Verhaeghe et al., 2016) and to facilitate the later peeling process, which is much more difficult to perform with fresh or frozen shrimp. Visual changes after boiling appear in the colour, shape, and size of the shrimp. The colour turns from brown-grey to pink-red due to the degradation of the protein crustacyanin and the liberation of astaxanthin (Cianci et al., 2002). The natural straight posture changes to the characteristic C-shaped form with the pleon bent under the ventral side. This is likely due to denaturation of intracellular proteins, which progresses gradually from 30 to 60°C (Mizuta et al., 1999). Collagen denaturation, which starts at 53°C, causes longitudinal shrinkage (Martens et al., 1982). The overall size of boiled shrimp also decreased due to mass loss. In this respect, boiling can also reduce major allergens such as tropomyosin, which leaches from the shrimp muscle into the boiling water (Lehrer et al., 1990; Ozawa et al., 2020). Loss of mass due to boiling accounts for

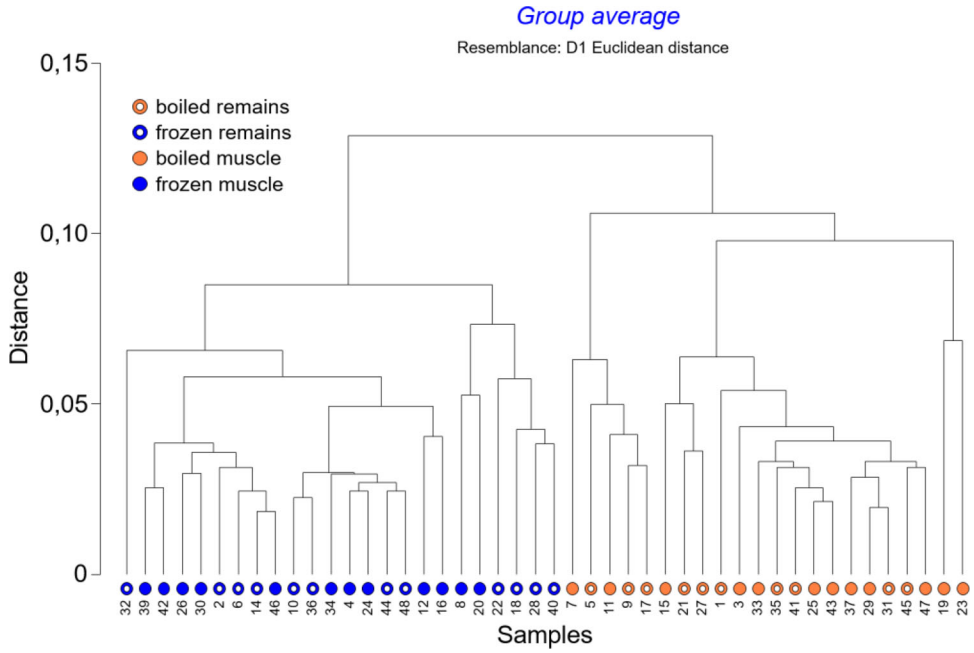

FIGURE 2 Cluster analysis (dendrogram) of the fatty acid composition of frozen and boiled shrimp (*C. crangon*) muscle and remains

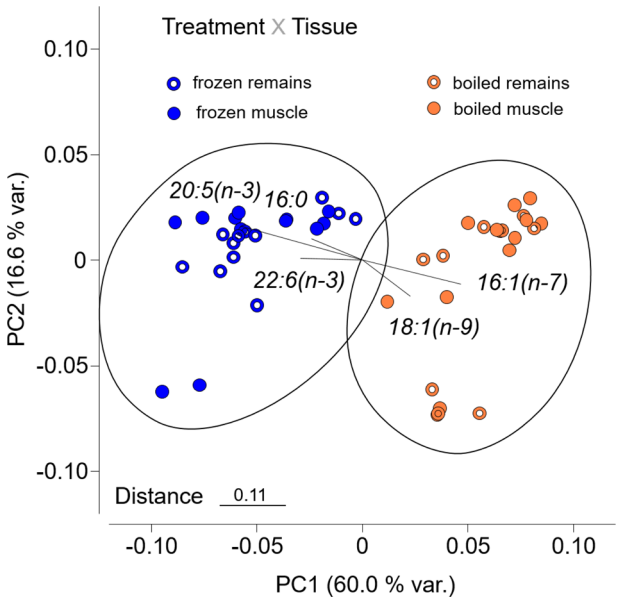

FIGURE 3 Principal component analysis (PCA) of the fatty acid composition of frozen and boiled shrimp (*C. crangon*) muscle and remains. The overlay clusters at the resemblance level (distance) of 0.11 correspond with the scale of the dendrogram in Figure 2

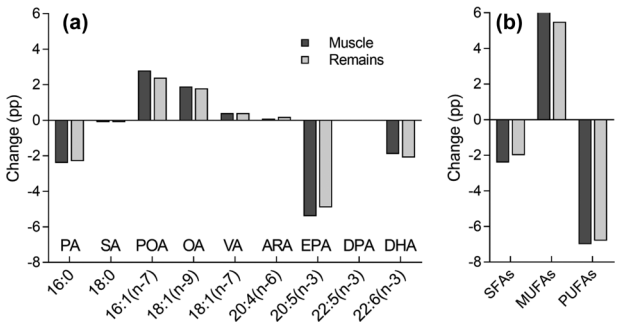

FIGURE 4 Average differences in percent points (pp) of (a) nine major fatty acids and (b) major groups of fatty acids between boiled and frozen *C. crangon* samples (muscle and remains). Abbreviations of fatty acid names are listed in Table 1. Abbreviations: MUFAs, monounsaturated fatty acids; PUFAs, polyunsaturated fatty acids; SFAs, saturated fatty acids

almost 10%. National fishery authorities apply conversion factors of up to 1.25 to convert the mass of boiled shrimp to live mass (ICES, 2019).

4.1 | Total lipid content and fatty acid composition

The lipid content of *C. crangon* is generally low, which is particularly due to a paucity of storage lipids, namely triacylglycerols (Martínez-Alarcón et al., 2019). Lipids consist mainly of polar lipids, the components of cellular membranes. However, the share of lipid classes may vary slightly with season, showing higher TAG levels in summer and fall (Mika et al., 2014; Martínez-Alarcón et al., 2019). The FA spectrum of *C. crangon* is dominated by palmitic acid 16:0, oleic acid 18:1(n-9), EPA (20:5(n-3)), and DHA (22:6(n-3)). It widely resembles the FA spectrum of the digestive gland, which is the primary nutrient resorption site and storage organ of lipids in higher decapods (Martínez-Alarcón et al., 2019). Moreover, only minor differences were evident in the FA composition between the frozen and cooked samples of the meat and the remains. This finding supports the observation that FAs are mostly derived from polar membrane lipids, which seem to maintain a rather uniform composition in these body parts.

The long-chain polyunsaturated fatty acids (LC-PUFAs) EPA and DHA are essential components of a healthy and balanced diet for humans as well as in animal feed. Conventional sources of omega-3 LC-PUFAs are marine fish oil and fish meal. As the demand for LC-PUFAs is rising (Tocher, 2015; Tocher et al., 2019), considerable research has been carried out mostly by the aquaculture sector to explore alternative sources of LC-PUFAs (Gladyshev, 2021; Patil et al., 2005; Romano et al., 2020).

In addition to palmitic acid (16:0) and oleic acid (18:1(n-9)), EPA and DHA are the dominant FAs, together representing approximately one fourth to one third of the total FAs in *C. crangon*. The shares of EPA and DHA were higher in *C. crangon* than in other crustacean species, which were analyzed with the same methodology and calculated in the same way. These include subtropical brachyuran marine and land crabs (Stumpp et al., 2021), marine brachyurans from temperate regions (Jungblut et al., 2018), and subpolar euphausiids and caridean shrimp (Kreibich et al., 2010). Moreover, shares of EPA and DHA are higher in *C. crangon* than in fresh and cooked heads and shells of whiteleg shrimp, *L. vannamei* (Darachai et al., 2019).

The higher amount of LC-PUFAs in *C. crangon* can be explained by both the diet and the lipid composition of the shrimp. Sources of LC-PUFAs, including EPA and DHA, are primary producers, such as benthic micro- and macroalgae or consumers, which feed on these primary producers (Dalsgaard et al., 2003). Both are frequent in the shallow waters off the Wadden Sea and form the staple food of *C. crangon* (Martínez-Alarcón et al., 2019). Additionally, PUFAs prevail as components in the polar lipid fraction derived from biomembranes rather than in neutral lipids (Jezyk & Penicnak, 1966; Levitsky, 2020). Since *C. crangon* exhibit limited lipid storage (Martínez-Alarcón et al., 2019), the higher share of EPA and DAH may be attributed to the higher proportion of polar lipids.

4.2 | Effects of boiling

EPA and DHA are sensitive to oxygen and temperature. Cooking, drying, and long-term storage impair PUFA levels by inducing various chemical transformations, such as oxidation, polymerization, cyclization, and others (Fournier et al., 2006 and references therein). The heating of PUFAs may generate various oxidation products, which can be both advantageous and disadvantageous to human health (Leung et al., 2018).

Surprisingly, reports about the fate of PUFAs during boiling are inconsistent. Several studies have shown reductions in EPA and DAH in marine species after heating and long-term storage, while others have found no changes in certain fish species (Leung et al., 2018 and references therein). For example, cooking of lipid-rich salmon (boiling, baking, and frying) did not significantly reduce PUFA levels (Bastias et al., 2017; Leung et al., 2018). Likewise, no reduction in EPA and DHA levels was detected in heated humpback salmon filets, which was attributed to a high level of natural antioxidants in the tissue (Gladyshev et al., 2006). In contrast, reductions in EPA and DHA were reported in fish lipids after indirect heating and heat smoking (Bienkiewicz et al., 2019; Hadipranoto, 2005). Apparently, the degradation and retention of PUFAs depend on various factors, such as boiling temperature, duration, and, particularly, the biochemical properties of the species under study (Choo et al., 2018).

In our study, boiled *C. crangon* samples (muscle tissue and remains, respectively) showed a distinctly different FA composition than frozen samples. The levels of three of the nine principal FAs decreased after boiling. These were palmitic acid (16:0), EPA (20:5(n-3)), and DHA (22:6(n-3)). The decrease in EPA accounted for 25% and that of DHA for 15%. These results are in agreement with other studies on the heat degradation of PUFAs in shrimp. Li et al. (2020) observed a decrease in EPA and DHA in boiled *Penaeus vannamei* (syn. *Litopenaeus vannamei*) muscle meat of 29% and 33%, respectively, due to oxidation. In addition to boiling, freeze-drying may entail a reduction in EPA and DHA levels, which was shown in *P. vannamei* (Li et al., 2020). In addition to EPA and DHA, palmitic acid (16:0) decreased also in our study. This is different from *L. vannamei* heads and shells, where the levels of palmitic acid were similar to those in *C. crangon* but remained almost unchanged after boiling (Darachai et al., 2019).

In contrast to EPA and DHA, the shares of MUFAs, particularly palmitoleic acid (16:1(n-7)) and oleic acid (18:1(n-9)), increased. These two FAs seem to be particularly stable and heat-resistant. Since SFA and PUFA decreased, the apparent increase in MUFA must be seen as a computational effect, reflecting the higher share of MUFA in relation to the reduced SFA and PUFA.

4.3 | Brown shrimp remains as feedstuff

For decades, researchers and industrial stakeholders have sought a sustainable use of marine resources and novel sources of essential omega-3 FAs, notably the LC-PUFAs EPA and DHA (Shepherd & Jackson, 2013). The annual landings of *C. crangon* from the North Sea exceeded 30,000 tons in the last decade with a value of more than 100 Mio Euro p.a. (BLE, 2019; ICES, 2019). Assuming a share of remains of two-thirds of the body mass (66%–70%), the remains account for at least 20,000 tons. The remains consist of the cephalothorax, including internal organs, the shell of the pleon, and adhering eggs, which are present in *C. crangon* females during most time of the year (Hünerlage et al., 2019; Siegel et al., 2008). The eggs may account for approximately 6% of the wet mass of the remains and contribute valuable FAs and other micronutrients as well (Saborowski, unpublished data).

The FA composition and PUFA contents (EPA and DHA) in brown shrimp are similar to those of high-quality anchovy and sardine fish meal. EPA and DHA shares are higher than those in various other fish meals, for example, capelin and herring (Cho & Kim, 2011). Since fish and shrimp are dependent on dietary n-3 and n-6 PUFAs to sustain health and growth, the FAs DHA and EPA are especially important components (National Research Council, 2011). Boiling reduces the EPA and DHA content but may also inactivate lipid-degrading enzymes, which may prevent further degradation. In our study, EPA and DHA still accounted for approximately 30% of TFA in brown shrimp after cooking, which is higher than the amount in ditch shrimp (*Palaemonetes varians*) meal of approximately 20% (Salas-Leiton et al., 2020).

Therefore, brown shrimp remains appear to be a valuable source of PUFAs and have great potential as animal feed for aquaculture purposes.

The growing aquaculture industry demands large amounts of fish meal and oils, exerting high pressure on marine ecosystems that cannot be exploited beyond their current state (FAO, 2020). As pointed out by Regueiro et al. (2021), the incorporation of biological byproducts in aquaculture feeds is one of the core aspects to implement more sustainable and durable aquaculture practices. The utilization of side-stream materials such as brown shrimp remains is a suitable supplement that contributes to waste reduction and supports positive ecological impacts. This practice is in alignment with the concept of circular economy, which is a key aspect in the European Green Deal strategy (European Commission, 2020).

5 | CONCLUSION

The fatty acid spectrum of brown shrimp shows a high share of nutritionally valuable long-chain PUFAs. Therefore, brown shrimp remains appear to be a suitable feed or feed supplement in shrimp aquaculture. Compared to global fish meal production, the amount of brown shrimp remains is low. Nevertheless, the exploitation of these remains would contribute to the sustainable use of marine resources and a circular economy. Follow-up studies are needed, particularly on the protein content, amino acid composition, and micronutrients, to fully explore the nutritional potential of brown shrimp remains as aquaculture feedstuff or feed supplement.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ETHICS STATEMENT

All international, national, and institutional guidelines for sampling and handling of organisms for this study have been followed.

AUTHOR CONTRIBUTIONS

Reinhard Saborowski: Conceptualization, methodology, writing – reviewing and editing, and supervision. Adrian Tanara: Methodology, writing – original draft preparation, data curation, and investigation. Marie Koch: Writing – reviewing and editing. Enno Fricke: Data curation and validation. Wilhelm Hagen: Methodology and writing – reviewing and editing.

DATA AVAILABILITY STATEMENT

The data of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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