2. Lipid profile and nutritional evaluation of shrimps

Sofia Miniadis-Meimaroglou\(^1\) and Vassilia J. Sinanoglou\(^2\)

\(^1\)Food Chemistry Laboratory, Department of Chemistry, University of Athens
Panepistimioupolis Zographou 15771, Athens, Greece; \(^2\)Instrumental Food Analysis Laboratory, Department of Food Technology, Technological Educational Institution of Athens, Ag. Spyridonos 12210, Egaleo, Greece

Abstract. The aim of this review is to present the shrimps (wild and cultured) lipid composition (focusing on the presence of lipid classes commonly found in shrimps) and carotenoids, as well as the PUFA/SFA, ω-3/ω-6 and EPA/DHA fatty acid ratios, in order to evaluate their fat nutritional value. Furthermore, certain aspects of the structures of natural phospholipids in the above mentioned organisms will also be reported.

2.1. Introduction

Seafood (such as fish, crustaceans and molluscs) is an essential component in the diet of the developed countries as well as an important source of proteins, vitamins, minerals and lipids (triacylglycerides, cholesterol, fatty acids, phospholipids etc). Lipids are the organic reserves of the crustaceans. Fat and essential polyunsaturated fatty acids contribute to
important aspects of the seafood (crustaceans) dietary quality and are central to their nutritional and sensory values.

Shrimp is a high cholesterol food and this is of concern since cardiovascular diseases are the principal cause of death. On the other hand, seafood including shrimp, is rich in polyunsaturated fatty acids, which are considered to be anticholesterolemic. Since the human plasma cholesterol level is dependent, not only on the dietary cholesterol concentration, but also on the fat content and fatty acid composition, the determination of these components in shrimp species is necessary [1].

The importance of lipids in crustaceans is suggested by their percentage contribution to the fresh weight of an organism, muscle and cephalothorax. Crustaceans ingest and accumulate $\omega$-3 fatty acids through the food chain from algae and phytoplankton, the primary producers of $\omega$-3 fatty acids. Crustaceans are thereby considered by nutritionists to be a high source of $\omega$-3 fatty acids, especially EPA and DHA, which are in turn believed to be protective of the human health in many ways.

The consumption of $\omega$-3 polyunsaturated fatty acids (PUFA), especially EPA (C20:5$\omega$-3) and DHA(C22:6$\omega$-3) has both anti-atherogenic and anti-thrombotic effects as well as an important role in the control of hypertension, while preventing cardiac arrhythmias, reducing the risk of coronary heart diseases, diabetes and cancer. Health problems such as asthma, arthritis, multiple sclerosis, headaches, and some kidney diseases may also be controlled or alleviated by $\omega$-3 fatty acids [2-6]. PUFA appear to play an essential role in the development of the nervous (brain), photoreception (vision) and reproductive systems [7].

Crustacean phospholipids (PhL) are also significant components for the human health since marine PhL can greatly facilitate the transportation of $\omega$-3 fatty acids over the blood-brain barrier and thus, prohibit the potential problems of $\omega$-3 fatty acid deficiency in the brain. [8,9]. Therefore, the assessment of PhL content as well as their fatty acid composition in shrimps is proved to be useful for the evaluation of their contribution to human health. In addition to that, crustacean phospholipids are also valuable components that can be applied within diverse areas such as nutrition, pharmacy and medicine as well as within basic research, because they contain high levels of $\omega$-3 fatty acids. PUFA/SFA, $\omega$-3/$\omega$-6 and EPA/DHA ratios [10-12] are used to evaluate the nutritional value of fat as well as the consumers’ health.

The contents of saturated (SFA) and monounsaturated (MUFA) fatty acids tend to increase faster with increasing fatness than the content of PUFA does, resulting in a decrease of the polyunsaturated/saturated fatty acid (PUFA/SFA) ratio. Although the PUFA/SFA ratio is an important factor of
the human nutrition, specific saturated and polyunsaturated fatty acids used for its calculation, have different metabolic effects as some saturated fatty acids do not increase plasma cholesterol and ignore the effects of monounsaturated fatty acids [13].

The $\omega-3/\omega-6$ ratio, which represents the role played by fatty acids in human atherosclerosis, becomes more critical as the SFA percentage increases. The importance of the $\omega-3/\omega-6$ ratio for the human health is also well known since many anthropological, nutritional and genetic studies indicate that a very low $\omega-3/\omega-6$ fatty acid ratio promotes the pathogenesis of many diseases, including cardiovascular disease, cancer, osteoporosis as well as inflammatory and autoimmune diseases, whereas increased levels of $\omega-3$ PUFA exert suppressive effects. Therefore, a higher $\omega-3/\omega-6$ ratio is more desirable in order to reduce the risk of many of the chronic diseases. Since many of them are multigenic and multifactorial, the optimal $\omega-3/\omega-6$ fatty acid ratio would vary with the disease under consideration [10-12].

Shrimps (crustaceans) fatty acid composition, besides its predominant effect on nutrition, is also related to the level of fatness, the genetic variation between species, the genotypes or breeds reflecting de novo fatty acid synthesis and the balance between triacylglycerols and phospholipids. Shrimps are the most popular crustaceans and are consumed in larger quantities than other edible crustaceans such as lobsters and crabs. A very large number of shrimp species, are consumed as part of the world’s population diet. There are two main categories of shrimps that are widely consumed as food, the wild (marine and freshwater) species and the commercially cultured species. The market value of the shrimp is predominately based on the visual appeal of their body colour and depends mainly on the presence of carotenoids. Product appearance and the resulting quality implications play a significant role in maintaining the highest consumer acceptance [14].

2.2. Methods used for the extraction, isolation and identification of lipids

A typical extraction procedure of total lipids from terrestrial or marine species usually uses the Bligh and Dyer method [15]. Most instrumental methods for lipid speciation are based on separation techniques such as Solid Phase Extraction, High Performance Liquid Chromatography, Iatroscan Analysis, preparative TLC, Gas Chromatography-Mass Spectrometry, Electrospray Ionization/Mass Spectrometry and LC/MS/MS spectrometry.
In particular, the total lipids extracted from the tissues (muscle and cephalothorax) of shrimps [8], were thereafter separated into neutral and polar lipid fractions by solid phase extraction [16]. In order to determine the neutral lipids, as well as the polar composition percentage, they were examined by the Iatroscan TLC-FID method [17, 18]. Neutral and polar lipid fractions are then separated to individual neutral and polar (phospho-) lipid classes by HPLC or Preparative TLC methods using different polar and neutral solvent systems [19]. Triacylglycerides were separated to triacylglycerol species by HPLC [20].

Sterols qualitative and quantitative composition was determined after they were converted to trimethylsilyl (TMS)-derivatives [21].

For the qualitative and quantitative determination (analysis) of phospho- and phosphonolipids in total lipids, polar lipids as well as in individual phospholipid classes, lipid phosphorous was assayed according to the Long and Staples [22] and phosphonate phosphorus according to the method Kapoulas et al. [23].

Aiming to the identification of the phospholipid molecular species, the determination of esters [24] (Snyder and Stephens method), glyceryl ethers [25] (Hanahan and Watts method), plasmalogens [26] (Gottfried and Rapport method) and sphingosin [27] (Lauter and Trams method) was carried out.

Both quantitative and qualitative analyses of total, polar, neutral lipids, triacylglycerides, as well as of individual phospholipid class fatty acids, were determined by Gas Chromatography/Mass Spectrometry analysis after they were converted to fatty acid methyl esters [28]. Phospholipid molecular species were also identified by Electrospray Ionization/MS analysis [19, 29].

2.3. Lipid classes of shrimp

Proximate composition in shrimp muscles is governed by many factors, including species, growth stage, feed and season [30]. Additionally, the fatty acid profile, the cholesterol content [31] as well as the total carotenoid content [14] of shrimps change seasonally.

In most marine organisms lipids are usually the second largest biochemical fraction after protein. Literature data concerning the total lipid content in (wild and cultured) shrimp’s whole body as well as in cephalothorax are quite limited; they mainly concern lipid concentration in muscle tissue (tails- the commonly edible part).

According to the literature data, the percentage of total lipid (TL), in certain shrimps whole body (wet tissue) was found to be: 0.734% for *Penaeus setiferus* (from the Gulf of Mexico), 0.665% for *Penaeus aztecus* (from the Gulf of Mexico), 1.32% for *Penaeus aztecus* (from Louisianna),
1.15-1.64% and 1.86-3.62% for males and females *Pandalous montagui* respectively (from the estuary of River Crouch Essex, U.K.) [32], 1.5% for *Funchalia villosa* (from the Eastern Gulf of Mexico [33], 1.57% for *Penaeus kerathurus* (North Aegean Sea- Platamona Bay) [9], 2% for *Penaeus indicus* from India [34], 2.80% and 2.75% for males and females *Penaeus japonicus* Bate respectively (from the Sea of Japan) [35], 1.99% for cultured *Penaeus merguiensis* (from Conwy U.K) [36] and 3.18% for the cultured prawn *Makrobrachium rosenbergii* [32].

As reported by a number of authors, the percentage of total lipids in shrimps (and prawns) muscle and cephalothorax was found to be less than 3.0 and 8.0% respectively. When comparing fat content between cultured and wild-caught shrimps, it should be remembered that cultured species have a tendency to show a higher proportion of muscle fat than their wild counterparts.

Besides that, the fat content of the shrimps (and prawns) muscle and cephalothorax has an important impact on proportionate fatty acid composition because of the different fatty acid composition of neutral lipids and phospholipids.

Total lipid content in various shrimp species muscle tissue (*Pandalus borealis*, *Penaeus setiferous*, *Penaeus durarum notialis*, *Penaeus vannamei*, *Penaeus azteca azteca*, *Penaeus durarum durarum*, *Penaeus azteca subtilis*) from five countries (Ecuador, Brazil, Honduras, Canada and the United States- the American species being taken from six different states) was found to range from 0.8 to 1.1 g/100 g of the wet tissue [37]. Similar results were reported by other authors [38-43] except for Kotb et al. [44] and Essien [45] who encountered lower (0.5 g/100 g) and higher (1.8 g/100 g) values respectively.

Furthermore, the concentration of total lipids in wild marine shrimps muscle *Penaeus brasiliensis*, *Penaeus schimitti*, *Xiphopenaeus kroyeri* was found to range from 0.9 to 1.0 g/100 g [1], while Sriket et al., [46] reported that no differences in the fat content (ranged from 1.23 to 1.30 g/100 g) between black tiger shrimp (*Penaeus monodon*) and white shrimp (*Penaeus vannamei*) meat was observed.

In addition, Karakoltsidis et al. [30] mentioned that the percentage of TL in the edible part of the Aegean Sea prawn *Aristeus antennatus* ranged from 0.2 to 2.0% of the wet tissue in different seasons while Miniadis-Meimaroglou et al. [9] reported a low percentage of total lipids in *Penaeus kerathurus* muscle (from the Aegean Sea); equivalent to 1.03±0.04% of the wet tissue.

Cultured Indian white shrimps (*Fenneropenaeus indicus*) fed different diets, which can be considered as a species of low fat content, showed no
significant differences in their muscle total lipid content (0.61–0.73 g/100 g muscle) [47]. On the contrary, Gonzalez-Felix et al. [48] observed higher values of total lipid content in cultured white shrimp (*Litopenaeus vannamei*) muscle (1.24-1.52 g/100 g).

Bragagnolo and Rodriguez-Amaya [1] reported that the concentration of total lipid in the freshwater cultured prawn (*Macrobrachium rosenbergii*) ranged from 0.9 to 1.1 g/100 g of the wet muscle tissue while the lipid content in the edible meat of two species of freshwater cultured prawns (*Macrobrachium nipponense* and *Macrobrachium rosenbergii*) varied from 1.33 to 1.86 g/100 g and of five species of marine cultured shrimps (*Exopalaemon carinicauda*, *Fenneropenaeus chinensis*, *Penaeus vannamei*, *Oratosquilla oratoria* and *Exopalaemon annandalei*) varied from 0.46 to 1.78 g/100 g [49].

In literature, few data concerning the crustacean cephalothorax TL are reported, especially for the hepatopancreas TL, which were for the *Penaeus japonicus* Bate 10.5% of the wet tissue [35] and for *Penaeus kerathurus* cephalothorax 2.36% (of the wet tissue) [9]. The latter was slightly higher than the TL percentage reported for the cephalothorax of the wild prawn, *Penaeus monodon* Fabricius, in which the average lipid content was 1.75% of the wet tissue, whereas in the farmed *Penaeus monodon* Fabricius the cephalothorax TL ranged from 0.8 to 3.2% of the wet tissue [50].

Polar lipids (PL) of shrimp (prawn) muscle and cephalothorax mainly consisted of phospholipids (PhL). Their percentage (in the TL in shrimps muscle and cephalothorax) varies widely in muscle lipids and is predominant. Phospholipids are the main constituents of biological membranes and have an essential role in regulating biophysical properties, protein sorting and cell signalling pathways. They are also essential components of the human diet. Lack of this type of lipids in the human organism can lead to a number of serious diseases.

According to a number of authors the PhL percentage was found to be in *Penaeus kerathurus* muscle and cephalothorax 75.9±0.8 and 45.5±0.8% of TL, respectively [9], in the Pacific white shrimp *Litopenaeus vannamei* muscle over 69.5% [51], in the wild *Penaeus monodon* Fabricius muscle and cephalothorax 70.54±5.89 and 56.70±6.51% of TL, respectively, while in the cultured *Penaeus monodon* Fabricius 57.00±10.18 and 39.23±5.86% of TL, respectively [50]; furthermore, in *Penaeus japonicus* muscle and cephalothorax (from the Gulf of Cadiz, south-west Spain) 68.4±3.86 and 35.5±1.93% of TL, respectively [52] whereas in *Penaeus japonicus* Bate muscle and hepatopancreas, PhL were found to be 22.1 and 7.7% of TL, respectively [35].
High PhL percentages (72-74% dry weight) were also found in *Penaeus monodon* (black tiger shrimp) and *Penaeus vannamei* (white shrimp) meat as quoted by Sriket et al. [46]. Each class of phospholipids is composed of a mixture of several molecular species containing a variety of fatty acids. The phospholipids of a majority of marine species including crustaceans, fishes and molluscs are rich in polyunsaturated fatty acids (PUFA), especially in ω-3 series, the latter being concentrated on the sn-2 position of the glycerol backbone of the molecule [29].

Phospholipid classes in shrimps tissues mainly consist of phosphatidylcholine (PC) and phosphatidylethanolamine (PE), followed by phosphatidylserine (PS), phosphatidylinositol (PI), sphingomyelin (Sphm) and lysophosphatidylcholine (LysoPC) [9, 51]. PE and PC are reported as the major phospholipid components of shrimp muscle and cephalothorax. According to Gopakumar and Nair [53] PE ranges from 23.1 to 30.8% and PC ranges from 44.5 to 52.5% in the muscle PhL of five different Indian prawns (*Metapenaeus dobsoni, Metapenaeus affinis, Penaeus indicus, Parapenaeus stylifera* (marine species) and *Metapeneus monoceros* (brackishwater species). O’Leary and Matthews [50] reported that PE and PC were also the major PhL of wild *Penaeus monodon* Fabricius muscle (26.43 and 44.84% of PhL, respectively) and cephalothorax (27.05 and 52.0% of PhL, respectively), as well as of the cultured *Penaeus monodon* Fabricius muscle (29.56 and 47.71%) and cephalothorax (28.42 and 52.57%) of PhL, respectively.

In *Penaeus kerathurus*, PE represented 26.4±0.6% (85.6% diacyl- and 14.4% alkyl-acyl- or alkenyl-acyl-analogues) of the muscle and 24.7±0.2% (90.7% diacyl- and 9.3% alkyl-acyl- or 1-alkenyl-2-acyl-analogues) of the cephalothorax PhL while PC represented 57.1±0.6% (86.9% diacyl- and 13.1% alkyl-acyl- or alkyl-acyl-analogues) of the muscle and 47.2±0.4% (89.1% diacyl- and 10.9% alkyl-acyl- or 1-alkenyl-acyl-analogues) of the cephalothorax PhL, respectively [9].

Since PC has been established as an essential nutrient with a recommended daily intake (RDI) of 550mg for men and 450mg for women [18], muscle and cephalothorax of several shrimp species (e.g. *Penaeus kerathurus, Penaeus longirostris, Aristaeomorpha foliacea*) were found to be an excellent source of dietary PC, providing 453-657 and 538-1373 mg of PC per 100 g, respectively [9, 54].

Neutral lipids (NL) consist mainly of triacylglycerides (TG) and sterols, followed by waxes, sterol esters, diglycerides (DG), monoglycerides (MG), free alcohols and free fatty acids (FFA). The proportion of NL in the TL of shrimp cephalothorax was much higher (ranging from 45.9±0.2 to 59.7±0.02%) to the one found in the muscle TL (ranging from 22.6±0.1 to
34±0.01%), as previously reported [9, 28]. The TG content of shrimp muscle and cephalothorax differed significantly, varying between 104.01 and 549.60 mg/100 g of edible portion, with muscle having the lowest (P<0.05) concentration [28]. The high percentages of TG in the cephalothorax NL are probably due to the fact that cephalothorax contains the hepatopancreas, the lipids of which are mainly composed of TG [55]. The TG fatty acid compositions of seafood lipids reflect their diet and usually comprise high concentrations of long chain monoenoic and polyunsaturated fatty acids, especially those of the ω-3 family. Myristic (C14:0), palmitic (C16:0) and palmitoleic (C16:1) acids are preferentially esterified to positions sn-1 and sn-3. Oleic (C18:1ω-9) and longer-chain monoenoic fatty acids are located mainly in the primary positions, with a tendency for a higher proportion to be found in position sn-3 as the chain-length increases. Polyunsaturated fatty acids are in greatest concentration in position sn-2 with substantial amounts also being found in position sn-3 [56]. *Penaeus kerathurus* muscle and cephalothorax TG are reported as an excellent source of polyunsaturated ω-3 and ω-6 fatty acids as well as a good source of monounsaturated and polyunsaturated fatty acids for the human diet [20]. The most important in quantitative terms are long chain TG containing C14:0, C16:0, C18:0 as SFA, C16:1, C18:1 as MUFA and C18:2ω-6, C20:4ω-6, C20:5ω-3, C22:6ω-3 as PUFA.

Crustaceans are incapable of de novo sterol synthesis, however they may biosynthesize cholesterol from other sterols such as β-sitosterol, brassicasterol, ergosterol and campesterol; thus, the sterols content in these depends on their diet. The different sterol composition in crustacean species indicates, either different feeding preferences or different food sources [57].

Cholesterol is the main sterol in shrimp’s muscles; King et al. [58] reported that cholesterol constituted more than 90% of the shrimp sterols. Similarly high values of cholesterol in crustaceans’ sterols were also reported by Karakoltsidis et al. [30]. In addition to that, in *Penaeus kerathurus* muscle and cephalothorax cholesterol accounted for 90.24 and 98.31% of total sterol respectively [28]. β-Sitosterol was also determined in relatively high percentages in the *Penaeus kerathurus* muscle. Low levels of brassicasterol, stigmasterol, D7-stigmasterol, campesterol, as well as campestanol (reduction product of campesterol) were also determined [28].

In particular, as reported in the literature, the cholesterol concentration (mg/100g), was found to range from 80.7 mg/100 g [59] for an unspecified species of shrimp to a high of 262 mg/100 g for a non-identified species of shrimp [60]. Johnston et al. [61] obtained cholesterol values of 201 mg/100 g for *Penaeus aztecs*, similar to those reported by Kritchevsky et al., [62] with
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a mean of 200 mg/100 g for a non-identified species of shrimp. Krzynowek and Panunzio [37] reported that the mean values of the cholesterol concentration for various species of shrimp (Penaeus setiferous, Penaeus durarum notialis, Penaeus vannanei, Penaeus aztecus aztecus, Penaeus durarum durarum, Penaeus aztecus subtilis) were found to be 152±15 mg/100 g of the edible muscle while Tsape et al. [28] reported that the cholesterol mean values for the Penaeus kerathurus muscle were found to be 144.29±14.08 mg/100 g while for the cephalothorax 521.44±9.63 mg/100 g of the wet tissue. Additionally, Luzia et al., [31] reported a mean of 165 mg/100 g for the seabob shrimp Xiphopenaeus kroyeri, Essien [45] a mean of 140 mg/100 g for the Palaemometes spp. and Bragagnolo and Rodriguez-Amaya [1] a general average cholesterol mean of 127 mg/100 g for the cultured freshwater prawn (Macrobrachium rosenbergii) and the wild marine shrimps muscle (Penaeus brasiliensis, Penaeus schimitti and Xiphopenaeus kroyeri).

Since shrimp muscle and cephalothorax fat differed significantly in their cholesterol concentration it is not possible to create a diet focussing on a lower cholesterol intake of the recommended maximum one (300 mg/day for a man and 225 mg/day for a woman), which was set by the European Olive Oil Medical Information and the World Health Organization.

This depends actually on the nutritional habits as well as the consumers’ culture; in particular, whether they only consume the shrimp muscle tissue (tail) or also the cephalothorax, like most Mediterranean people use to do.

2.4. Carotenoids commonly found in shrimps

Carotenoids, a group of more than 600 naturally occurring fat-soluble pigments, have attracted many researchers because of their commercially desirable properties, such as their natural origin, null toxicity and high versatility, providing both lipo- and hydro-soluble colorants and provitamin A [63]. Carotenoids can be synthesized by plants, algae, yeast, fungi and photosynthetic bacteria and contain 40 carbon atoms. They can be classified into carotenes (e.g. β-carotene, α-carotene, lycopene) and xanthophylls (e.g. β-cryptoxanthin, lutein, zeaxanthin, canthaxanthin). These compounds show antioxidiant and inmunomodulation activities and they can prevent degenerative diseases, such as cardiovascular diseases, diabetes, and several types of cancer especially prostate and digestive-tract tumors [64].

Crustaceans are known to contain various carotenoids which are responsible for their characteristic colours and are considered as one of the important sources of natural carotenoids [65]. Carotenoids in crustaceans are
assumed to have various functions relevant to biological processes such as reproduction [66], hatching, growth and protein stabilization [67].

Shrimps contain astaxanthin as the main pigment, which is principally formed from ingested β-carotene or zeaxanthin through oxidative transformation [68]. It has been reported that astaxanthin presents more than ten fold higher antioxidant activity than zeaxanthin, lutein, canthaxanthin and β-carotene and more than one hundred fold than α-tocopherol [69].

Astaxanthin and its esters have been isolated as major pigments from the temperate water shrimp *Pandalus borealis* [70]. In the *Penaeus japonicus* shrimp, astaxanthin and β-carotene were found to be the major pigments [71]. Astaxanthin in free, monoester and diester forms were found to constitute 86–98% of the total pigments in *Penaeus monodon*, while small amounts of β-carotene (3.6%) and zeaxanthin (1.5%) were also present in the exoskeleton [72]. Astaxanthin and its esters have also been isolated as major carotenoids of the Farfantepenaecus paulensis [73], *Pandalus borealis* [74], *Penaeus japonicus* [71] shrimps and of deep-sea shrimps from Atlantic waters [75]. Yamaguchi et al. [76] also identified various carotenoids as astaxanthin diester, astaxanthin monoester and free astaxanthin in the antarctic Krill shrimp (*Euphasia superba*).

Sachindra et al. [77] examined the quantitative and qualitative distribution of carotenoids in different body components of four species of shrimp (*Penaeus monodon*, *Penaeus indicus*, *Metapenaeus dobsonii* and *Parapenaeopsis stylifera*) harvested from shallow waters of the Indian coast. They found that astaxanthin and its mono- and diesters were the major carotenoids (63.5–92.2% of total carotenoids) present in the carotenoid extracts from the shrimps, while these extracts contained low levels of β-carotene and zeaxanthin.

Soultani et al. [54] found that free astaxanthin predominated in both muscle and cephalothorax of the shrimps *Aristaeomorpha foliacea* and *Penaeus longirostris*. Furthermore, lesser amount of zeaxanthin, canthaxanthin, cryptoxanthin and astaxanthin esters were also determined. The comparison between *Penaeus kerathurus* muscle and cephalothorax carotenoids showed that canthaxanthin predominated in both tissues, followed by zeaxanthin, free astaxanthin and lutein in muscle and free astaxanthin, lutein and zeaxanthin in cephalothorax. Moreover, lesser amounts of cryptoxanthin and astaxanthin esters were also determined in both tissues [78].

Howell and Matthews [79] identified β-carotene, astaxanthin diesters, astaxanthin monoesters and astaxanthin as the major carotenoids in wild *Penaeus monodon* extracts while cultured blue *Penaeus monodon* contained
only the carotenoid astaxanthin in any significant concentration. However, the carotenoid contents of shrimps vary, depending on their native habitat or manufactured diets [14]. According to the above mentioned data significant quantitative differences in carotenoid content between cultured and wild shrimp species have been reported. Howell and Matthews [79] found that the cultured blue *Penaeus monodon* shrimp exhibited low carotenoid concentrations (4.3-7.0 ppm) compared to those of the wild shrimp (26.3 ppm). The total carotenoid content of four species of shrimp (*Penaeus monodon, Penaeus indicus, Metapenaeus dobsonii* and *Parapenaeopsis stylifera*) from the Indian coast ranged from 10.4 to 17.4 ppm in the meat, 35.8 to 153.1 ppm in the chephalothorax and 59.8 to 104.7 ppm in the carapace [77].

### 2.5. Fatty acids commonly found in shrimps

An increase in the seafood consumption has been suggested as an alternative to elevate the ω-3 polyunsaturated fatty acid (PUFA) level in the western diet. Another alternative that is being well accepted by the population is the consumed of food supplements based on sea oils, with a high ω-3 PUFA concentration [4].

The consumption of seafood is known, as mentioned above, to provide many benefits for the human health due to its high contents of essential PUFA of the ω-3 family, namely eicosapentaenoic acid (EPA, 20:5ω-3) and docosahexaenoic acid (DHA, 22:6ω-3). A regular consumption of EPA+DHA prevents cardiovascular diseases and neural disorders [3].

Nutrition recommendations for daily intakes of ω-3 PUFAs (DHA+EPA), ranging from 1.6 g to 0.5 g for healthy adults, infants, pregnant and lactating women have been published by several international scientific authorities [80-84]. The American Heart Association (AHA) has also recommended, for individuals with established coronary heart disease, a combined DHA+EPA intake of 900-1000 mg/day and of 4 g/day for those with hypertriglyceridemia, without specifying the proportion of the mixture which should be represented by each of the two components. In addition, the findings of a systematic review [85] of combined results from numerous randomized controlled trials as published up to the fall of 2008, which have been researching the potential effects of supplementation with EPA/DHA combined at varying doses and durations on numerous risk factors for cardiovascular disease in individuals with type 2 diabetes, support the AHA recommendations. Furthermore, EPA and DHA may have individually potential roles in the function of the human organism, since EPA-enriched
supplements significantly improved psychological distress and depressive symptoms during menopausal transitions and have been suggested as an effective anti-cachexia anti-inflammatory agent [86]. On the other hand, DHA is essential for the growth and functional development of the brain in infants and is also required for the maintenance of normal brain function in adults, while it is taken up by the brain in preference to other fatty acids [4, 87-88]. The deficiency of ω-3 fatty acids in the brain is thought to induce memory, learning impairment, as well as psychological disorders [8].

The turnover of DHA in the brain is very fast, more than generally realized. Brain PUFAs are highly exposed to oxidative stress and there is no known mechanism for the reversal of such oxidation once it has occurred: partly oxidized fatty acids have to be broken down and replaced by new fatty acids [87]. Since the brain has a very limited capacity for the synthesis of new ω-3 fatty acids, replacements must be imported.

Shrimp muscle lipids contain highly polyunsaturated fatty acids (PUFA) such as EPA and DHA acids. The predominant individual SFA was palmitic acid (16:0) while oleic acid (18:1ω-9) represented the most abundant individual MUFA [28, 49]. In several shrimp species (Parapenaeus longirostris, Aristeus antennatus, Penaeus semisulcatus and Metapenaeus monoceros) it is also reported that palmitic acid (C16:0), stearic acid (C18:0), DHA and EPA were the most abundant fatty acids [89-90].

Moreover, the shrimp fatty-acid composition is species specific and depends on the type of dietary fat or environment. The crustaceans are influenced by seasonality, showing higher saturated and unsaturated fatty acid contents in the summer, whereas the origin and size of the organisms have no significant influence [1, 31]. Therefore, PUFA were found as the major fatty acids in several shrimp species followed by monounsaturated and saturated fatty acids (MUFA and SFA). Bragagnolo and Rodriguez-Amaya [1] reported that Makrobrachium rosenbergii, Penaeus brasiliensis, Penaeus schimitti and Xiphopenaeus kroyeri muscle lipids contained 29–35% SFA, 22-29% MUFA and 39-46% PUFA, Karakoltsidis et al. [30] and Bottino et al. [91] found for Aristeus antennatus and Penaeus aztecus 30% SFA, 30% MUFA and 41% PUFA of TFA, respectively, while Sriket et al. [46] found for the black tiger shrimp (Penaeus monodon) as well as for the white shrimp (Penaeus vannamei) 42.2–44.4% PUFA of TFA (Fig. 1). Krzeczkowski [39] found in Pandalus borealis values of 22%, 31% and 47% for SFA, MUFA and PUFA, respectively. In accordance with the above data, Li et al. [49] observed that the PUFA, ranging from 32.8% of total fatty acids in the Oriental river shrimp to 47.5% in fleshy prawn, predominated over the SFA (from 25.5% in ridgetail white prawn to 38.4% in Oriental river shrimp) and
Lipid profile and nutritional evaluation of shrimps

MUFA (from 19.4% in fleshy prawn to 29.3% in ridgetail white prawn) levels. Contradictory to that, Essien [45] encountered 54% SFA and 43% MUFA and PUFA in Palaemonetes spp.

According to Tsape et al. [28] the SFA and PUFA percentage of TL in Penaeus kerathurus muscle and cephalothorax vary greatly (30.95% SFA, 23.54% MUFA, 45.35% PUFA and 42.40% SFA, 22.40% MUFA, 35.10% PUFA of TL, respectively), which in turn significantly affected their PUFA/SFA ratio. Erkkila et al. [92] reported that several studies have found an inverse association of the PUFA/SFA ratio with cardiovascular outcomes, suggesting that a replacement of SFA with PUFA in the diet will decrease cardiovascular disease (CVD).

MUFA/SFA (monounsaturated/saturated), PUFA/SFA (polyunsaturated/saturated) and ω-3/ω-6 fatty acid ratios are widely used to evaluate the nutritional value of fat [13]. Nutritionists have focussed on the type of PUFA and the balance in the diet between ω-3 PUFA formed from a-linolenic acid (C18:3) and ω-6 PUFA formed from linoleic acid (C18:2) [93]. Several sources of information suggest that a very high ω-6/ω-3 ratio may promote many diseases, including cardiovascular disease, cancer, as well as inflammatory and autoimmune diseases. Shrimps provide an adequate intake of these ω-3 fats thus, improving the ω-6 to ω-3 fatty-acid ratio.

The fatty acid composition and especially fatty acid ratios of shrimp muscle can be affected by diet, size, age, reproductive cycle, salinity, temperature, season and geographical location (Tables 1, 2).

The fatty acid sums and composition as well as the MUFA/SFA, PUFA/SFA, ω-3/ω-6 and EPA/DHA fatty acid ratios varied with species.

Figure 1. Fatty acid sums (% of TL) of wild species of crustacean muscle.
(Tables 1, 2 Fig. 1). These differences among species might be associated with the different characteristics of the shrimp species. The contents of ω-3 PUFA in several shrimp species muscle were 1 to 19-fold greater than those of ω-6 PUFA (Table 1).

**Table 1.** P/S, M/S, ω-3/ω-6 and EPA/DHA ratios in the TL of wild species of crustacean muscle.

<table>
<thead>
<tr>
<th>Wild species</th>
<th>P/S</th>
<th>M/S</th>
<th>ω-3/ω-6</th>
<th>EPA/DHA</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Penaeus monodon</em></td>
<td>1.25</td>
<td>0.57</td>
<td>1.30</td>
<td>0.58</td>
<td>Sriket et al., 2007</td>
</tr>
<tr>
<td><em>Penaeus vannamei</em></td>
<td>1.18</td>
<td>0.61</td>
<td>1.00</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td><em>F. penicillatus</em></td>
<td>1.54</td>
<td>0.84</td>
<td>5.0</td>
<td>1.1</td>
<td>Nisa &amp; Asadullah, 2006</td>
</tr>
<tr>
<td><em>F. merquiensis</em></td>
<td>1.17</td>
<td>0.77</td>
<td>4.06</td>
<td>1.16</td>
<td></td>
</tr>
<tr>
<td><em>Penaeus kerathurus</em></td>
<td>1.46</td>
<td>0.76</td>
<td>2.34</td>
<td>1.32</td>
<td>Tsape et al., 2010</td>
</tr>
<tr>
<td><em>Penaeus brasilienis</em></td>
<td>1.5</td>
<td>0.83</td>
<td>3.8</td>
<td>1.39</td>
<td>Bragagnolo &amp; Rodriguez-Amaya, 2001</td>
</tr>
<tr>
<td><em>Penaeus brasilienis</em> (large)</td>
<td>1.5</td>
<td>0.93</td>
<td>4.0</td>
<td>1.62</td>
<td></td>
</tr>
<tr>
<td><em>Penaeus schimitti</em> (medium)</td>
<td>1.4</td>
<td>0.75</td>
<td>2.5</td>
<td>1.37</td>
<td></td>
</tr>
<tr>
<td><em>Penaeus schimitti</em> (large)</td>
<td>1.3</td>
<td>0.94</td>
<td>2.7</td>
<td>1.37</td>
<td></td>
</tr>
<tr>
<td><em>Xiphopenaeus kroyeri</em></td>
<td>1.2</td>
<td>0.79</td>
<td>3.8</td>
<td>0.89</td>
<td>Luzia et al., 2003</td>
</tr>
<tr>
<td><em>Xiphopenaeus kroyeri. (summer)</em></td>
<td>0.27</td>
<td>0.54</td>
<td>5.32</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td><em>Xiphopenaeus kroyeri. (winter)</em></td>
<td>0.32</td>
<td>0.61</td>
<td>4.14</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td><em>Penaeus longirostris</em></td>
<td>1.13</td>
<td>0.80</td>
<td>2.73</td>
<td>0.89</td>
<td>Soultani et al., 2011</td>
</tr>
<tr>
<td><em>A. foliatea</em></td>
<td>1.31</td>
<td>0.90</td>
<td>4.30</td>
<td>0.69</td>
<td>Karakoltsidis et al., 1995</td>
</tr>
<tr>
<td><em>Aristeus antennatus</em></td>
<td>1.37</td>
<td>1.00</td>
<td>19.5</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. P/S, M/S, $\omega$-3/$\omega$-6 and EPA/DHA ratios in the TL of cultured species of crustacean muscle.

<table>
<thead>
<tr>
<th>Cultured species</th>
<th>P/S</th>
<th>M/S</th>
<th>$\omega$-3/$\omega$-6</th>
<th>EPA/DHA</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Penaeus vannamei</em> (marine)</td>
<td>1.61</td>
<td>1.01</td>
<td>3.5</td>
<td>0.82</td>
<td>Li et al., 2011</td>
</tr>
<tr>
<td><em>Macrobrachium rosenbergii</em> (freshwater)</td>
<td>1.53</td>
<td>1.15</td>
<td>4.2</td>
<td>1.51</td>
<td></td>
</tr>
<tr>
<td><em>Exopalaemon carinicauda</em> (marine)</td>
<td>1.70</td>
<td>0.69</td>
<td>2.0</td>
<td>1.02</td>
<td></td>
</tr>
<tr>
<td><em>Fenneropenaeus chinensis</em> (marine)</td>
<td>1.43</td>
<td>0.88</td>
<td>0.8</td>
<td>2.37</td>
<td></td>
</tr>
<tr>
<td><em>Macrobrachium nipponense</em> (freshwater)</td>
<td>1.14</td>
<td>0.65</td>
<td>1.6</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td><em>Exopalaemon annandalei</em> (marine)</td>
<td>0.85</td>
<td>0.66</td>
<td>1.1</td>
<td>1.19</td>
<td></td>
</tr>
<tr>
<td><em>Oratosquilla oratoria</em> (marine)</td>
<td>1.33</td>
<td>0.86</td>
<td>3.2</td>
<td>0.91</td>
<td>Bragagnolo &amp; Rodriguez-Amaya, 2001</td>
</tr>
<tr>
<td><em>Macrobrachium rosenbergii</em></td>
<td>1.2</td>
<td>0.63</td>
<td>1.7</td>
<td>1.36</td>
<td></td>
</tr>
</tbody>
</table>

As reported by Luzia et al. [31], the fatty acids in the Seabob shrimp (*Xiphopenaeus kroyeri*) were influenced by seasonality, showing higher saturated and unsaturated fatty acid contents in summer. Regarding the $\omega$-3/$\omega$-6 ratio during summer, it showed the highest value, though the opposite was observed with the PUFA/SFA and MUFA/SFA ratio. Additionally, shrimp species seem to be influenced by the diet, as the wild species showed a higher $\omega$-3/$\omega$-6 ratio than the cultured ones (Tables 1, 2). As regards the EPA/DHA ratio no significant differences were established among species. The above mentioned data show that the fatty acid profile of cultured shrimps is sometimes different from that of wild species. The main difference is the generally lower $\omega$-3/$\omega$-6 ratio and EPA+DHA levels in cultured shrimps.

As shown in Table 3, the fatty acid composition of experimental diets was reflected to a certain extent in the fatty acid composition of shrimp muscle tissue [47]. Data calculated by Ouraji et al. [47] (Table 3) resulted in the fact that, the PUFA/SFA ratio was significantly higher in the muscle
Table 3. P/S, M/S, ω-3/ω-6 and EPA/DHA ratios in the TL of cultured species of crustacean muscle fed different diet.

<table>
<thead>
<tr>
<th>Cultured species</th>
<th>Diet</th>
<th>P/S</th>
<th>M/S</th>
<th>ω-3/ω-6</th>
<th>EPA/DHA</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Fenneropenaeus indicus</em></td>
<td>Control diet contained fish oil</td>
<td>1.16</td>
<td>1.26</td>
<td>1.82</td>
<td>0.49</td>
<td>Ouraji et al., 2009</td>
</tr>
<tr>
<td></td>
<td>fish oil substituted by 50% with the linseed oil</td>
<td>2.33</td>
<td>1.18</td>
<td>1.81</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fish oil substituted by 50% with soybean oil</td>
<td>1.51</td>
<td>1.36</td>
<td>0.46</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fish oil substituted by 50% with canola oil</td>
<td>1.25</td>
<td>2.07</td>
<td>1.06</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td><em>Artemia salina</em></td>
<td>Wild control diet contained baker’s yeast</td>
<td>0.98</td>
<td>1.61</td>
<td>2.68</td>
<td>-</td>
<td>Zhukova et al., 1998</td>
</tr>
<tr>
<td></td>
<td>diet contained micro algal <em>Isochrysis galbana</em></td>
<td>1.32</td>
<td>1.27</td>
<td>2.53</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>diet contained micro algal <em>Phaeodactylum tricornutum</em></td>
<td>1.92</td>
<td>1.46</td>
<td>2.99</td>
<td>90.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>diet contained micro algal <em>Nannochloropsis oculata</em></td>
<td>1.19</td>
<td>1.58</td>
<td>1.5</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

tissue of shrimps (*Fenneropenaeus indicus*) fed fish oil substituted by 50% with the linseed oil while the MUFA/SFA ratio was higher when shrimps, fed fish oil substituted by 50% with canola oil. ω-3/ω-6 and EPA/DHA ratios significantly affected by diet, presented higher values when shrimps, fed fish oil or fish oil substituted by 50% with the linseed oil.

Zhukova et al. [95] have shown that the PUFA/SFA, MUFA/SFA, ω-3/ω-6 and EPA/DHA ratios of Artemia salina muscle TL are significantly affected by the diet. Specifically, the PUFA/SFA ratio in muscle lipids is higher when shrimps have consumed micro algal grass based diets than when they have been fed baker’s yeast. The opposite change was observed for the MUFA/SFA ratio. The comparison of the ratio values of Table 3 suggest variability in the fatty acid content related to variations in food.
Therefore, the fatty acid composition of cultured shrimps largely depends on the fatty acid composition of the feed and can be customised by adjusting dietary intakes. Since cultured shrimp feeds are formulated on the basis of multiple experimental studies, their consumption can provide consumers with a nutritional composition that is at least as beneficial as that provided by wild species.

2.6. Conclusion

Shrimps constitute is a popular seafood of excellent nutritional value in terms of lipid profile, due to their high content of health-promoting nutrients such as polyunsaturated fatty acids, especially of the ω-3 family, phospholipids and carotenoids. The relatively increased cholesterol level is counterbalanced by the dominant presence of phospholipids and ω-3 fatty acids. Moreover, since carotenoids commonly found in shrimps have a significant antioxidant activity, their consumption could have a beneficial dietary effect. Carotenoids could also be extracted from shrimp cephalothorax and used both as colorants and functional ingredients in food. As a conclusion, shrimps which are low in saturated fats, but high in essential fatty acids and other nutrients can be part of a heart-healthy diet.

2.7. References

84. International Society for the Study of Fatty Acids and Lipids (ISSFAL), 2004, Recommendations for Dietary Intake of Polyunsaturated Fatty Acids in Healthy Adults.