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Chemical and nutritional characterisation of the Central Mediterranean Giant red shrimp (Aristaeomorpha foliacea): Influence of trophic and geographical factors on flesh quality

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Abstract

The Giant red shrimp (GRS, Aristaeomorpha foliacea) is a seafood product that is highly appreciated on the Italian market. This work aims at investigating whether a close relationship can be established amongst the area of origin, sex and the GRS quality. GRS samples caught in five Geographical Sub-Areas in the Central Mediterranean Sea, were analysed for their chemical and physical parameters. All the GRS samples had a good nutritional quality and those caught from Northern Tunisia, the Southern Ionian Sea and in the Crete areas showed the highest levels of polyunsaturated fatty acids of the n3 series, with high concentrations of eicosapentaenoic and docosahexaenoic acids. Samples caught from Northern Tunisia and in the Crete areas also showed the best colour and lightness values, whilst those caught from Northern Tunisia and in the Southern Ionian Sea areas showed the highest flesh hardness values. The highest total carotenoids content was found in the GRS samples caught in the Northern Tyrrhenian Sea and Crete areas. Finally, the GRS composition indicates that this seafood is a good source of nutrients and natural antioxidants, with lower atherogenic and thrombogenic indexes, which may provide some health bene- fits to consumers.

Introduction

Seafood products include a wide variety of species and have significant importance in the food industry. Amongst these products, crustaceans belonging to the Decapoda order, including prawns, shrimps, lobsters, crayfish, crabs and hermit crabs, are of remarkable commercial interest. Crustaceans have attracted considerable attention as an important source of nutrients in the human diet. Apart from their delicacy, crustacean species contain amino acids, peptides, protein and other useful nutrients such as calcium and vitamins (Heu, Kim, & Shahidi, 2003). Shrimps are an extremely good source of protein, yet are very low in fat and calories, making them a very healthy choice of food. Shrimps are low in saturated fat, which is the fat that raises cholesterol levels in the body. Additionally, shrimp flesh consists of highly unsaturated fatty acids such as eicosapentaenoic (C20:5n3, EPA) and docosahexaenoic (C22:6n3, DHA) acids, which are considered as essential for the human diet (King, Childs, Dorsett, Ostrander, & Monsen, 1990). Amongst the other shrimp species, the Giant red shrimp (Aristaeomorpha foliacea) (GRS) is a seafood product that is requested and appreciated, and it has therefore obtained a very high commercial

value (about 35 Euro/kg) and resulted in the development of an important niche market for Italian fishermen from Mazara del Vallo (on the southern coast of the Isle of Sicily). This interest seems to be justified by a cliché that is popular amongst local fishermen, which states that the GRS caught in the different fishing grounds of the Strait of Sicily show significant differences in the colour of the outer skin, the flavour and texture of the flesh. The market value of shrimp is predominately based on the visual appearance of their body colour. The appearance of the product and the resulting quality implications play a significant role in maintaining a high consumer acceptance. The colour of shrimp is due to their carotenoid content, which provides the typical red–orange tissue pigmentation and which varies according to their native habitat (Okada, Nur-E-Borhan, & Yamaguchi, 1994). These differences seem to be highly dependent on the type and variability of the oceanography of the sea and the trophic characteristics in which this species spends most of its adult life. The aim of this work was to investigate whether there is in fact a close relationship amongst the area of origin, sex and the quality of GRS, as claimed by local fishermen and consumers. The results of the analysis carried out on five batches of shrimp, caught in five different sampling areas in the Central Mediterranean Sea, were compared in order to clarify the complex biochemical pathways that are responsible for the synthesis of fatty acids that give the flesh the typical flavour of this shrimp species.

2. Materials and methods

2.1. Sample collection and preparation

All the samples were caught by bottom trawlers on muddy bottoms at between 500 and 700 meters of depth, in five different fishing areas in the Central Mediterranean Sea, as indicated in Fig. 1. On the basis of an allocation in macro-areas and Geographical Sub-Area (GSA), suggested by the General Fisheries Commission for the Mediterranean (GFCM, 2000), the sampling sites were identified as follows: Ligurian and Northern Tyrrhenian Sea (GSA9), Northern Tunisia (GSA12), South of Sicily (GSA16), Southern Ionian Sea (GSA21) and Crete (GSA23), respectively. All the samplings were made during the months of May–June 2008 and the shrimps were directly shipped on dry ice (mean temperature of -18°C) from each of the vessel landing areas (Mazara del Vallo and Porto Santo Stefano) to the Institute of Science of Food Production – CNR laboratory, where the analyses were carried out. Upon arrival in the laboratory, sub-samples of frozen whole red shrimps (head-on) were weighted, length measured and separated on the basis of gender and carapace length in order to create homogenous size classes. Part of these samples were beheaded and the outer shells (exoskeleton) carefully removed, before the flesh was freeze-dried, weighed to determine the moisture content, minced and stored at –30°C until the successive chemical analysis, whilst the remaining part of the frozen shrimp was used for the physical analysis.

2.2. Chemical composition

The crude protein (CP) content was calculated by converting the nitrogen content, which was determined using Kjeldahl's method (N x 6.25) (AOAC, 1995). The ash content was determined by dry ashing in a furnace oven at 550°C for 24 h. The gross energy (GE) content was determined using an adiabatic calorimeter bomb (IKA C7000, Staufen, Germany), calibrated with benzoic acid.

2.3. Gas-chromatographic analysis of the fatty acids

The fatty acid (FA) composition was determined on the flesh shrimp samples. The lipid extraction of the samples was performed according to Peiretti and Meineri (2008); the extract was expressed as crude fat and used for the trans-methylation of the FAs. The FA methyl esters in hexane were then injected into a

gas chromatograph (Dani Instruments S.P.A.GC1000 DPC; Cologno Monzese, Italy) equipped with a flame ionisation detector (FID). The separation of the FA methyl esters was performed using a Famewax™ fused silica capillary column (30 m x 0.25 mm [i.d.], 0.25 μm) (Restek Corporation, Bellefonte, PA, USA). The peak area was measured using a Dani Data Station DDS 1000. Each peak was identified and quantified on the basis of pure methyl ester standards (Restek Corporation, Bellefonte, PA, USA). Ulbricht and Southgate (1991) proposed equations for the calculation of two indices, which they called the atherogenic index (AI) and the thrombogenic index (TI). In these indices, different weights are attributed to various categories of FAs in relation to the different contribution of these to the prevention or promotion of pathological phenomena. The atherogenic (AI) and thrombogenic (TI) indexes were calculated as follows:

$$AI = (C12:0 + 4 \times C14:0 + C16:0) / [\Sigma MUFA + \Sigma(n-6) + \Sigma(n-3)]$$

$$TI = (C14:0 + C16:0 + C18:0) / [0.5 \times \Sigma MUFA + 0.5 \times \Sigma(n-6) + 3 \times \Sigma(n-3) + \Sigma(n-3)/\Sigma(n-6)]$$

where MUFA and PUFA are monounsaturated fatty acids and polyunsaturated fatty acids, respectively.

2.4. Cooking losses

The shrimps tails were weighed, vacuum packed in plastic bags and cooked in boiling water (100 °C) for exactly 2 min, as described by Di Turi, Ragni, Vicenti, Melodia, and Vonghia (2005). The boiled tails were cooled for 30 min in cold running water and then removed from the bags, blotted and reweighed. Cooking losses was expressed as the weight difference between the raw tails and the cooked tails, divided by the weight of the raw tails. After establishing the cooking losses, the tails were submitted to shear force analysis.

2.5. Textural analysis

Shear force was measured using a Warner–Bratzler shear blade with a triangular slot cutting edge (WB) fitted to an Instron Universal Testing Machine (Instron 5544, Minnesota, USA). As the shear force is affected by the diameter of the sample, the tails were individually measured using a calliper at the level of the second segment and the diameter was inserted into the Instron computer software. Then, the tails were shared transversally to the body axis. The cross-head speed of the Instron was set at 50 mm/min (Chen et al., 2007) and the highest peak, which represented the maximum shear force required to cut the tails, was recorded. The values were expressed in Newtons (N).

2.6. Colour measurements

The flesh colour was measured using a bench colorimeter Chroma Meter CR-400 Konica Minolta Sensing (Minolta Sensing Inc, Osaka, Japan) in the CIELAB colour space (CIE, 1976). The lightness (L*), redness (a*) and yellowness (b*) were recorded, and the Chroma and Hue indices were calculated as Chroma [$C^* = (a^{*2} + b^{*2})^{1/2}$] and Hue [$H_0 = \tan^{-1}(b^*/a^*)$] (Boccard et al., 1981). Chroma is related to the quantity of pigments and high values represent a more vivid colour and denote a lack of greyness. Hue is the attribute that permits colours to be classified as red, green, yellow, blue, and so on. Three readings were taken on the fresh surface over the level of the second segment, and averaged.

2.7. Determination of total carotenoid content

The total carotenoid (TC) assay was modified from that of Sachindra, Bhaskar, and Mahendrakar (2005) and performed on 1 g of the freeze dried material (head and whole GRS sample, respectively). The sample was homogenised for 30 s at high speed with 20 ml of acetone using a Polytron tissue homogenizer (Type PT 10–35; Kinematica GmbH, Luzern, Switzerland). 10 ml of petroleum ether (BP 40–60°C) was added to the acetone extract and then vortexed for 30 s. Ten milliliters of 0.1% NaCl was added to the acetone/petroleum ether mixture and then vortexed for 30 s. After centrifugation of the homogenate (6000 rpm for 5 min), the supernatant was picked up and then evaporated under vacuum at room temperature using a Speedvac (SC210A; Savant Instruments, Farmingdale, NY). The resulting TC concentrate was taken up in chloroform and the absorbance of the appropriately diluted extract was measured at 468 nm using a Helios spectrophotometer (Unicam Limited, Cambridge, UK) against a reagent blank. The concentration of TC in the extract was quantified using a standard calibration curve at four concentration levels (1, 2, 4, 8 mg/l) utilising a pure synthethic astaxanthin standard (Dr. Ehrenstorfer GmbH, Ausburg, Germany) and then expressed as mg of astaxanthin per kg of freeze dried sample.

2.8. Statistical analysis

Data were evaluated by means of the GLM procedure of the SPSS software package (version 11.5.1 for Windows, SPSS Inc., USA) and by considering the fishing area, sex and their interaction as the main effects. The data were presented as the means of each group and the standard error of the means (SEM) together with the significance levels of the main effects and interactions. Significance was established at $P < 0.05$.

3. Results and discussions

3.1. Chemical analyses

The size, chemical composition and GE of the GRS samples ranged according to the sampling areas and sex are reported in Table 1. The flesh protein content did not differ for the sampling sites or sex, whilst dry matter (DM), crude fat (CF) and ash were affected by the GSA and sex and showed a significative interaction. In particular, the ash values appeared to be inversely related to the size of the shrimps and was significantly different between sex and GSA. This result was also found in white shrimp (Lim, Ako, Brown, & Hahn, 1997). The GE content ranged from 20.8 to 22.0 MJ kg^{-1} DM and differed according to sex and GSA. These values appeared higher than those reported by Rosa and Nunes (2004) for the edible part of three crustacean species sampled in two distinct periods of the year. Moreover, the GE content of our GRS samples reflected the same trend observed for the CF content, that varied from 1.5 g 100 g^{-1} DM in female GSA23 to 2.9 g 100 g^{-1} DM in female GSA16 samples. A higher level of fat was observed in different prawn species caught off the Lagos lagoon in Nigeria (Adeyeye & Adubiaro, 2004) or in Indian White Shrimp (Penaeus indicus) caught from the Southeast coast of India (Ravichandran, Rameshkumar, & Prince, 2009). Higher values of CF content were also found in pond cultured shrimp Penaeus monodon (6.3 g 100 g^{-1} DM) and Penaeus vannamei (5.7 g 100 g^{-1} DM) as reported by Sriket, Benjakul, Visessanguan, and Kijroongrojana (2007). The chemical composition values confirmed that GRS is an excellent food source, due to their balance of nutrients, with a good level of protein. The protein content ranged from 87 g 100 g^{-1} DM in the GSA9 to 89 g 100 g^{-1} DM in the GSA23 samples. Similar flesh protein values were recorded in a work on Kuruma prawn (Di Turi et al., 2005), which had the aim of typifying the variations of the meat quality characteristics in shrimp from semi-intensive or extensive rearing systems. A similar crude protein content was found in Penaeus monodon (87.7 g 100 g^{-1} DM), whilst

Penaeus vannamei showed a low crude protein content (82.5 g 100 g^{-1} DM), as reported by Sriket et al. (2007).

3.2. Fatty acid composition

The flesh fatty acid (FA) profile is summarised in Table 2, where it is expressed in g 100 g^{-1} total FA, according to GSA and sex. All the FAs showed significant differences amongst site, sex and their interaction, with the exception of a minor FA (C22:5n3), which did not differ for sex and GSA sex interaction. Amongst the FAs, those occurring in the highest proportions were: palmitic acid (C16:0, 15.2–18.4 g 100 g^{-1} FA), oleic acid (C18:1n9, 20.0–28.3 g 100 g^{-1} FA), eicosapentaenoic acid (EPA, C20:5n3, 8.8–14.7 g 100 g^{-1} FA) and docosahexaenoic acid (DHA, C22:6n3, 16.4–26.4 g 100 g^{-1} FA). The variation in the shrimp flesh FA profile could be due to the type of pasture feeding. The lower percentages of linoleic acid (LA, C18:2n6), a typical plant FA, could be correlated to the omnivorous habit of wild shrimp. In fact, higher contents of LA were found in the muscle of cultured Indian white shrimp (Fenneropenaeus indicus) fed diets added with different plant oils (Ouraji et al., 2009), but also in the muscle of whiteleg shrimp (Litopenaeus vannamei) fed diets supplemented with two species of marine algae (Ju, Forster, & Dominy, 2009). Dietary lipids have been found to affect the fatty acid composition of Penaeus vannamei.Whole body shrimps have been found to be higher in MUFA and PUFA when fed safflower, corn, soybean, linseed or menhaden oil diets which contained high levels of unsaturated fatty acids, whilst shrimps fed stearic acid or coconut oil diets, which are high in saturated fatty acids (SFA), were lower in MUFA and PUFA (Lim et al., 1997). Amongst the most valuable FAs, EPA and DHA play important roles in the prevention of inflammatory and cardiovascular diseases due to their serum triglycerides-lowering effects. As far as the EPA and DHA contents are concerned, they were moderately high in all the samples, although lower values were recorded in female samples caught in GSA9 and GSA16, indicating a lower nutritional value of these products than the other GRS. The EPA content found in the present research was similar to that reported by Huang, Wang, Lu, Dai, and Zhou (2004) for farmed white shrimp (Penaeus vannamei), a value which ranged from 11.5 to 13.7 g 100 g^{-1} FA, whilst the DHA content, which ranged from 8.9 to 10.4 g 100 g^{-1} FA, was lower than that of our data. In another study, the EPA and DHA contents of juvenile Penaeus vannanei were 16.6 and 13.6 g 100 g^{-1} FA, respectively (Lim et al., 1997) and this study indicated that menhaden oil rich in n3 PUFA was better utilised by Penaeus vannanei than the plant oil sources that were evaluated. Rosa and Nunes (2004) found EPA contents which ranged from 14.6 to 14.9 g 100 g^{-1} FA and from 14.0 to 14.8 g 100 g^{-1} FA in red shrimp (Aristeus antennatus) and pink shrimp (Parapenaeus longirostris), respectively. The DHA contents ranged from 17.4 to 23.4 g 100 g^{-1} FA and from 17.2 to 22.2 g 100 g^{-1} FA in red and pink shrimps, respectively. Yanar and Çelik (2005) found a lower EPA content in Penaeus semisulcatus (7.7–12.5 g 100 g^{-1} FA) and Metapenaeus monoceros (8.3–12.6 g 100 g^{-1} FA) caught off the coast of eastern Turkey in different seasons; whilst a lower proportion of DHA was found in these shrimps species (Penaeus semisulcatus: 5.1–12.2 g 100 g^{-1} FA and Metapenaeus monoceros: 5.3–10.1 g 100 g^{-1} FA). In another work, Bottino, Gennity, Lilly, Simmons, and Finne (1980) comparing three species of shrimp, Penaeus setiferus, P. aztecus and P. duorarum caught off the Gulf of Mexico and reported EPA and DHA values ranged from 12.5 to 16.9 g 100 g^{-1} FA, and from 7.2 to 12.2 g 100 g^{-1} FA, respectively. Gopakumar and Nair (1975) reported FA profile of five species of Indian prawns (Metapenaeus monoceros, M. dobsoni, M. Affinis, Penaeus indicus, Parapenaeopsis stylifera); these authors found lower levels of EPA and DHA that ranged from 0.5 to 2.0 g 100 g^{-1} FA and from 6.2 to 14.7 g 100 g^{-1} FA, respectively. As for the FA fractions, all the fractions showed significant differences according to site, sex and their interaction, with the exception of SFA, which did not differ between sexes. The FA compositions of GRS ranged from 22.3 to 25.2 g 100

g^{-1} FA for SFA, from 28.7 to 44.6 g 100 g^{-1} FA for MUFA and from 30.2 to 46.7 g 100 g^{-1} FA for PUFA. In three species of shrimp (Penaeus setiferus, Penaeus aztecus and Penaeus duorarum) caught off the Gulf of Mexico (Bottino et al., 1980), SFA fractions showed higher values (ranged from 29 to 48 g 100 g^{-1} FA) than GRS samples. Rosa and Nunes (2004) found that the PUFA fraction was dominant (42.1– 48.4 g 100 g^{-1} FA) in red shrimp, pink shrimp and Norway lobster, and this was followed by MUFA (26.3–34.6 g 100 g^{-1} FA) and SFA (22.9–27.4 g 100 g^{-1} FA). Bragagnolo and Rodriguez-Amaya (2001) reported FA fractions of other wild marine shrimps (Penaeus brasiliensis, Penaeus schimitti, Xiphopenaeus kroyeri). In these species the SFA fraction ranged from 29 to 34 g 100 g^{-1} FA, the MUFA fraction ranged from 23 to 29 g 100 g^{-1} FA and the PUFA fraction ranged from 39 to 46 g 100 g^{-1} FA. The values of the n3/n6 ratio and the atherogenic (AI) and thrombogenic (TI) indexes are reported in Table 2, where significant differences between GSA, sex and their interaction can be observed. The values of the n3/n6 ratio (19.1–36.4) vary to a great extent for GSA and sex. Moreover, these values are three to six-fold higher than those found by Huang et al. (2004) for white shrimp grown at different salinity levels in the laboratory. Low levels of the n3/n6 ratio (0.5–1.5) were found in cultured Indian white shrimp by Ouraji et al. (2009), and this was due to the diet type, which in their experiment was rich in PUFA n6 because fish oil was substituted, by 50%, linseed, soybean and canola oils, respectively. In wild marine shrimps flesh, Bragagnolo and Rodriguez- Amaya (2001) found low levels of the n3/n6 ratio (2.5–4.0) due to the highest level of PUFA n6 that ranged from 7.9 to 12.0 g 100 g^{-1} FA. In Penaeus semisulcatus and Metapenaeus monoceros caught off the coast of eastern Turkey in different seasons similar levels of the n3/n6 ratio (1.9–3.1 and 1.4–2.0, respectively) were found (Yanar & Çelik, 2005). In terms of human health a high n3/n6 ratio has been considered as an indication of a high nutritional value of any potential food and this makes shrimp a very healthy food, because it is an extremely good source of protein, whilst very low in fat and calories. The AI values (0.21–0.27) and TI values (0.12–0.18) were lower than those reported in cultured Indian white shrimp by Ouraji et al. (2009), but similar to those reported for three crustacean species (red shrimp, pink shrimp and Norway lobster) caught off the south coast of Portugal (Rosa & Nunes, 2004). It is interesting to notice that the TI values recorded in the GRS samples are extremely low, compared to those of other seafood products, whether caught or farmed. Valfrè, Caprino, and Turchini (2003) reported higher TI values for anchovy, eel, rainbow trout and sea bass (0.45, 0.32, 0.37 and 0.45, respectively). This is probably due to the higher n3/n6 ratio in GRS flesh than that found in other freshwater and marine fish.

3.3. Length measurements, cooking losses and texture

As shown in Table 3, there were significant differences in total and carapace lengths between sex, whilst cooking losses showed significant differences amongst the fishing capture areas and sexes. Cooking losses (CL) were lowest in the GSA12 females, whilst those of GSA9, GSA21 and GSA23 were the highest. A similar trend was observed in the males, who exhibited higher values than the females. The male shrimps caught in GSA21 and GSA12 had the highest and the lowest values, respectively. Overall, due to their size, the male shrimps showed higher values than the females, when the GRS males were smaller than the females. A similar trend was observed by Erdogdu, Balaban, Otwell, and Garrido (2004), who studied the cooking-related yield losses for different sizes of white (Penaeus vannamei) and brown (Penaeus californiensis) shrimp. These authors stated that yield losses increased with a decrease in the size of the shrimp, despite the shorter cooking times of the smaller shrimps. The greater diffusion thickness of the large shrimp could be a reason for this contrast. As proteins denature and water is liberated from the tissue, this water needs to reach the surface to be ‘‘lost’’. This would be more easily achieved in smaller shrimps. Sex affected shear force, whilst no significant differences were found amongst the GSA. In general the males were more tender than the females, particularly those caught in GSA9. The female shrimps

harvested in GSA21 were the hardest. This difference is probably due to the shrimp size, as previously observed by Niamnuy, Devahastin, and Soponronnarit (2007) in wild white shrimp (Penaeus indicus). These authors noticed that the hardness of large shrimps was greater than that of small shrimps due to the larger amount of muscle fibre, which leads to the necessity of a higher compressive force to cause the required deformation.

3.4. Colour measurements

The flesh colour of the male and female GRS are summarised in Table 3 on the basis of the capture area. No significant differences were observed for lightness (L*) or hue between sex and GSA and their interaction. The redness (a*) and yellowness (b*) values only differed between GSA, with the highest values recorded in GSA12 and GSA23, whereas chroma showed significant difference for all the main effects. However, considering sexes, the males tended to have a higher chroma than the females in all the fishing areas, except for those caught in GSA21 and GSA23. As regards lightness (L*) and hue, the females showed higher values in the GRS16 and in GRS 21 areas. The males caught in GSA9 had the highest yellowness (b*) and chroma values, whilst the lowest values were recorded in GSA16 and in GSA 21. As far as the females are concerned, the highest redness (a*), yellowness (b*) and chroma values were observed in GSA23, whilst the lowest redness (a*) and chroma values were recorded in GSA16 and the lowest yellowness (b*) values in GSA16 and GSA9. In the females, a more saturated colour was observed in GSA23, whilst on the contrary, the GSA16 females had a less brilliant colour due to the lower redness (a*) and yellowness (b*) values. A darker and less yellow meat was observed in GSA9. In other shrimp species, Benjakul, Visessanguan, Kijroongrojana, and Sriket (2008) stated that black tiger shrimp (Penaeus monodon) meat had a higher redness (a*) value than white shrimp meat and they suspected that black tiger shrimp meat might have a higher carotenoid content than white shrimp. The colour differences observed in GRS samples could probably be related to their carotenoid content, the colour of shrimps in fact is quite different for different species and is influenced by different parameters such as feed, season and environment (Yanar, Çelik, & Yanar, 2004). The carotenoid content of wild shrimps varies according to their native habitat and its algae presence, the main carotenoid producers in the aquatic environment (Yanar et al., 2004), which enhances pigmentation in the shrimp tail muscle.

3.5. Total carotenoids content

The total carotenoids (TC) content of the whole body and head of the male and female GRS are reported in Table 4 according to their fishing area. Significant differences were observed amongst the samples for sex and GSA and their interaction. As far as the sampling area is concerned, the highest values were recorded in the head GRS samples of GSA9, GSA21 and GSA12, whilst in the whole body GRS, the highest values were found in GSA9 and GSA23. As far as sex is concerned, in GSA16, GSA21 and GSA23 the highest TC values were found in the whole body female GRS and in the head of the male GRS. The health benefits of carotenoids are well known. One of the most important characteristics of carotenoids is their ability to act as antioxidants, by protecting cells and tissues from the damaging effect of free radicals and singlet oxygen (Hirayama, Nakamura, Hamada, & Kobayashi, 1994). The TC content in shrimps has been found to vary according to the species and tissues within single species (Sachindra et al., 2005). In our study, the TC content in the GRS head (30.0–113.3 mg kg^{-1} DM) was similar to those observed by Sachindra et al. (2005) in the heads of four species of shrimps harvested from shallow waters off the Indian coast: Parapenaeopsis stylifera (153.1 mg kg^{-1} DM), Penaeus monodon (58.4 mg kg^{-1} DM), Metapenaeus dobsonii (51.3 mg kg^{-1} DM) and Penaeus indicus (35.8 mg kg^{-1} DM). Yanar et al. (2004) examined seasonal changes in the muscle tissue TC contents of the most commercially important shrimp species

(Penaeus semisulcatus and Metapenaeus monoceros) in the north-eastern Mediterranean Sea caught in different seasons. These authors found that the TC contents were considerably higher, for both species, during spring (16.2 and 18.1 mg kg^{-1} DM, respectively) and summer (15.8 and 18.0 mg kg^{-1} DM, respectively), than in the winter and autumn seasons. These values, relative to the muscle tissue of these two shrimp species, were lower than the values we found in the whole body GRS sampled during the summer season.

4. Conclusions

Taking into account all the physical quality parameters, the samples taken from the GSA12 and GSA23 areas have shown the best colour and lightness values, whereas the GSA12 and GSA21 samples have shown the highest flesh hardness values. Finally, from the nutritional point of view, all the GRS samples analysed had a good nutritional quality and in particular those caught in the GSA12, GSA21 and GSA23 areas showed the highest levels of polyunsaturated fatty acids and, above all, those of n-3 series. Finally, the high TC content found in the whole body of the GRS indicates that this seafood is a good source of natural antioxidants, which may provide some health benefits to consumers.

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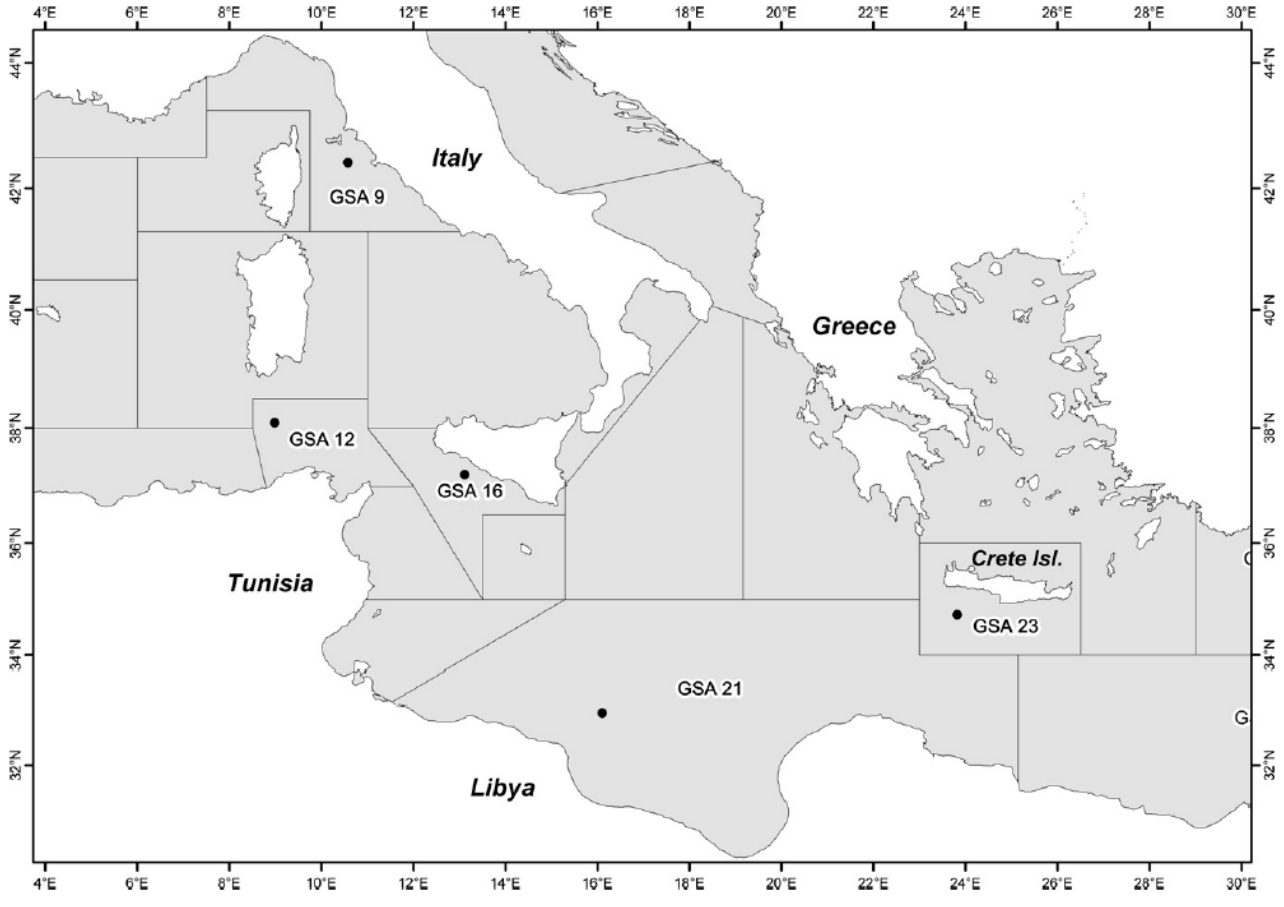

Fig. 1. Chart of the Mediterranean Sea indicating the sampling fishing areas (red points) (GFCM, 2000). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1 Size (g), chemical composition (g 100 g^{-1} DM) and gross energy (MJ kg^{-1} DM) of tail muscles of Giant red Shrimp (n = 4) ranged according to sampling sites (GSA) and sex.

	GSA9		GSA12		GSA16		GSA21		GSA23		SEM	Significance		
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂		GSA	Sex	GSA × Sex
Size	45.5	21.1	51.5	17.7	56.1	16.4	36.5	16.1	39.0	14.1	35.5	0.020	0.000	0.060
Dry matter	25.9	27.4	24.2	23.7	25.3	26.4	25.6	27.4	24.7	25.8	0.07	0.000	0.000	0.001
Crude fat	2.7	2.0	1.8	2.0	2.9	1.8	2.3	1.9	1.5	2.2	0.00	0.022	0.015	0.001
Crude protein	87.5	87.7	91.0	85.7	88.4	90.6	85.4	89.9	90.0	88.6	8.49	0.828	0.986	0.244
Ash	8.3	9.3	7.9	10.1	8.2	8.3	7.2	7.7	8.3	8.5	0.03	0.000	0.000	0.000
Gross energy	21.7	21.2	21.9	20.9	22.0	20.8	21.3	21.3	21.7	21.2	0.05	0.037	0.000	0.000

Table 2 Fatty acids (FA) composition (g 100 g^{-1} total FA), of Giant red Shrimp flesh (n = 4) ranged according to sampling sites (GSA) and sex.

	GSA9		GSA12		GSA16		GSA21		GSA23		SEM	Significance		
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂		GSA	Sex	GSA × Sex
C14:0	0.49	0.22	0.29	0.19	0.52	0.21	0.32	0.31	0.29	0.15	0.01	0.046	0.000	0.048
C16:0	16.97	15.18	17.66	16.39	17.28	17.80	18.02	17.49	18.36	17.40	0.05	0.000	0.000	0.000
C16:1	5.10	2.25	4.18	2.14	5.55	2.27	4.30	3.23	3.75	3.56	0.00	0.000	0.000	0.000
C18:0	4.36	5.47	4.41	5.18	4.48	5.58	5.66	5.88	5.23	5.31	0.00	0.000	0.000	0.000
C18:1n9	28.34	19.95	24.05	20.71	28.16	20.10	21.87	19.98	21.48	21.49	0.02	0.000	0.000	0.000
C18:1n7	5.09	3.25	3.85	3.50	5.58	3.28	3.09	2.68	3.25	3.21	0.00	0.000	0.000	0.000
C18:2n6	0.93	1.27	0.82	0.98	0.89	0.95	0.65	0.87	0.82	0.92	0.00	0.000	0.000	0.003
C20:1	3.65	3.13	2.61	0.89	4.53	2.48	2.16	2.54	2.01	2.47	0.07	0.000	0.030	0.000
C20:2n6	0.55	0.90	0.48	0.70	0.57	0.73	0.44	0.77	0.58	0.51	0.01	0.039	0.000	0.009
C20:3n3	2.65	3.46	3.63	2.85	2.65	3.40	3.02	3.39	3.89	3.97	0.00	0.000	0.000	0.000
C20:5n3	10.10	14.73	11.81	13.78	8.80	13.79	11.93	12.40	12.92	12.55	0.01	0.000	0.000	0.000
C22:5n3	0.73	0.84	0.87	0.75	0.85	0.96	0.53	0.72	0.68	0.75	0.01	0.005	0.057	0.126
C22:6n3	18.13	25.50	21.86	26.43	16.42	25.73	24.58	26.12	24.50	24.43	0.28	0.000	0.000	0.000
SFA[a]	23.02	22.29	23.51	23.10	23.40	24.73	25.17	25.14	25.01	23.93	0.07	0.000	0.147	0.001
MUFA[b]	42.96	29.23	35.56	29.82	44.55	28.74	32.20	29.24	31.23	31.46	0.09	0.000	0.000	0.000
PUFA[c]	33.09	46.71	39.47	45.49	30.18	45.56	41.15	44.28	43.40	43.13	0.29	0.000	0.000	0.000
n3/n6	20.92	20.10	28.58	25.67	19.10	25.50	36.36	25.54	29.49	29.07	1.19	0.000	0.004	0.000
AI[d]	0.25	0.21	0.25	0.23	0.26	0.26	0.27	0.26	0.26	0.24	0.00	0.000	0.000	0.013
TI[e]	0.16	0.12	0.14	0.13	0.18	0.14	0.14	0.14	0.14	0.13	0.00	0.000	0.000	0.000

a Saturated FA.
b Monounsaturated FA.
c Polyunsaturated FA.
d Atherogenic index.
e Trombogenic index.

Table 3 Total and carapace length (mm), cooking losses (%), shear force (N), and flesh colour variables of Giant red Shrimp (n = 6) ranged according to sampling sites (GSA) and sex.

	GSA9		GSA12		GSA16		GSA21		GSA23		SEM	Significance		
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂		GSA	Sex	GSA × Sex
TOTL[a]	153.7	127.7	163.0	125.0	166.7	126.3	184.3	118.0	173.0	124.0	147.6	0.630	0.000	0.101
CARL[b]	56.7	49.3	57.5	41.0	63.3	45.3	73.7	47.0	63.7	48.3	41.3	0.168	0.000	0.118
CL[c]	19.0	20.9	10.3	11.5	13.0	12.0	16.7	26.7	16.5	17.0	9.0	0.000	0.011	0.070
SF[d]	16.6	8.1	16.7	10.6	18.7	19.0	26.2	12.1	15.7	9.6	25.5	0.095	0.003	0.171
L	35.1	39.7	37.6	39.7	41.5	39.1	44.5	41.8	39.9	41.7	16.3	0.089	0.623	0.364
*a**	19.2	26.4	24.8	26.3	15.9	21.2	21.3	20.8	27.5	25.8	11.2	0.002	0.059	0.077
*b**	13.9	21.6	18.4	20.2	13.6	15.9	17.4	16.6	20.8	20.2	8.9	0.031	0.063	0.051
Chroma	23.8	34.2	31.0	33.2	21.0	26.5	27.5	26.8	34.5	32.8	17.4	0.004	0.045	0.048
Hue	35.7	39.1	36.6	37.3	39.6	36.6	39.4	38.5	36.8	38.2	11.4	0.849	0.787	0.433

a Total length.
b Carapace length.
c Cooking losses.
d Shear force.

Table 4 Whole body (WB) and head total carotenoids content (TC, mg kg^{-1} DM) of Giant Red Shrimp (n = 4) ranged according to sampling sites (GSA) and sex.

	GSA9		GSA12		GSA16		GSA21		GSA23		SEM	Significance		
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂		GSA	Sex	GSA × Sex
TC_{WB}	66.3	63.3	22.1	23.7	58.1	25.8	46.7	37.1	54.4	46.9	16.4	0.000	0.000	0.002
TC_{Head}	113.3	78.9	64.5	74.7	36.4	77.8	68.2	86.7	30.0	38.8	25.6	0.000	0.028	0.001