Bioactive fatty acids of three commercial scallop species

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ABSTRACT

The fat content and fatty acid profile of commercially important scallops Flexopecten glaber, Mimachlamys varia, and Pecten jacobaeus were investigated in samples of adductor muscle, gonad, mantle, and viscera. The viscera showed the highest lipid content in all species examined. Significant differences were found in the fatty acid composition among tissues and among scallops. All pectinids exhibited high levels of eicosapentaenoic and docosahexaenoic acids in the adductor muscle, with a maximum value of 211 mg/100 g tissue and 252 mg/100 g tissue in the viscera of F. glaber. Highest n3/n6 ratios were recorded in F. glaber gonad and viscera, in P. jacobaeus muscle, and in the gonad of M. varia. M. varia adductor muscle had the lowest values of atherogenicity and thrombogenicity indices used as indicators of beneficial health effects. These data contribute to the overall evaluation of the nutritional quality of scallops and suggest that their consumption may provide health benefits.

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Introduction

The consumption of food from the aquatic environment has long been recognized as healthy for human consumption. Their benefits are related to high biological value proteins, essential vitamins, minerals, and mainly to the presence of bioactive long-chain omega-3 polyunsaturated fatty acids (n-3 PUFAs). In recent years, increasing attention has been focused on significance of n-3 PUFAs in human nutrition, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids (FA) play vital roles in disease prevention and health promotion.\cite{1,2}

Contemporary literature abounds with arguments about their potential role in the prevention of cardiovascular diseases (CVDs) that are the leading cause of death around the world. Moreover, they may be beneficial in preventing asthma in children, as well as neurological disorders (retinitis pigmentosa, depression, schizophrenia, and Alzheimer’s disease), infertility, inflammatory diseases (rheumatoid arthritis, Crohn’s disease), and certain types of cancers.\cite{1,4,5-6} Long-chain n-3 PUFAs cannot be synthesized by humans and must be obtained through the diet.\cite{7}

Nowadays, the Western diet tends to be too low in n-3 PUFAs, mainly due to low consumption of seafoods and a lack of adequate information for consumers regarding the nutritional value of these foodstuffs.\cite{2} Scallops belonging to Pectinidae family are one of the most demanding bivalve species for the customers all over the world. Their European market share has increased significantly in recent years,\cite{8} representing an important part of the global seafood market and supporting both commercial fisheries and aquaculture all around the world.\cite{9} Pecten jacobaeus, Mimachlamys varia, and Flexopecten glaber are the most commercially important scallops from the Ionian Sea (central Mediterranean Sea), for the peculiar organoleptic characteristics of their meat, their high market

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value, and high growth rates in the wild and in cultured. The knowledge of their biochemical composition is extremely important because it reflects their nutritional value. This information can help consumers to make healthy food choices and can be for producers a powerful marketing tool.

Extensive research exists which describes lipids and fatty acid composition of many species of bivalves. However, the lipid content and the fatty acid composition of bivalves, besides varying for several parameters, such as fishing season, geographical location, size, sex, and reproductive cycle period, are also species-specific. Moreover, almost all the data included in the molluscan lipid studies concern the entire organism and only a few report the distribution of fatty acids in separate tissues.

The aim of this study was to evaluate the nutritional quality of four different tissues (adductor muscle, gonad, mantle, and viscera) of three scallops’ species (F. glaber, M. varia, and P. jacobaeus), with emphasis on fatty acids profile. These data may contribute to a better understanding and interpretation of the health benefits given by the lipid fraction of some of the most economically important scallops from the central Mediterranean Sea.

Materials and methods

Sampling area, animal collection, and sample preparation

Adult specimens of P. jacobaeus (shell length: 100.0 ± 5.5 mm; edible weight: 8.6 ± 1.7 g), F. glaber (shell length: 44.2 ± 1.5 mm; edible weight: 5.36 ± 1.7 g), and M. varia (shell length: 41.1 ± 2.1 mm; edible weight: 4.51 ± 0.9 g) were collected from suspended cages of a pilot plant in the Ionian Sea (central Mediterranean, southern Italy: 40° 25’ 54” N, 17° 14’ 22” E) during autumn months (October–December 2014). Taxonomic determination of species has been made by use of classification keys available in literature. On arrival in the laboratory, samples of the adductor muscles, viscera, gonads, and mantles were taken from 10 specimens for each species and stored at −30°C, until analysed. Biochemical analysis, performed on pooled tissues originating from 10 specimens, was done in triplicate (three for species for each organ).

Total lipid and fatty acids analysis

All used reagents and solvents (analytical grade) were purchased from Sigma (Sigma–Aldrich GmbH, Steinheim, Germany). Total lipid (TL) content was determined gravimetrically after chloroform–methanol extraction according to Folch et al. FAs of TLs were transesterified to methyl esters (FAMEs) in a boron trifluoride-catalyzed methanol:benzene solution (1:2, v:v). The mixture was shaken, and then heated in boiling water for 45 min. Samples were allowed to cool, and 1 ml of distilled water was added followed by vigorous shaking. FAMEs were recovered in the upper benzene phase and concentrated under nitrogen and kept at −20°C until further analysis. Triplicate samples were analysed. Analysis of FAMEs was performed by gas chromatography (GC) using an HP 6890 series GC (Hewlett Packard, Wilmington, DE, USA) equipped with flame ionization detector. FAMEs were separated with an Omegawax 250 capillary column (Supelco, Bella, PA, USA) (30 m long, 0.25-mm internal diameter, and 0.25-mm film thickness). Helium was used as carrier gas at a flow rate of 1 ml/min. The column temperature program was as follows: 150–250°C at 4°C/min and then held at 250°C. FAMEs were identified by comparing retention times with a standard (Supelco 37 Component FAME Mix). The area under each FA peak, relative to the total area of all FA peaks, was used to quantify the FAs identified. The results obtained are reported as percentage of FA. All samples were analysed in triplicate. Relative quantities were expressed as weight % of total fatty acids. Per cent of total fatty acids data were converted to amounts per 100 g wet fillet according to Greenfield and Southgate.
Lipids nutritional quality indexes (NQI)

Atherogenicity index (AI)\textsuperscript{[24]}: AI shows the inhibition of the aggregation of plaque and diminishing the levels of esterified FA, cholesterol, and phospholipids, thereby preventing the appearance of micro- and macro-coronary diseases) where:

\[
AI = \frac{(C12:0 + 4\times C14:0 + C16:0)}{(\text{Sum MUFAs} + \text{Sum PUFAs})}
\]

\[
Thrombogenicity index (TI)\textsuperscript{[24]}: TI shows the tendency to form clots in the blood vessels:
\[
TI = \left(\frac{(C14:0 + C16:0 + C18:0)}{(0.5 \times \text{Sum MUFAs} + 0.5 \times \text{Sum n6 PUFAs} + 3 \times \text{Sum n3 PUFAs} + (n3/n6))}\right)
\]

Fatty acids hypocholesterolemic/hypercholesterolemic ratios (HH): HH\textsuperscript{[25]} shows the hypocholesterolemic effect of PUFA:

\[
HH = \frac{(C18:1\text{cis9} + C18:2\text{n6} + C20:4\text{n6} + C18:3\text{n3} + C20:5\text{n3} + C22:5\text{n3} + C22:6\text{n3})}{(C14:0 + 16:0)}
\]

Statistical analysis

Results are reported as means ± standard deviations (\(n = 30\)). The normality of distributions and homogeneity of variances were assessed by means of the Kolmogorov–Smirnov test of goodness of fit and Levene’s test, respectively. Data with homogeneous variances were analysed using ANOVA and post hoc Tukey’s test to determine differences among species and tissues. A principal component analysis (PCA), based on the Pearson’s correlation matrix, was used to simplify the data interpretation showing a visual representation of the main variations of the fatty acids content in the four tissues (adductor muscle A, gonad G, mantle M, and viscera V) of the three scallops. Analysis was performed with the statistical package software XLSTAT (Version 2008.4.01).

Results and discussion

TL content

The TL contents of different tissues and pectinid species, expressed on a wet weight basis (ww), are shown in Fig. 1. Of all tissues examined, viscera had the highest lipid content in all species, and

![Figure 1. Mean and standard deviation of total lipids (g/100 g wet weight) in the examined tissues of *F. glaber*, *M. varia*, and *P. jacobaeus.*](image-url)
particularly in *F. glaber* with a value of 3.11 ± 0.42 g/100 g ww (*p* < 0.05) (Fig. 1). No significant differences among species (*p* > 0.05) were registered in the mantle (range 0.21–0.25 g/100 g ww) and the adductor muscle (range 0.32–0.44 g/100 g ww) that showed the lowest lipid content (*p* < 0.05). These data are in agreement with values reported by Caers et al.\(^{17}\) for *Argopecten purpuratus* from Chile.

**Fatty acids**

Fatty acid profiles of lipids are listed in Table 1. In all species and tissues a relative pattern with saturated fatty acid (SAFA) > polyunsaturated Fatty acids (PUFA) > monounsaturated fatty acid (MUFA) was observed, except for the adductor muscle of *M. varia* and viscera of *F. glaber* in which the PUFA was the most represented group.

Palmitic acid was the major SAFA in all samples, with the lowest contents in the mantle of all species (between 35.76 and 46.71 mg/100 g ww tissue) and the highest 390 mg/100 g ww tissue in the viscera of *F. glaber*, followed by stearic (C18:0) and myristic (C14:0) acids. Relatively to adductor muscle and gonad, in general the values, expressed as % of total FAs, are consistent with the findings reported by Telahigue et al.\(^{9}\) in a study on the same species from Tunisia water, while Caers et al.\(^{17,26}\) for *A. purpuratus* found values slightly lower than pectinidae of this study.

Diet high in SAFA increase the risk for developing heart disease\(^{27}\) given that it is known to increase blood total cholesterol and Low Density Lipoprotein (LDL); recent studies have, however, shown that only three SAFAs, lauric (12:0), myristic (14:0), and palmitic acids (16:0), significantly influence total and LDL-cholesterol.\(^{28}\) These fatty acids reduce the activity of the LDL receptors and thereby decrease the cellular LDL uptake.\(^{29}\) In this study, the proportion of C14:0 acid was highest in the viscera of the three scallops, registering the maximum content in *F. glaber* (390.7 mg/100 g ww tissue, representing 17.9% of total FAs). On the contrary, stearic acid (18:0) does not cause a significant increase of cholesterol levels,\(^{28}\) but rather a High Density Lipoprotein (HDL)-cholesterol-level-lowering effect.\(^{30}\)

MUFA\(s\) represented the lowest proportion of extracted FAs. *F. glaber* showed in the gonad and viscera higher values than the other species examined, while *P. jacobaeus* and *M. varia* in the adductor muscle and mantle (*p* < 0.05) (Table 2). The adductor muscle had values % of MUFA comparable results to those reported by Telahigue et al.\(^{9}\) in the same species. Oleic acid (C18:1n-9) was the most abundant in all species, with highest content in viscera and gonad (64.24–177.92 mg/100 g and 47.03–73.82 mg/100 g, respectively). Though the mantle had a lower content of oleic acid, in terms of percentage of total fatty acids it was the tissue with the highest value % (12.37–16.46% of total FAs).

Palmitoleic acid (C16:1n-7) was the other predominant MUFA, with higher values in viscera and gonads of all scallops species (Table 1). The same value % of C16:1n-7 was found by Telahigue et al.\(^{9}\) in the gonad of *P. jacobaeus* (6.4%).

Caers et al.\(^{17}\) found lower values % of C18:1n-9 in all studied tissues of *A. purpuratus* than those of this study. The percentage values of C16:1n-7 in the gonad of *P. jacobaeus* and viscera of *M. varia* (6.4% and 8.3%, respectively), were equivalent to those found by Caers et al.\(^{17}\) in the female gonad (6.6%) and viscera of *A. purpuratus* (8.2%). Both these MUFA\(s\) may have exogenous origins, from the diets, or endogenous by desaturation of C16:0 and C18:0 acids.

From a nutrition point of view, MUFA\(s\) have received increasing attention because of their mixed effects on human health. Recent evidence tends to indicate more beneficial effects and, in particular, on reducing risk of CVDs and other inflammation-related diseases.\(^{31,32}\) When MUFA\(s\) (primarily, oleic acid: 18:1, n-9) are supplied instead of SAFA in metabolic studies, they lower total and LDL-cholesterol significantly.\(^{33}\)

PUFAs showed values ranging from 27% of total FAs in the mantle of *P. jacobaeus* to 52% of total FAs in the adductor muscle of *M. varia*. In general, PUFAs are considered as hypocholesterolemic and hypotriglyceridemic compared to SAFAs,\(^{34}\) but different PUFAs have different effects. PUFAs content proved to be predominant in the viscera and gonad of all species, reaching the maximum value in the viscera of *F. glaber* (903 mg/100 g tissue). DHA was the predominant PUFA in all
Table 1. Fatty acid composition (mg/100 g tissue wet weight) and nutritional quality indexes of adductor muscle and gonad of *F. glaber*, *M. varia*, and *P. jacobaeus* (mean value ± SD; *n* = 30).

| Fatty acids | Adductor | Gonad |
|-------------|----------|-------|
| **F. glaber** | **M. varia** | **P. jacobaeus** |
| C12:0 | 1.21 ± 0.35 (0.53) | 1.07 ± 0.70 (0.37) | 2.17 ± 0.27 (0.71) |
| C14:0 | 18.18 ± 2.40 (7.99) | 9.32 ± 3.47 (2.85) | 17.46 ± 1.97 (5.71) |
| C16:0 | 3.96 ± 0.14 (1.74) | 3.57 ± 0.72 (1.24) | 5.66 ± 0.79 (1.85) |
| C18:0 | 60.58 ± 3.82 (26.63) | 62.97 ± 13.33 (19.12) | 81.98 ± 6.10 (26.80) |
| C18:2n6c | 4.59 ± 0.05 (2.02) | 5.17 ± 0.49 (1.79) | 5.48 ± 1.18 (1.79) |
| C18:3n6 | 21.07 ± 2.37 (9.26) | 21.15 ± 3.07 (6.93) | 20.48 ± 0.45 (6.69) |
| C20:0 | 0.88 ± 0.56 (0.38) | 1.84 ± 0.09 (0.21) | 1.41 ± 0.12 (0.24) |
| C21:0 | 0.77 ± 0.13 (0.34) | 2.33 ± 0.58 (0.76) | 3.19 ± 0.04 (0.37) |
| **ΣFAA** | **111.26 ± 3.72 (48.9)** | **103.25 ± 24.85 (32.3)** | **135.56 ± 8.50 (44.3)** |
| **ΣMUFA** | **38.52 ± 1.66 (16.9)** | **47.33 ± 2.29 (16.0)** | **53.02 ± 3.08 (17.3)** |
| **ΣPUFA** | **77.72 ± 2.16 (34.2)** | **143.42 ± 24.0 (51.7)** | **117.31 ± 11.42 (38.3)** |
| **Σ Total FAs** | **227.50 ± 3.00** | **294.00 ± 0.00** | **305.90 ± 0.00** |
| **Σ ω3** | **67.69 ± 1.67 (29.75)** | **124.58 ± 23.01 (45.24)** | **103.40 ± 11.10 (33.79)** |
| **Σ ω6** | **10.03 ± 0.54 (4.41)** | **18.84 ± 4.86 (6.48)** | **13.96 ± 0.43 (4.56)** |
| **ω3/ω6** | **6.75 ± 0.22** | **7.77 ± 0.12** | **7.40 ± 0.64** |
| **PUFA/SAFA** | **0.70 ± 0.04** | **1.47 ± 0.53** | **0.87 ± 0.14** |
| **UNS/SAT** | **1.05 ± 0.07** | **1.95 ± 0.62** | **1.26 ± 0.14** |
| **DHA/EPA** | **1.32 ± 0.02** | **1.80 ± 0.34** | **1.43 ± 0.16** |

(Continued)
Table 1. (Continued).

| Fatty acids | Adductor | Gonad |
|-------------|----------|-------|
|             | *F. glaber* | *M. varia* | *P. jacobaeus* | *F. glaber* | *M. varia* | *P. jacobaeus* |
| **DHA + EPA** | 55.24 ± 1.38 (24.28) | 103.57 ± 21.58 (38) | 84.54 ± 10.37 (27.64) | 161.93 ± 0.87 (18.75) | 96.87 ± 8.47 (16.47) | 152.5 ± 29.85 (20.35) |
| 11:0 | 1.16 ± 0.15 | 0.48 ± 0.13 | 0.91 ± 0.12 | 1.14 ± 0.03 | 1.02 ± 0.10 | 1.00 ± 0.19 |
| 11:1 | 0.41 ± 0.02 | 0.19 ± 0.03 | 0.33 ± 0.05 | 0.37 ± 0.00 | 0.42 ± 0.04 | 0.35 ± 0.08 |
| 11:2 | 1.21 ± 0.09 | 2.58 ± 0.46 | 1.35 ± 0.21 | 0.98 ± 0.02 | 0.96 ± 0.14 | 1.06 ± 0.29 |
| 12:0 | 3.47 ± 0.18 (0.65) | 7.25 ± 1.50 (0.98) | 6.52 ± 1.37 (1.68) | 5.96 ± 1.07 (1.80) | 5.23 ± 1.01 (1.58) | 4.75 ± 0.94 (1.39) |
| 12:1 | 1.76 ± 0.18 (1.22) | 3.96 ± 0.67 (1.51) | 3.31 ± 0.68 (1.75) | 2.68 ± 0.54 (1.37) | 2.29 ± 0.47 (1.29) | 2.02 ± 0.43 (1.17) |
| 12:2 | 5.24 ± 0.58 (4.45) | 10.23 ± 1.50 (4.68) | 8.57 ± 1.37 (4.64) | 7.34 ± 1.18 (4.32) | 6.51 ± 1.07 (3.94) | 5.93 ± 0.94 (3.36) |
| **ΣFA** | 66.80 ± 4.91 (45.0) | 82.37 ± 2.22 (42.0) | 76.26 ± 3.47 (43.6) | 860.43 ± 6.26 (39.5) | 388.01 ± 18.27 (45.1) | 607.67 ± 22.84 (51.1) |
| C14:1 | 8.14 ± 0.93 (0.94) | 5.06 ± 0.35 (0.42) |
| C14:2 | 4.44 ± 0.18 (2.96) | 4.67 ± 0.29 (2.12) |
| C14:3 | 0.32 ± 0.01 (0.19) | 0.28 ± 0.01 (0.17) |
| **ΣSAFA** | 35.75 ± 2.25 (24.1) | 52.59 ± 5.39 (26.8) | 51.71 ± 2.23 (29.5) | 415.96 ± 20.91 (19.1) | 214.23 ± 6.73 (24.9) | 240.74 ± 18.33 (20.2) |
| C18:2n6t | 4.39 ± 0.74 (2.96) | 4.59 ± 0.53 (2.34) | 6.35 ± 0.49 (3.63) | 68.28 ± 4.28 (3.13) | 24.38 ± 0.80 (2.83) | 30.33 ± 0.18 (2.55) |
| C18:3n6 | 4.18 ± 0.48 (2.82) | 4.39 ± 0.98 (2.24) | 3.65 ± 0.13 (2.08) | 106.81 ± 11.03 (4.90) | 33.54 ± 2.91 (3.89) | 36.52 ± 0.27 (3.07) |
| C18:4n3 | 3.77 ± 0.32 (2.54) | 5.27 ± 1.26 (2.69) | 3.12 ± 1.32 (1.78) | 218.62 ± 1.01 (10.03) | 57.82 ± 1.52 (6.71) | 69.99 ± 2.15 (5.88) |
| **ΣMUFA** | 35.75 ± 2.25 (24.1) | 52.59 ± 5.39 (26.8) | 51.71 ± 2.23 (29.5) | 415.96 ± 20.91 (19.1) | 214.23 ± 6.73 (24.9) | 240.74 ± 18.33 (20.2) |
| C18:2n6 | 3.49 ± 0.31 (2.64) | 3.74 ± 0.51 (2.62) | 4.15 ± 0.49 (2.73) | 68.28 ± 4.28 (3.13) | 24.38 ± 0.80 (2.83) | 30.33 ± 0.18 (2.55) |
| C18:3n3 | 3.77 ± 0.32 (2.54) | 5.27 ± 1.26 (2.69) | 3.12 ± 1.32 (1.78) | 218.62 ± 1.01 (10.03) | 57.82 ± 1.52 (6.71) | 69.99 ± 2.15 (5.88) |
| **ΣPUFA** | 45.85 ± 2.97 (30.9) | 61.03 ± 6.81 (31.1) | 47.03 ± 1.24 (26.9) | 902.71 ± 153.70 (41.4) | 258.76 ± 14.62 (30.0) | 341.59 ± 45.11 (28.7) |
| **Σ Total FAs** | 148.4 ± 0.00 | 196.0 ± 0.00 | 2179.1 ± 0.00 | 861.0 ± 0.00 | 1190.0 ± 0.00 | 354.6 ± 1.82 (4.49) |
| **Σ ω3** | 35.46 ± 1.64 (23.90) | 64.92 ± 7.63 (25.01) | 34.89 ± 0.00 (19.94) | 800.0 ± 143.5 (36.70) | 217.19 ± 10.79 (25.22) | 288.13 ± 2.69 (24.21) |
| **Σ ω6** | 10.15 ± 1.93 (6.84) | 12.02 ± 0.91 (6.12) | 12.14 ± 1.25 (6.94) | 101.2 ± 12.04 (4.64) | 39.49 ± 2.45 (4.59) | 53.46 ± 1.82 (4.49) |
Table 1. (Continued).

| Fatty acids | Adductor | Gonad |
|-------------|----------|-------|
|             | F. glaber | M. varia | P. jacobaeus | F. glaber | M. varia | P. jacobaeus |
| ω3/ω6       | 3.57 ± 0.62 | 5.39 ± 0.35 | 2.89 ± 0.29 | 7.87 ± 0.61 | 5.50 ± 0.15 | 6.34 ± 0.16 |
| PUFA/SFA    | 0.69 ± 0.09 | 0.74 ± 0.10 | 0.62 ± 0.04 | 1.08 ± 0.33 | 0.67 ± 0.07 | 0.56 ± 0.03 |
| UNS/SAT     | 1.23 ± 0.17 | 1.38 ± 0.06 | 1.30 ± 0.10 | 1.57 ± 0.39 | 1.22 ± 0.11 | 0.96 ± 0.07 |
| DHA/EPA     | 1.64 ± 0.18 | 2.0 ± 0.07  | 1.80 ± 0.35 | 1.17 ± 0.21 | 1.0 ± 0.04  | 1.27 ± 0.04 |
| DHA + EPA   | 25.61 ± 1.73 (17.26) | 36.87 ± 6.17 (18.80) | 26.59 ± 0.72 (15.19) | 463.0 ± 127.7 (21.25) | 116.97 ± 7.11 (13.58) | 170.99 ± 1.21 (14.37) |
| AI          | 0.85 ± 0.40 | 0.76 ± 0.07 | 0.85 ± 0.09 | 1.22 ± 0.43 | 1.23 ± 0.25 | 1.91 ± 0.07 |
| TI          | 0.45 ± 0.05 | 0.39 ± 0.04 | 0.44 ± 0.03 | 0.29 ± 0.10 | 0.44 ± 0.04 | 0.52 ± 0.02 |
| HH          | 1.48 ± 0.43 | 1.41 ± 0.12 | 1.50 ± 0.19 | 1.31 ± 0.46 | 0.95 ± 0.14 | 0.67 ± 0.01 |

The values given in parentheses indicate the percentage of the total fatty acids.
Table 2. Summary of ANOVA (F-ratio and p value) for fatty acid content (mg/100 g tissue wet weight) and ratios in four tissues [factor: *F. glaber* (F), *M. varia* (M), *P. jacobaeus* (P), and samples means ranked in order of magnitude according to Tukey post hoc test].

|                | Adductor muscle | Gonad | Mantle | Viscera |
|----------------|-----------------|-------|--------|---------|
|                | F-ratio | p-Value | Tukey rank | F-ratio | p-Value | Tukey rank | F-ratio | p-Value | Tukey rank | F-ratio | p-Value | Tukey rank |
| SAFA           | 3.620    | 0.093   | N.S.     | 17.93   | 0.003   | F > P > M | 15.77   | 0.004   | M = P > F | 26.21   | 0.001   | F > P > M |
| MUFA           | 22.30    | 0.002   | P > M > F | 42.87   | 0.000   | F > P = M | 22.10   | 0.002   | M = P > F | 166.19  | 0.000   | F > P = M |
| PUFA           | 12.14    | 0.008   | M = P > F | 22.47   | 0.002   | F = P > M | 11.45   | 0.009   | M > P = F | 45.14   | 0.000   | F > P = M |
| Σ ω3           | 11.34    | 0.009   | M = P > F | 24.05   | 0.001   | F = P > M | 43.56   | 0.000   | M > F = P | 44.18   | 0.000   | F > P = M |
| Σ ω6           | 7.24     | 0.025   | M = P; M > F; P = F | 18.11   | 0.003   | P = F > M | 2.09    | 0.205   | N.S.     | 69.82   | 0.000   | F > P = M |
| ω3/ω6          | 0.55     | 0.603   | N.S.     | 44.39   | 0.000   | F > M = P | 27.47   | 0.001   | M > F = P | 32.10   | 0.000   | F = P > M |
| PUFA/SAFA      | 4.86     | 0.055   | N.S.     | 1.66    | 0.266   | N.S.      | 1.70    | 0.260   | N.S.     | 5.81    | 0.040   | F > M = P |
| UNS/SAT        | 4.80     | 0.060   | N.S.     | 0.70    | 0.532   | N.S.      | 1.37    | 0.323   | N.S.     | 5.14    | 0.050   | F = M; M = P; F > P |
| EPA            | 16.32    | 0.004   | M = P > F | 11.27   | 0.009   | F = P > M | 3.53    | 0.097   | N.S.     | 39.06   | 0.000   | F > P = M |
| DHA            | 7.27     | 0.025   | M = P; M > F; P = F | 11.78   | 0.008   | F = P > M | 10.35   | 0.011   | M > P = F | 12.28   | 0.008   | F > P = M |
| DHA + EPA      | 9.28     | 0.015   | M = P > F | 11.54   | 0.009   | F = P > M | 8.47    | 0.018   | M > P = F | 19.06   | 0.002   | F > P = M |
| DHA/EPA        | 3.21     | 0.113   | N.S.     | 12.01   | 0.008   | P > F = M | 2.92    | 0.130   | N.S.     | 3.27    | 0.08    | N.S.     |
| AI             | 18.67    | 0.000   | F = P > M | 0.91    | 0.45    | N.S.      | 0.14    | 0.87    | N.S.     | 5.44    | 0.04    | P > M = F |
| TI             | 24.36    | 0.000   | F = P > M | 1.49    | 0.30    | N.S.      | 2.03    | 0.21    | N.S.     | 9.78    | 0.01    | P = M; M = F; P > F |
| HH             | 19.33    | 0.000   | M > P = F | 0.24    | 0.79    | N.S.      | 0.09    | 0.92    | N.S.     | 3.96    | 0.08    | N.S.     |

N.S.: not significant differences.
studied species and in all tissues and mean % ranged from 6.8 ± 0.5% of total FAs (viscera of *M. varia*) to 24.9 ± 2.6% of total FAs (adductor muscle of *M. varia*). Caers et al.\(^{[17,26]}\) report similar results for *A. purpuratus*. However, the highest DHA content was found in the viscera with its value ranging from 58.6 mg/100 g tissue (*M. varia*) to 252 mg/100 g tissue (*F. glaber*).

EPA was the second most abundant PUFA, ranging from 5.5 ± 1.5% of total FAs (mantle of *P. jacobaeus*) to 13.1 ± 0.9% of total FAs (adductor muscle of *M. varia*) (Table 1). Although the content of EPA is significantly low in the adductor muscle of all species (23.75–36.8 mg/100 g tissue), in terms of percentage values of EPA on the total of fatty acids it shows to be more represented in the muscle compared to the other tissues (Tables 1–3)

Highest proportions (%) of EPA and DHA were observed in adductor muscle of all species \((p < 0.05)\), and this is consistent with available literature data, which report a low lipid content in the adductor muscle compared to the other tissues and a fatty acid profile characterized by a high n-3 PUFA level.\(^{[17,35]}\) Telahigue et al.\(^{[9]}\) reported, for the same species, lower % values of DHA and EPA than those found in this study, mainly in the adductor muscle of *F. glaber* (3.64% and 3.29% of total FAs for DHA and EPA vs. 10.4 and 13.8 in this study, respectively).

Humans can synthesize SAFAs and MUFAs but cannot synthesize PUFA n-3 and n-6 fatty acids *de novo*. This is because humans, like other animals, lack the desaturase enzymes required to produce the simplest members of these families (α-linolenic acid and linoleic acid, respectively).\(^{[36]}\) However, DHA and EPA are considered to be among the major beneficial nutrients obtained from seafood consumption. They inhibit inflammatory processes by influencing the eicosanoid metabolism. Furthermore, they influence blood coagulation by reducing platelet adhesion and aggregation and have blood pressure-reducing properties and CVDs.\(^{[37]}\) EPA and DHA have also been shown to contribute to the reduction of certain types of cancers, diabetes, mental health disorders, and asthma.\(^{[7]}\) DHA, also, is highly abundant in brain and retina where it plays important structural and functional roles. Consequently, DHA status is important to ensure optimum neural and visual functions.\(^{[38]}\)

There were also noteworthy amounts of stearidonic acid (18:4n3) in the gonad (39.2–71.6 mg/100 g tissue; 6.7–8.9% of total FAs) and in the viscera (57.8–218.6 mg/100 g tissue; 6.7–10% of total FAs) of the studied species, as also noted by Telahigue et al.\(^{[9]}\) Furthermore, small contents of linoleic acid (18:2n-6), α-linolenic acid (18:3n-3), arachidonic acid (ARA; 20:4n-6), and docosapentaenoic acid (22:5n-3) were also detected (Table 1). In all species and tissues, more than 80% of PUFA (except for mantle of *P. jacobaeus* and *F. glaber*) are n-3 fatty acids. Statistical analysis showed that the sum of n-3 PUFAs was significantly higher in the viscera of all species (217–800 mg/100 g tissue) than in the other tissues (Tables 1–3). High levels of PUFA n-3 are important for the human health and seafood products are the only significant source in the diet. Epidemiological findings of a negative correlation between the intake of n-3 fatty acids and mortality from coronary heart disease (CHD) provide further evidence for the protective effects of n-3 PUFA.\(^{[39]}\)

The level of the n-6 series was detected as lower than n-3, with % values ranging from 3.8% in the gonad of *M. varia* to 7% in the mantle of *P. jacobaeus*. Within tissues no significant differences were recorded among species \((p > 0.05)\). *P. jacobaeus* exhibited in the gonad a content of n-6 higher than the other species \((p < 0.05)\) (Tables 1–3). All species had the highest n-6 percentage in the mantle \((p < 0.05)\) (Table 3). Linoleic (C18: 2n-6) and ARAs (20: 4n-6) dominated n-6 PUFA, even though ARA was reported as present in low amount in the gonads of all pectinids species by Caers et al.\(^{[17,26]}\) and Telhaigue et al.\(^{[9]}\) ARA is associated with membrane phospholipids and can be oxidized to a variety of eicosanoid compounds important in cell–cell signalling.\(^{[40]}\) A biplot summarized the PCA results of the most significant fatty acids, expressed as % of total FAs, along the two first principal components and the groupings and/or differences among organs of the three pectinids examined (Fig. 2). The PCA clearly discriminated among the fatty acid composition of tissues and species. The values for fatty acid profiles were determined as 64.36% and 26.32% for PC1 and PC2, respectively. Therefore, the two-axis ordination diagram described 90.68% of the variation. The scatter plot of scores on the first two principal components PC1 and PC2 shows a separation among species and tissues (Fig. 2). The samples were clustered in four zones of the plot. A cluster formed by the viscera of *P. jacobaeus*, viscera, and gonad of *M. varia* and adductor muscle of *F. glaber* grouped for the high SAFAs content. Another distinct cluster
### Table 3

Summary of ANOVA (F-ratio and p value) for fatty acid content (mg/100 g tissue wet weight) and ratios in *F. glaber*, *M. varia*, and *P. jacobaeus* [factor: adductor muscle (A), gonad (G), mantle (M), viscera (V)] and samples means ranked in order of magnitude according to Tukey post hoc test.

| F. glaber | M. varia | P. jacobaeus |
|-----------|----------|--------------|
| **F-ratio** | **p-Value** | **Tukey rank** | **F-ratio** | **p-Value** | **Tukey rank** | **F-ratio** | **p-Value** | **Tukey rank** |
| SAFA | 85.59 | 0.000 | V > G > A = M | 203.62 | 0.000 | V > G > A = M | 409.70 | 0.000 | V > G > A > M |
| MUFA | 851.79 | 0.000 | V > G > A = M | 781.18 | 0.000 | V > G > M = A | 361.64 | 0.000 | V > G > A = M |
| PUFA | 77.97 | 0.000 | V > G > A = M | 74.10 | 0.000 | V > G > A > M | 140.35 | 0.000 | V > G > A > M |
| Σω3 | 72.64 | 0.000 | V > G > A = M | 58.70 | 0.000 | V > G > A > M | 137.37 | 0.000 | V > G > A > M |
| Σω6 | 149.22 | 0.000 | V > G > M = A | 50.70 | 0.000 | V > G > A > M | 197.75 | 0.000 | V > G > A = M |
| ω3/ω6 | 59.45 | 0.000 | G > V > A > M | 4.74 | 0.034 | G = A; A = V; V = M; G > V; G > M | 104.56 | 0.000 | A = G; G = V; V > M; A > V; A > M |
| PUFA/SAFA | 3.30 | 0.080 | N.S. | 5.90 | 0.020 | A > M = G > V | 197.75 | 0.000 | G = A; A = M; M = V; G > M; A > V |
| UNS/SAT | 3.11 | 0.090 | N.S. | 3.56 | 0.070 | NS | 3.74 | 0.060 | N.S. |
| EPA | 149.22 | 0.000 | V > G > M = A | 114.85 | 0.000 | V > G > A = M | 57.60 | 0.000 | V > G > A > M |
| DHA | 18.20 | 0.001 | V > G = M = A | 10.40 | 0.004 | A = V = G > M | 45.53 | 0.000 | V > G > A > M |
| DHA + EPA | 29.36 | 0.000 | V = G = A; G > M; A = M | 24.10 | 0.000 | V = A > G > M | 52.37 | 0.000 | V > G > A > M |
| DHA/EPA | 8.55 | 0.007 | M > A = V > G | 24.07 | 0.000 | M > A = G > V | 10.37 | 0.004 | M > A = V = G |
| AI | 0.85 | 0.50 | N.S. | 12.59 | 0.00 | V = G; G = M; G > M = A | 44.38 | < 0.0001 | V > G = A = M |
| TI | 3.82 | 0.06 | N.S. | 21.12 | 0.00 | V = G = M > A | 9.53 | 0.00 | V = M; V > G = A; M = G = A |
| HH | 1.30 | 0.34 | N.S. | 26.99 | 0.00 | A > M = G = V | 9.52 | 0.00 | M = A = G; M = A > V; G = V |

N.S.: not significant differences.
from the other species was represented by *M. varia*, characterized by highest levels of PUFAs, PUFA/SAFA, DHA, DHA + EPA UNS/SAT, n-3, DHA, and EPA in the adductor muscle. A third group located on the left of the top was characterized by the higher values of MUFA in the mantle of the three scallop species. The last group was formed by the gonad and adductor muscle of *P. jacobaeus* and viscera of *F. glaber* with a relatively high amount of EPA and n-3/n-6 ratio.

**Lipid NQI**

In order to evaluate and compare the nutritional quality of the investigated scallops, the amount of the main bioactive fatty acids, DHA + EPA, DHA/EPA, n-3/n-6, and PUFA/SFA ratios were investigated in the TL matter of the scallops’ edible part. DHA + EPA and DHA/EPA are important for nutritional qualities of seafood. In this study, the sum of DHA + EPA significantly varied among the scallops species and among tissues examined (*p* < 0.05), while, as regards DHA/EPA ratio, significant differences were observed only for the gonad, with highest value (1.80) found in *P. jacobaeus* (*p* < 0.05) (Table 3). Gogus and Smith[^41] reported that high ratio of DHA/EPA has an advantageous impact on consumer health and that DHA is more efficient than EPA in reducing the risk of CHDs. In this study, DHA/EPA ratio was always ≥1 and the DHA + EPA sum was found to be higher in the adductor muscle and mantle than in any other tissue in all species.

In the last 50 years, in developed countries diet patterns have changed, resulting in a higher intake of fat, specifically SAFA and n-6 PUFA and relatively low in n-3 PUFA. It is widely accepted that a high n-3/n-6 fatty acid ratio is healthful, particularly with regard to reducing the risk of CVD[^42] and it can be used as an index for comparing the nutritional values of shellfish. The U.K. Department of Health recommends an ideal relationship of n3/n6 of 4.0 at maximum.[^43] In this study, all tissues of all species showed a high n-3/n-6 ratio, always >5, except in the mantle. Gonad and viscera of *F. glaber* (n-3/n-6 ratio 8 and 7.9, respectively) showed the highest values (*p* < 0.05), followed by adductor muscle of *P.* [^529]
**jacoraeus** (n-3/n-6 ratio 7.4) and *M. varia* (n-3/n-6 ratio 7.2 for adductor and 7.1 for gonad) (Table 1). These aspects contribute to a positive evaluation of the lipid quality in the scallops examined.

The n-3/n-6 ratio of gonads in *F. glaber* and *P. jacobaeus* was higher than the ratio reported by Telhaigue et al.\[9\] from the Tunisian coast (n-3/n-6 ratio of 8 and 6.8 in this study; c.f. 4.76 and 5.27, respectively), but comparable to that of *M. varia* (7.72). Caers et al.\[17\] reported values of 12.1 for adductor muscle of *A. purpuratus* and male and female gonads (11.3 and 11.9, respectively). In bivalve species such as *Chamelea gallina* from the central Adriatic Sea (Italy), this ratio varies between 4.28 and 10.8\[11\], referred to the whole organism.

Another useful factor for assessing the nutritional quality of the lipid fraction of foods is the PUFA/SAFA ratio, considered as a measure of the propensity of the diet to influence the incidence of CHD. A recommended minimum value of this ratio is 0.45 or not less than 0.1.\[43\] In this study, the PUFA/SAFA ratio in all tissues and in all species was found to be high, with the highest values found in the adductor muscle of *M. varia* (1.47) and in the viscera of *F. glaber* (1.08) (Tables 2 and –3).

Ulbricht and Southgate\[24\] used the AI to measure of the ability of a diet to reduce blood lipid content, a TI as a measure of the ability to reduce platelet activity, and H/H to describe the functional effects of different PUFAs of cholesterol metabolism. Diets with low AI and TI values could reduce the potential risk of CHD. AI values from 0.33 to 2.37 and TI values from 0.01 to 1.18 are reported in the literature for different seafoods.\[28\] In this study, AI and TI fall within the above-mentioned range, with the lowest values of AI and TI in the adductor muscle of *M. varia* (0.48 and 0.19, respectively; \(p < 0.05\)), while the ‘worst’ in health terms (the highest) AI and TI values were recorded in the viscera of *P. jacobaeus* (1.91 and 0.52) \(p < 0.05\) (Tables 1–3). Therefore, the presented AI and TI values (Table 2) provide beneficial information for human nutrition. As regards the HH fatty acid ratio, higher ratio amounts are desirable. In this study, the highest values were shown in adductor of *M. varia* (2.58) while lower values in the viscera of *P. jacobaeus* (0.67). However, all species showed values within those reported in the literature for some other species (0.25–3.23).\[14\]

### Conclusion

This work investigated for the first time the composition and distribution of fatty acids in the different edible portions of three scallop species from Ionian Sea (southern Italy coast) during the autumn months. The results obtained reveal that *F. glaber*, *M. varia*, and *P. jacobaeus* are beneficial nutritionally due to their low levels of lipid and high percentage of healthy PUFAs. Indeed, the pectinids’ tissues contained high levels of n-3 PUFA, especially bioactive fatty acids, such as EPA and DHA. In addition, all three species have low amounts of n-6 PUFA; consequently, the n3/n6 PUFA ratio is high. While analyses of selected tissues showed the three scallop species have different characteristic fatty acids profiles, and all the scallops examined provide the consumers with a satisfying level of n-3 PUFA. *M. varia* appeared to be the species with highest nutritional quality as evidenced by the lipid quality indices. In general, adductor muscle presented a healthier lipid profile compared to the other tissues and showed good anti-thrombogenic, anti-atherogenic, and hypo-cholesterolemic properties of scallop lipids.

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