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Nutritional Quality of the Edible Tissues of European Lobster *Homarus gammarus* and American Lobster *Homarus americanus*

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The clawed lobsters *Homarus gammarus* and *Homarus americanus* are high-priced and appreciated food items in southern Europe. From a nutritional point of view there is still limited information on the chemical composition of edible tissues (muscle, hepatopancreas, and gonads) of both species. Therefore, the aims of the present work were to study the proximate chemical composition, energy, fatty acid and amino acid profiles, and cholesterol content in each edible tissue of both species and to evaluate their nutritional quality. Differences were observed between tissues, sexes, and species. Muscle and gonads were rich in protein, whereas hepatopancreas had high fat, cholesterol, and energy contents. All edible tissues were valuable sources of essential amino acids. Contrary to the common belief that shellfish consumption should be reduced in a low-fat and -cholesterol diet, all edible tissues of clawed lobsters have a nutritious value perfectly compatible with nutritious and healthy diets.

KEYWORDS: Clawed lobsters; *Homarus americanus*; *H. gammarus*; hepatopancreas; gonads; muscle; biochemistry; nutritional quality

INTRODUCTION

Marine resources are important constituents of the human diet, and their consumption has increased worldwide in recent decades (*1*). At the same time, seafood has been much publicized for its health-promoting qualities. In general, seafood is a valuable nutrient source, providing all essential amino acids, trace elements, vitamins, and polyunsaturated fatty acids that are precursors of biologically active molecules and crucial in preventing human cardiovascular and inflammatory diseases (*2*). Among seafood, crustaceans are regarded as nutritionally valuable sources of proteins and minerals (*3*−*5*). Yet, crustaceans have long been assumed to be rich in cholesterol, and their use in low-fat and low-cholesterol diets is sometimes considered to be controversial (*6*).

Clawed lobsters present an increasing nutritional, commercial, and economical importance, being widely consumed in southern Europe, particularly in Mediterranean countries. The European lobster, *Homarus gammarus*, is a commercially high-priced species that is mainly captured off the northeastern Atlantic coasts of Europe, between southern Norway and Portugal (*7*, *8*). In 2006, captures of *H. gammarus* in European countries totaled 3383 tons (*9*). Due to the decrease of *H. gammarus* catching figures, American lobsters, *Homarus americanus*, are imported by several European countries. This species is caught off the eastern American coasts of the United States and Canada, supporting an important inshore fishery (*7*, *10*). In 2006, the American lobster total captures totaled 94750 tons (*9*). Both lobster species have a marketable higher price when sold alive. Therefore, lobsters not immediately marketed are stored either in large creels or pots moored in sheltered coves and harbors, or in land-based tanks and tidal ponds (*8*). However, the European lobster is much more expensive, as much as 3 times the price, and considered to be more flavored than the American counterpart (*11*). In European countries the muscle from claws and abdomen are much appreciated, but viscera (gonads and hepatopancreas) and eggs when present are also very flavorsome. It is well-known that the chemical composition differs between species, tissues, seasons, feeding habits, habitats, and sexes. As far as European and American lobsters are concerned, these parameters were not taken into account in previous studies. The present work aims to determine the chemical composition (protein, fat, carbohydrate, ash, moisture, fatty acid, amino acid, and cholesterol) of the edible tissues of both female and male *H. gammarus* and *H. americanus* and to evaluate the nutritional quality to human consumption.

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MATERIALS AND METHODS

Ethical Statement. All live animals utilized in the experiments have been treated with proper care, minimizing discomfort and distress and were painlessly killed. Also, the number of animals was kept to the minimum necessary to obtain scientific results, considering that the gain in knowledge and long-term benefit to the subject species is high.

Biological Material. Twenty European lobsters *H. gammarus* (10 females and 10 males; origin, Scotland) and 21 American lobsters *H. americanus* (11 females and 10 males; origin, United States and Canada) were acquired in early spring (April 2007) from a retailer in Portugal and transported alive to the laboratory. All animals were intermolt hard-shelled and were kept under refrigerated conditions (4 °C) during 1 h to decrease their metabolism before being euthanized. The muscle (from claws), hepatopancreas, and gonads from each animal were individually separated and weighed. Samples were pooled when there was insufficient amount of tissue to perform all analyses (e.g., male gonads). Each tissue was subsequently homogenized with a grinder (Retasch Grindomix GM200; 5000 rpm; material: PP cup and stainless steel knifes), vacuum packed, and stored at −20 °C. A portion of each frozen sample was freeze-dried for 48 h at −50 °C under low pressure (approximately 10^{-1} atm). Samples were powdered and stored at −20 °C under controlled humidity conditions (vacuum packed) until further analyses.

Proximate Chemical Composition and Energy Content. Moisture, ash, protein, and lipid contents were determined in each specimen's tissue according to the AOAC (*12*). Briefly, the moisture content was obtained by drying the sample overnight at 105 °C, ash was quantified after combustion for 16 h at 550 °C, crude protein content was determined according to the Kjeldahl method, using a conversion factor of 6.25, and total lipid was determined with the Soxhlet extraction method using ethyl ether. The results were expressed in grams per 100 g of wet weight. The energy content was estimated as proteins, 4.27 kcal g^{-1} of wet weight; lipids, 9.02 kcal g^{-1} of wet weight; and carbohydrates, 4.11 kcal g^{-1} of wet weight (1 kcal = 4184 kJ) (*13*).

Cholesterol. The quantification of cholesterol content was based on the modified procedure of Naeemi and coauthors (*13*). Each sample (300 mg of dry weight) was combined with 260 μL of internal standard solution (5α-cholestane; 5 mg mL^{-1} cyclohexane), 3 mL of saturated methanolic potassium hydroxide solution, and 3 mL of methanol. Following heating (80 °C; 30 min), samples were cooled and supplied with 250 μL of 1 M magnesium chloride solution and 1.5 mL of cyclohexane. Samples were shaken and centrifuged (4000 rpm; 4 min) until phase separation. The moisture content of the upper phase was removed with anhydrous sodium sulfate. The cholesterol in the upper phase (2 μL) was separated by gas chromatography (Varian Star 3400 Cx, Walnut Creek, CA) using helium as carrier gas at a flow rate of 1 mL min^{-1} in a flame ionization detector and a fused silica capillary CP-Sil 8 CB column (30 m length × 0.25 mm internal diameter, 0.25 μm film thickness; J&W Scientific, Folsom, CA). The temperatures of the oven, injector, and detector were 280, 285, and 300 °C, respectively. Cholesterol was identified and quantified by comparison with the calibration curve of a pure cholesterol standard (Sigma) with 5α-cholestane. Cholesterol/cholestane peak area ratios obtained with the Varian software were plotted with cholesterol concentrations, and a straight line was fitted to data points by linear regression.

Fatty Acid Analysis. The percent distribution of fatty acids methyl esters (FAME) of nonpolar and polar lipids was based on the experimental procedure of Lepage and Roy (*14*) as modified by Cohen and coauthors (*15*). Each sample (300 mg of dry weight) was dissolved in 5 mL of acetyl chloride/methanol (1:19 v/v), shaken, and heated (80 °C; 1 h). After cooling, 1 mL of Milli-Q distilled water and 2 mL of *n*-heptane were added, and samples were shaken and centrifuged (5000 rpm; 5 min) until phase separation. The moisture content of the upper phase was removed with anhydrous sodium sulfate. An aliquot (2 μL) of the upper phase was then injected onto a Varian Star 3800 Cp gas chromatograph, equipped with an autosampler and fitted with a flame ionization detector at 250 °C, for FAME analysis. The separation was carried out with helium as carrier gas at a flow rate of 1 mL min^{-1}, in a capillary column DB-Wax (30 m length × 0.32 mm internal diameter; 0.25 μm film thickness; Hewlett-Packard, Albertville, MN) programmed at 180 °C for 5 min, raised to 220 at 4 °C min^{-1}, and maintained at 220 °C for 25 min, with the injector at 250 °C. FAME were identified by comparing their retention time with those of Sigma standards. Quantitative data were calculated using the peak area ratio (% of total fatty acids) and the Varian software.

Amino Acids. To extract total amino acids (protein bound + free), 40−90 mg of sample was placed in 10 mL ampules with 3 mL of 6 M HCl, according to the method described by AOAC (*12*). Ampules were vacuum-sealed, and samples were hydrolyzed at 110 °C for 24 h; hydrolysates were frozen at −80 °C, freeze-dried, dissolved in 5 mL of 0.1 M HCl, 0.2μm pore size filtered, and stored at −80 °C until amino acid separation. Separation was performed with high-performance liquid chromatography (Agilent 1100 HPLC, Agilent, Palo Alton, CA) using precolumn *o*-phthalaldehyde (OPA) and 9-fluorenylmethyl chloroformate (FMOC) derivatization, a Phenomenex Gemini ODS C18 guard column (4 × 3 mm), and a Phenomenex Gemini ODS C18 110A column (4.6 × 150 mm, 5 μm). The solvents and gradient conditions were as described by Henderson and coauthors (*16*). Detection wavelengths were set at UV (338 and 262 nm) and fluorescence (340/450 and 266/305). The identity and quantity of the amino acids were assessed by comparison with the retention times and peak areas of standard amino acids (Sigma) using norvaline as internal standard.

Nutritional Quality. To measure the propensity of each edible tissue to influence the incidence of coronary heart disease, atherogenic (AI) and thrombogenic (TI) indices were calculated according to the Ulbricht and Southgate (*17*) equations: $AI = [12:0 + (4 \times 14:0) + 16:0]/[\sum MUFA + \sum PUFA(n\text{-}6) + (n\text{-}3)]$; $TI = (14:0 + 16:0 + 18:0)/[(0.5 \times \sum MUFA) + (0.5 \times \sum PUFA(n\text{-}6)) + (3 \times \sum PUFA(n3) + ((n\text{-}3)/n\text{-}6))]$ (MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids).

Three ratios related with fatty acid content were also calculated: DHA/EPA (docosahexaenoic acid/eicosapentaenoic acid), EPA/DHA, and PUFA/SFA, in order to allow comparisons with the U.K. Department of Health recommendations (*18*).

Essential amino acid scores (AS) were also computed with respect to reference amino acid requirements for adults (*19*). This score determines the effectiveness with which absorbed dietary nitrogen can meet the indispensable amino acid requirement at the safe level of protein intake (*19*). This is achieved by comparing the content of each essential amino acid in the protein/diet with its content in the requirement pattern: AS (%) = (mg of amino acid in 1 g of test protein/mg of amino acid requirement) × 100. The ratio of essential amino acids to nonessential amino acids was also calculated.

Statistical Analysis. All analyses were carried out in duplicate. Results were expressed as mean values ± standard deviation (SD). Differences in the concentration of nutritional elements between tissues were tested with analysis of variance (ANOVA) followed by multiple-comparison test (Tukey HSD). Whenever necessary, data were transformed to satisfy normal distribution and homoscedasticity requirements. If transformed data could not meet these assumptions, differences were analyzed with nonparametric analysis of variance (Kruskall−Wallis) followed by nonparametric multiple-comparison test (Mann−Whitney). All statistical analyses were tested at the 0.05 level of probability with the software STATISTICA 6.1.

RESULTS

Proximate Chemical Composition and Energy Content. The biometric data of animals sampled in this study are presented in **Table 1**. The proximate chemical composition of edible tissues of *H. gammarus* and *H. americanus* is shown in **Table 2**. Significant differences were detected between

Table 1. Biometric Data (Average ± Standard Deviation) of Female (F) and Male (M) *H. gammarus* and *H. americanus*, Including the Edible Contribution (EC) of Muscle, Hepatopancreas, and Gonads

	H. gammarus		*H. americanus*	
	F	M	F	M
body weight (g)	580.1 ± 102.8	607.8 ± 105.0	610.6 ± 32.8	546.8 ± 62.4
total length (mm)	90.3 ± 5.2	95.0 ± 4.8	89.5 ± 2.4	87.1 ± 4.0
cephalotorax length (mm)	27.3 ± 1.7	27.6 ± 1.2	26.6 ± 0.7	24.9 ± 1.1
muscle EC (%)	83.3 ± 1.7	87.8 ± 1.7	82.3 ± 4.4	86.0 ± 1.7
hepatopancreas EC (%)	12.7 ± 1.5	11.9 ± 1.7	15.0 ± 3.3	13.4 ± 1.7
gonads EC (%)	4.0 ± 1.7	0.3 ± 0.1	2.8 ± 2.0	0.5 ± 0.1
total meat yield (%)	31.8 ± 5.0	32.4 ± 4.2	30.2 ± 4.6	28.5 ± 4.6

Table 2. Proximate Chemical Composition (Percent), Cholesterol Content (Milligrams per 100 g of Wet Weight), Energy Content (Kilocalories per 100 g of Tissue Wet Weight Basis), and Quantity of Fatty Acids (Percent) and Amino Acids (Milligrams per 100 g of Wet Weight) in Muscle, Hepatopancreas, and Gonads of Female (F) and Male (M) Lobsters, *H. gammarus* and *H. americanus* (Average ± Standard Deviation)[a]

	muscle				hepatopancreas				gonads			
	H. gammarus		*H. americanus*		*H. gammarus*		*H. americanus*		*H. gammarus*		*H. americanus*	
	F	M	F	M	F	M	F	M	F	M	F	M
moisture	78.1 ± 2.5^b	79.2 ± 1.4	79.2 ± 1.7	80.5 ± 1.6^a	67.4 ± 8.1	70.7 ± 6.1	58.8 ± 8.9	68.9 ± 5.8	58.9 ± 0.7^b		68.5 ± 0.1^a	
ash	1.8 ± 0.2	2.0 ± 0.2	1.8 ± 10.1	1.9 ± 0.1	1.7 ± 0.2	1.8 ± 0.2	1.5 ± 0.2	1.7 ± 0.2	1.5 ± 0.0		1.5 ± 0.1	
proteins	18.3 ± 2.0^a	17.6 ± 1.2^a	17.1 ± 1.0^a	15.6 ± 1.4^b	12.6 ± 1.7	13.2 ± 0.4	12.3 ± 0.3	12.4 ± 1.0	24.1 ± 1.7		22.1 ± 1.2	
fat	0.3 ± 0.0	0.5 ± 0.3	0.7 ± 0.3	0.6 ± 0.1	16.6 ± 8.5	11.8 ± 6.6	25.5 ± 12.1	14.9 ± 6.8	3.8 ± 0.8		4.4 ± 0.2	
cholesterol	36.6 ± 7.6	31.2 ± 6.0	43.2 ± 7.9	37.2 ± 10.5	42.5 ± 8.1^b	76.0 ± 14.9	80.1 ± 24.5	103.5 ± 3.13^a	114.9		105.4 ± 37.2	
energy	87.0 ± 11.7	83.0 ± 7.8	82.3 ± 7.1	78.2 ± 7.3	213.1 ± 76.6	172.8 ± 61.4	290.4 ± 99.6	194.9 ± 58.4	185.2		148.3	
Σ SFA	22.7 ± 1.3^a	22.6 ± 0.6^a	21.6 ± 1.52	20.4 ± 0.7^b	26.6 ± 4.4b^c	32.1 ± 0.5^a	24.4 ± 1.0^c	27.1 ± 1.2^b	18.7 ± 0.1^a	16.0 ± 0.0^b	16.8 ± 0.7^b	16.7 ± 0.3^b
Σ MUFA	28.8 ± 1.7^b	28.4 ± 2.0^b	31.5 ± 1.3^a	30.0 ± 1.1^a	47.2 ± 1.9^c	55.1 ± 3.8^b	58.9 ± 3.2	61.6 ± 2.4^a	34.3 ± 0.1^b	30.3 ± 0.1^c	36.0 ± 0.7^a	35.1 ± 0.4a^b
Σ PUFA	43.6 ± 2.5	44.8 ± 1.0^a	42.0 ± 1.7^b	44.6 ± 0.8^a	20.1 ± 5.1^a	7.0 ± 3.9^b	11.2 ± 3.2^b	5.8 ± 0.1^c	40.8 ± 0.3^b	42.9 ± 0.1^b	41.0 ± 1.0^b	46.3 ± 0.7^a
Σ n-3	34.3 ± 1.7	35.0 ± 1.3	35.5 ± 1.4	37.0 ± 0.9	14.2 ± 3.2^a	3.9 ± 2.8b^c	7.7 ± 2.7^b	3.4 ± 0.4^c	32.4 ± 0.3^c	34.3 ± 0.1^b	35.6 ± 1.1^b	38.8 ± 0.6^a
Σ n-6	8.2 ± 1.0^a	8.6 ± 0.6^a	5.8 ± 0.8^b	6.5 ± 0.5^b	4.8 ± 2.0^a	2.1 ± 1.0	2.5 ± 0.4	1.6 ± 0.4^b	7.9 ± 0.0^b	8.3 ± 0.0^a	5.4 ± 0.2^c	6.8 ± 0.1^c
Σ n-3/n-6	4.2 ± 0.3^b	4.1 ± 0.4^b	6.2 ± 0.6^a	5.7 ± 0.5^a	3.1 ± 0.7^a	1.7 ± 0.4^b	3.1 ± 0.7^a	2.2 ± 0.8^a	4.1 ± 0.0^b	4.2 ± 0.0^b	5.4 ± 0.4^a	5.7 ± 0.1^a
Σ n-6/n-3	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.3 ± 0.1	0.6 ± 0.2	0.3 ± 0.1	0.5 ± 0.2	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0	0.2 ± 0.0
PUFA/SFA	1.9 ± 0.2	2.0 ± 0.1	2.0 ± 0.2	2.2 ± 0.1	0.8 ± 0.3^a	0.2 ± 0.1^b	0.5 ± 0.1^a	0.2 ± 0.0^b	2.1 ± 0.0^c	2.7 ± 0.0^a	2.4 ± 0.0^b	2.8 ± 0.0^a
AI	0.24 ± 0.02	0.23 ± 0.01	0.26 ± 0.04	0.22 ± 0.01	0.40 ± 0.07	0.53 ± 0.08	0.50 ± 0.08	0.47 ± 0.04	0.24 ± 0.00^a	0.16 ± 0.00^b	0.24 ± 0.01^a	0.16 ± 0.00^b
TI	0.17 ± 0.01	0.16 ± 0.01	0.15 ± 0.02	0.14 ± 0.01	0.35 ± 0.1^b	0.73 ± 0.14^a	0.41 ± 0.07^b	0.58 ± 0.07^a	0.14 ± 0.00^a	0.12 ± 0.00^b	0.12 ± 0.00^b	0.11 ± 0.00^b
EAA/NEAA	0.80 ± 0.07	0.78 ± 0.01	0.81 ± 0.01	0.82 ± 0.01	0.81 ± 0.04^a	0.82 ± 0.02^a	0.74 ± 0.03^b	0.75 ± 0.02^b	0.96 ± 0.01^a	0.73 ± 0.00^c	0.78 ± 0.03^b	0.65 ± 0.01^d
TAA	17.04 ± 2.51	16.45 ± 0.89	16.93 ± 1.76	17.34 ± 1.18	10.99 ± 1.37	9.46 ± 0.04	10.46 ±1.27	9.69 ± 0.08	24.64 ± 0.63^a	10.56 ± 0.39^d	17.93 ± 0.09^b	10.71 ± 0.02^c

[a] In each row different letters indicate significant differences per tissue ($p < 0.05$), whereas values without letters indicate no significant differences. Abbreviations: SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; AI, atherogenic index; TI, thrombogenic index; EAA, essential amino acids; NEAA, nonessential amino acids; TAA, total amino acids.

tissues, sexes, and species. Gonads and muscle were rich in proteins, whereas hepatopancreas had high fat content. On the other hand, gonads and hepatopancreas generally had higher energy and cholesterol contents compared to muscle. Differences between sexes and species were seen in the content of cholesterol (hepatopancreas), moisture (muscle and gonads), and proteins (muscle).

Fatty Acid Profile. The fatty acid profiles were different between species and between the edible tissues (**Figure 1**). *H. americanus* had proportionally more MUFA, particularly eicosenoic acid, than *H. gammarus*, but less n-6 fatty acids (**Table 2** and **Figure 1**). For both species, muscle and gonads had a similar pattern dominated by PUFA, followed by MUFA and SFA. In contrast, hepatopancreas had proportionally more MUFA, followed by SFA and PUFA (**Table 2**). Muscle had the most homogeneous fatty acid composition with fewer differences between sexes and species compared to gonads and hepatopancreas (**Figure 1**). The main saturated fatty acids in all tissues were palmitic (16:0) and stearic (18:0) acids. Palmitic acid was predominant in the hepatopancreas, particularly in males, whereas stearic acid was dominant in the muscle of the European lobster. Among MUFA, oleic acid (18:1n-9) was the prevailing fatty acid mostly in the hepatopancreas of *H. gammarus*. Palmitoleic (16:1n-7) and eicosenoic (20:1n-9) acids also contributed to the high proportion of MUFA in the hepatopancreas and in female gonads. The main n-3 PUFA in all tissues were eicosapentaenoic (EPA, 20:5n-3) and docosahexaenoic (DHA, 22:6n-3). In gonads, docosapentaenoic acid (DPA, 22:5n-3) also contributed to the high proportion of n-3, particularly in males, in contrast to its absence in hepatopancreas. The n-3 PUFA were dominant in muscle (36.2%) and gonads (37.3%), compared to hepatopancreas (5.3%) (**Table 2**). The major n-6 PUFA was arachidonic acid (AA, 20:4n-6), mainly in muscle and gonads. The ratios of n-3 to n-6 and PUFA to SFA were similar in muscle and gonads, but comparatively lower in hepatopancreas (**Table 2**). The opposite results were found for ratios of n-6 to n-3 and for AI and TI. Females of both lobster species had generally higher AI and TI in gonads compared to males, whereas TI was lower in hepatopancreas of female lobsters compared to male hepatopancreas.

Amino Acid Profile. The amino acid profile of edible tissues of female and male *H. gammarus* and *H. americanus* is shown in **Figure 2**. Proteins of both lobsters contained high amounts of nonessential amino acids (NEAA), such as glutamic acid, aspartic acid, and glycine. Particularly, female gonads had the highest values of NEAA (**Table 2**).

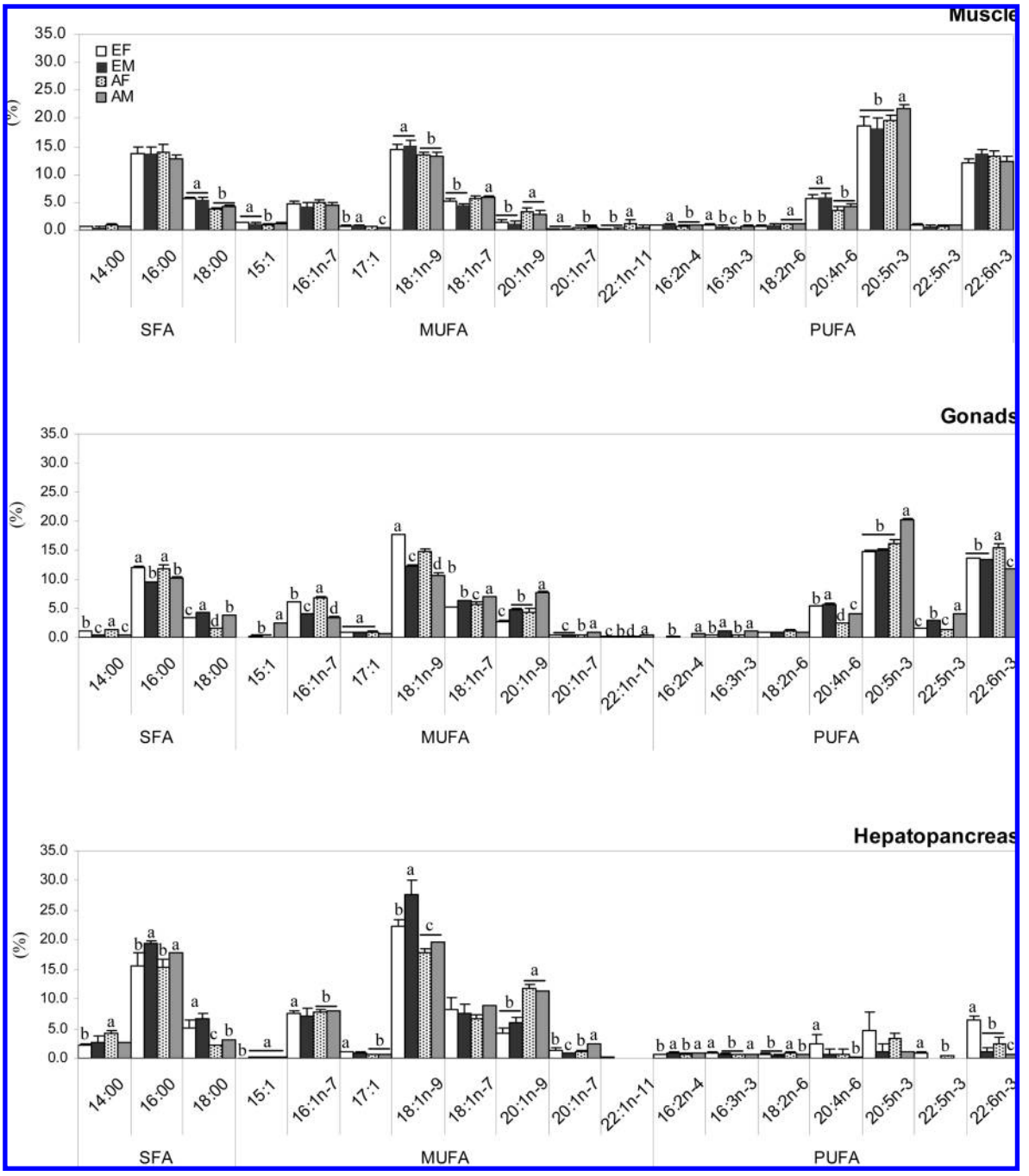

Figure 1. Fatty acid profile (%; average ± standard deviation) of edible tissues of *H. gammarus* and *H. americanus*. Different letters represent statistical differences ($p < 0.05$), whereas bars without letters indicate no significant differences. Abbreviations: EF, female *H. gammarus*; EM, male *H. gammarus*; AF, female *H. americanus*; AM, male *H. americanus*; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Muscle and hepatopancreas had similar concentration patterns of essential amino acids (EAA), dominated by arginine, leucine, and lysine, although generally higher contents were detected in muscle. Also, the amino acid content in muscle was very homogeneous between sexes and species. The amino acid pattern was more heterogeneous in hepatopancreas and gonads according to sex and species. In hepatopancreas, *H. gammarus* had more tyrosine and taurine than *H. americanus*, but less histidine. Methionine was more concentrated in hepatopancreas of female *H. gammarus* compared to male, whereas the opposite results were found in *H. americanus* hepatopancreas. In general, gonads of European lobster had higher concentration of most amino acids than the American counterpart. The most striking differences were found between sexes of both species, in which females had a higher concentration of most amino acids than males (except taurine). In this tissue the major essential amino acids were leucine, arginine, valine, tyrosine, and lysine.

The ratio of EAA to NEAA did not vary in muscle (**Table 2**), whereas in hepatopancreas significant differences were found between species (higher in *H. gammarus*), and in gonads both sex and species affected this ratio (higher in *H. gammarus* and in females).

With regard to the amino acid score presented in **Figure 3**, the highest scores were obtained for threonine, phenylalanine plus tyrosine, and histidine in all tissues. Particularly, female gonads of European lobsters had the highest scores.

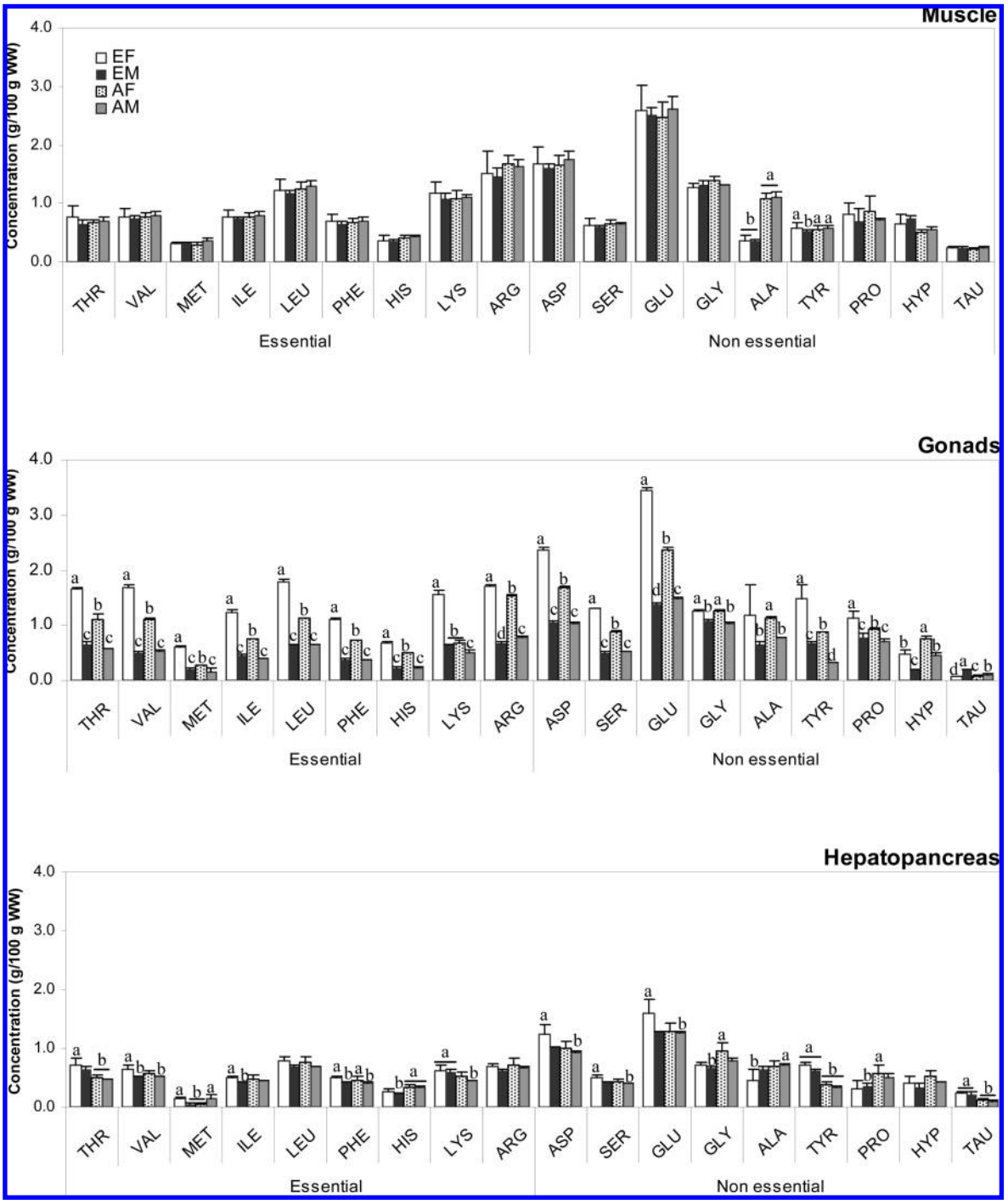

Figure 2. Amino acid profile (g/100 g of wet weight; average ± standard deviation) of edible tissues of *H. gammarus* and *H. americanus*. Different letters represent statistical differences ($p < 0.05$), whereas bars without letters indicate no significant differences. Abbreviations: EF, female *H. gammarus*; EM, male *H. gammarus*; AF, female *H. americanus*; AM, male *H. americanus*); THR, threonine; VAL, valine; MET, methionine; ILE, isoleucine; LEU, leucine; PHE, phenylalanine; HIS, histidine; LYS, lysine; ARG, arginine; ASP, aspartic acid; SER, serine; GLU, glutamine; GLY, glycine; ALA, alanine; TYR, tyrosine; PRO, proline); HYP, hydroxyproline; TAU, taurine.

The limiting amino acids were leucine and methionine in hepatopancreas and gonads, and tryptophan and cysteine were not quantified.

DISCUSSION

Chemical Composition. This study showed significant differences in the chemical composition of the edible tissues of both homarid species. The most important variations were found in tissues involved in regulatory processes (hepatopancreas and gonads), in opposition to structural tissues (muscle). In crustaceans, hepatopancreas is the major lipid storage organ, having the highest fat content compared to the other tissues (*20*), whereas muscle is a protein-rich tissue low in fat. These characteristics are essential considering that muscle is involved in locomotion and prey hunting. The high protein and cholesterol levels found in female gonads indicate that these nutrients, together with proteins and fatty acids, are important for maturation of crustacean ovaries (*21*).

The fatty acid patterns obtained for *H. americanus* in muscle and hepatopancreas were consistent with previous

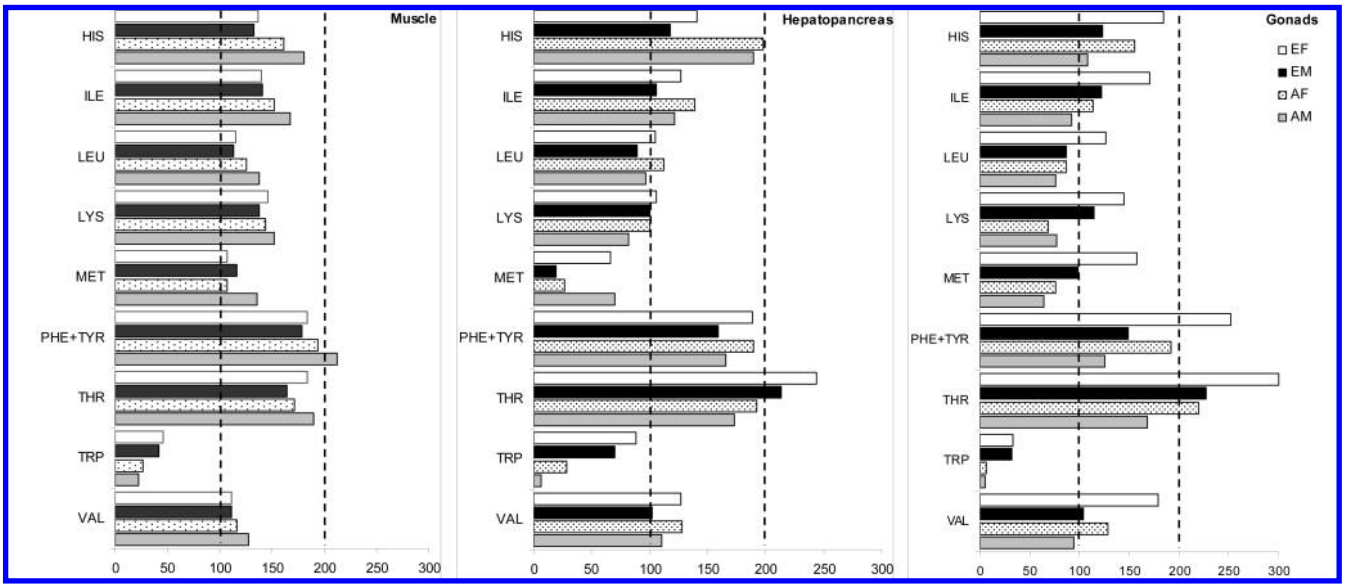

Figure 3. Representation of the essential amino acid score (%) of edible tissues of *H. gammarus* and *H. americanus*. Dotted lines represent 100 and 200% scores. Abbreviations are as in **Figure 2**.

results (*10*). Variations in the fatty acid content between species, such as European lobster having proportionally more stearic acid (all tissues), oleic acid (hepatopancreas), and n-6 PUFA (all tissues), are most probably related to different diets. Other factors can also influence the distribution of lipids and fatty acids in crustaceans, namely, metabolism, molting cycle, captivity duration, seawater temperature, and salinity (*21*). PUFA from the n-3 series, especially DHA and EPA, have been identified in the past few decades as essential nutrients for marine animals in general (*22*, *23*). Previous studies showed that n-3 fatty acids, such as DHA and EPA, are essential for the maturation and reproduction of crab and lobsters (*20*, *24*, *25*) and might even be implicated in the molting process (*26*). This probably explains the fatty acid pattern in the gonads, which was dominated by PUFA, and the differences between females and males, especially in the European lobsters. Therefore, differences between sexes and tissues are probably related to the cumulative effects of diets, molting cycle, and reproductive metabolism. In this study gonads and muscle had more PUFA than hepatopancreas, but less MUFA and SFA. It has been suggested that gonads use essential fatty acids from hepatopancreas to synthesize MUFA contained in the yolk, where these fatty acids may come from triacylglycerols in the hepatopancreas (*20*). Our results suggest that the depletion of essential fatty acids in hepatopancreas to be used by gonads can also occur in males, as DPA was absent in male hepatopancreas but accumulated in male gonads.

As far as amino acids are concerned, their profiles in muscle of both lobster species are similar to those of other decapod crustaceans, such as *Carcinus maenas* and *Parapenaeus longirostris* (*27*, *28*). However, few studies have dealt with the amino acid composition in hepatopancreas and gonads of crustaceans. Most studies concerned the dietary requirements during larval stages in order to formulate efficient diets to use in aquaculture. Amino acids are the building blocks of proteins and are also fuel sources and precursors for other biological molecules. Arginine, leucine, and methionine are necessary for molting of *H. americanus* (*26*). Most amino acids, such as glutamine, aspartic acid, leucine, and arginine, were more concentrated in female gonads, particularly in European lobsters, which is probably related to their physiological role, but also the life cycle, as female *H. gammarus* had more developed gonads (bigger and greener). For example, arginine is highly important as the main reserve of ATP in crustaceans, whereas aspartic acid is part of the urea cycle and contributes to the formation of purines and pyrimidines (*29*). Both functions seem to be essential in a regulating organ that must invest energy and nutrients in the development of eggs. On the other hand, taurine was less concentrated in gonads compared to the remaining tissues. Taurine plays an essential role in anaerobic energy metabolism via the formation of tauropine, which is an end product of glycolysis (*30*).

Nutritional Quality. The human health aspects of eating seafood have primarily been linked to marine lipids because epidemiological studies have evidenced that seafood consumption has a potential protective role against coronary heart diseases, mainly attributed to the effects of long-chain polyunsaturated fatty acids and their cardioprotective action (*31*). The majority of studies concerning the benefits of seafood consumption consider only the muscle as edible tissue. Yet, several tissues can be consumed in different parts of the world. Crabs and lobsters are especially appreciated for their viscera, namely, hepatopancreas and gonads. To address the nutritional quality of each edible tissue of clawed lobsters several parameters, including indices, were considered, and the results clearly indicated differences between tissues, species, and sexes.

Total fat contents of muscle and gonads were below 5 g/100 g, a value generally considered to characterize a low-fat food (*32*), in contrast to hepatopancreas, which contained 11.8−25.5 g/100 g.

All edible tissues had an n-6/n-3 fatty acid ratio in the range of the recommended values: the U.K. Department of Health stipulated an ideal n-6/n-3 ratio of 1.0−4.0 for human consumption (*33*). On the other hand, the PUFA to SFA ratio in female hepatopancreas (PUFA/SFA = 0.5−0.8) was below the recommended minimum value of 0.4 set by that department. The ratio of n-3 to n-6 has been cited as an excellent index to compare the relative nutritional value of lipids, where high values correspond to better quality foods. The ratios obtained in muscle (4.1−6.2), gonads (4.1−5.4), and hepatopancreas (1.7−3.1) indicate

that gonads and muscle had higher quality than hepatopancreas. Compared to other crustacean species, such as the crabs *Callinectes sapidus* (muscle, 2.32; hepatopancreas, 1.57) and *Carcinus mediterraneus* (muscle, 1.4), all edible tissues of clawed lobsters had higher nutritional quality (*21*, *34*). Hepatopancreas had the highest AI and TI values compared to muscle and gonads. Nevertheless, hepatopancreas AI (0.40−0.53) was lower than those of other food items, such as lamb (1.00), beef (0.72), pork (0.69), and rabbit (0.82), but similar to values obtained with chicken (0.50) (*28*).

According to the amino acid score, proteins available in the edible tissues of both lobster species were well balanced in the essential amino acid composition, and the EAA to NEAA ratios were particularly good for female gonads of European lobsters. Tryptophan and the sulfur-containing amino acid cysteine are lost during the acid hydrolysis of meat products (*35*) and, therefore, were not quantified. Both lobster species had good levels of taurine (2-aminoethanesulfonic acid), which is a biologically active compound in foods. Despite not being regarded as an essential nutrient, taurine can be beneficial under certain circumstances. Taurine plays an important role in several essential processes such as membrane stabilization, osmoregulation, antioxidation, development of the central nervous system and retina, and reduction of cholesterol absorption (*36*, *37*).

Nowadays, one of the major concerns about food quality and nutrition in developed countries is the cholesterol content. In this regard, muscle (31−43 mg/100 g) and hepatopancreas (42.5−103.5 mg/100 g) of both clawed lobsters had less cholesterol content than other commercially important decapod species, such as the crab *C. maenas* (muscle, 57.4 mg/100 g), crayfish *Nephrops norvegicus* (muscle, 97 mg/100 g), and shrimp *Pandalus borealis* (muscle, 107 mg/100 g) (*38*, *39*). Gonads (105−114 mg/100 g) had the highest cholesterol concentration in both clawed lobsters. Yet these concentrations are similar to the muscle of squid, *Todarodes sagittatus* (140 mg/100 g) and are considered to be moderate values for human consumption (*39*).

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