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Lipid content and fatty acid composition of the liver from the rajiforms *Urotrygon chilensis*, *Urobatis halleri*, *Rhinobatos glaucostigma*, *Rhinoptera steindachneri* and *Dasyatis dipeteura* captured in Sinaloa, México

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Abstract

The lipid content and fatty acid composition of the liver oil from the ray fish species *Urotrygon chilensis*, *Urobatis halleri*, *Rhinobatos glaucostigma*, *Rhinoptera steindachneri* and *Dasyatis dipterura*, rajiforms captured in the State of Sinaloa, México, was examined, and the variation in the fatty acid composition determined by multivariate analysis. Total lipid content in their liver was relatively high, ranging between 30.67 - 46.41%, the highest observed in *D. dipterura.* These species showed important concentrations of n-3 long chain polyunsaturated fatty acids, particularly eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids (EPA+DHA= 4.79 - 14.47 g/100 g of liver oil), both provide health and medical benefits, including the reduction in the risk of death from coronary heart disease. The atherogenicity (0.93 - 1.53) and thrombogenicity (0.31 - 0.53) indexes were noticeably low, supporting the evidence of their high quality for cardiovascular disease prevention. Variation in the fatty acid composition, determined by multivariate analysis, showed the separation of the five species group means is fully explained in the two-dimensional discriminant space acounting for 83.34% of the dispersion. In conclusion, ray fish liver oil can be considered an important and interesting alternative to fish oil as a source of EPA and DHA.

Introduction

Nowadays consumption of nutraceutics is significant and it has increased steadily over the past few years. Nutraceutics are natural food products that provide health and medical benefits, including the prevention and treatment of disease. Among these food products essential fatty acids stand out, particularly the n-3 long-chain polyunsaturated fatty acids (LC-PUFA), such as eicosapentaenoic acid (EPA, C20:5 n-3) and docosahexaenoic acid (DHA, C22:6n-3). Among their health benefits, a reduction in the risk of death from coronary heart disease with a daily consumption of 400 - 500 mg of EPA+DHA in healthy patients has been reported (Harris *et al.*, 2008). In patients with schizophrenia and attention-deficit/hyperactivity disorder, low plasma DHA levels have been observed (Riediger *et al.*, 2009). On the other hand, DHA consumption during pregnancy and later in infant formulas results in improved brain and eye (retina) development in babies (Dobs *et al.*, 2008).

Up until today fish oil is the most important source of EPA and DHA. Among the fish species with the highest content of these essential fatty acids are wild salmon, cod and herrings. However, the sustained increment in fish oil demand over the last years, and the projected increment in the near future, requires the search for alternative sources of these essential fatty acids (González *et al.*, 2010).

Ray fish liver oil has presented itself as an important and interesting alternative (Ould El Kebir *et al.*, 2007) found that the liver of three species of ray fish captured in the Republic of Mauritania have concentrations of EPA and DHA ranging from 1.88-5.01% and 10.00 - 13.04%, respectively. In Mexico some of the first studies on lipid content of ray fish liver oil were presented by Navarro *et al.* (2004a) and Navarro *et al.* (2004b), they found that the liver of some ray fish species captured in the Gulf of California represents between 5 and 11% of the animals' wet weight, and the lipid content of the liver corresponds to 50% of that weight. The liver oil of the studied species had 16 - 18% of EPA+DHA,

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a similar concentration to that reported for cod oil characterized for its high n-3 LC-PUFA content. Three more species from the state of Campeche, in the Gulf of Mexico, *Rhinoptera bonasus*, *Aetobatus narinari* and *Dasyatis americana*, showed an oil yield of 43.0, 41.2 and 38.2% of the liver wet weight, respectively. The highest sum of eicosapentaenoic, docosahexaenoic and docosapentaenoic n-3 LC-PUFA were found in *Rhinoptera bonasus* (22.4%) and *Dasyatis americana* (21.6%) (Navarro *et al.*, 2009).

The Gulf of California is an important ray fish fishing area in Mexico. Recent surveys indicated a high diversity of elasmobranchs (shark and batoid) in the artisanal fisheries of this region. Assessments of Mexican elasmobranchs fisheries indicate that sharks dominate landings (Bonfil, 1994, 1997; Castillo *et al.*, 1998), but rays are important fishery targets by the artisanal ray fishery (Márquez *et al*., 2002) and are commonly caught as bycatch by shrimp trawlers in the area (Flores *et al*., 1995; García *et al*., 2000). The ray fish species incidentally captured in shrimp trawlers include the families Urotrygonidae, Myliobatidae, Narcinidae, Rhinobatidae, and Rhinopteridae, which include demersal species that distribute along the Mexican Pacific. Abundance of a particular species in the catches depends on the season, depth and whether conditions. In spite of the progress of their artisanal fishery, still very little is known on their biology and biochemistry (Márquez, 2002; Navarro *et al*., 2004a, b). Most of the ray fish species are underutilized; only the meat is used and its price depends on its color.

Sinaloa is one of the states with an important ray fisheries activity in the Gulf of California (CONAPESCA, 2010). However, no information is available on the liver quality and oil yield of the captured species that would encourage the utilization and commercialization of this resource. Thus, the objective of the present study was to analyze the lipid content and fatty acid composition of the liver oil from *Urotrygon chilensis*, *Urobatis halleri*, *Rhinobatos glaucostigma*, *Rhinoptera steindachneri* and *Dasyatis dipterura*, rajiforms captured in the State of Sinaloa, México, and evaluate the variation in the fatty acid composition determined by multivariate analysis.

Materials and methods

Sample acquisition

Samples of *U. chilensis* (20), *U. halleri* (20), *R. glaucostigma* (5), *R. steindachneri* (3) and *D. dipterura* (7) were obtained during 2009 from experimental shrimp trawl surveys conducted in Teacapan, Sinaloa by the Instituto Nacional de Pesca, and Facultad de Ciencias del Mar from the Universidad Autonoma de Sinaloa. Sets were performed at different depths including 2, 5, 8, 10 and 12 fathoms (Fig. 1). The livers were dissected, placed in polyethylene bags and frozen at -20°C for their transportation in coolers to the Departamento de Investigaciones Científicas y Tecnológicas de la Universidad de Sonora (DICTUS) (Hermosillo, Sonora, Mexico). Livers were stored at -80°C, for no more than 2 weeks, until lipid extraction.

Lipid content and fatty acid analysis

Total lipid was extracted from the liver by homogenizing in chloroform/methanol (2:1, v/v) in an Ultra-Turrax T-18 tissue disrupter (IKA Work, Inc, Wilmington, NC, USA.) and measured gravimetrically according to the method of Folch *et al.* (1957). Fatty acids were derivatized to their corresponding methyl-esters using 7% BF3-MeOH, according to method Ce 2-66, A.O.C.S. (1992). Identification and quantification of fatty acids methyl-esters (FAME) was done by capillary gas chromatography with a Varian 3800 gas chromatograph (Varian Inc., Walnut Creek, CA) fitted with a 50 m, 0.25 mm i.d. CP-Cil 88 52CB capillary column (Varian, Walnut Creek, CA, USA) and equipped with a flame ionization detector. The initial oven temperature was set at 195°C, raised to 240°C at 5°C/min and maintained at this temperature for 3 min. Individual components were identified by comparing retention times with those obtained from the FAME mixture standard (Supelco-Sigma cat. No. 4-7885, Aldrich, Química, México). Tricosanoic acid (C23:0) was used as an internal standard. The fatty acid content was expressed as g of FAME per 100 g of liver oil. Once the fatty acid content and composition were determined, dietary scores such as the atherogenicity index (AI) and index of thrombogenicity (IT) (Ulbricht and Southgate, 1991) were determined to obtain information on the oils' benefits as nutraceutics for cardiovascular disease prevention.

Statistical analysis

Sample analysis was performed in triplicate and data presented are means ± standard deviation. Analysis of variance of total lipid content of the liver was performed, and Duncan's multiple range test was used as the mean separation procedure ($P < 0.05$). Fisher discriminant analysis (FDA) was performed by using centred and standardised ray fish species data. The data set was composed by sixteen fatty acids and five ray fish species. Subsequently, the Lachenbruch's holdout procedure [C, D] (sometimes referred to

as jackknifing or cross-validation) was used in conjunction with the Fisher's classification analysis based on the first two sample discriminants in order to estimate the total misclassification probability or actual error rate (AER). The last process was repeated for each variables subset possible. The variables subset with dimension minimum associated to the estimated AER minimum was selected in order to see how well they classify compared to the discriminant function, which uses all the variables. Data were processed with MATLAB program version 7.0.

Results and discussion

Total lipid content in the liver of the analyzed species was relatively high, ranging between 30.67 and 46.41% (Table 1); *D. dipterura* showed the highest lipid content and *R. steindachneri* the lowest. Navarro *et al.* (2004 a, b) reported higher lipid content for *R. steindachneri* and lower for *D. dipterura*, this makes evident the role of the liver as an energy storage organ, which determines that its total lipid content varies according to the animals' feeding status, age or size, gender, geographical distribution, or season, even for the same species (Wetherbee and Nichols, 2000). Similar total liver lipid contents have also been reported for other ray species, such as *D. bleekeri* (63.4%) (Pal *et al*., 1998), *D. marmorata*, *R. cemiculus*, *R. marginata* (47.4, 40.5, and 22.6% respectively) (Ould El Kebir *et al*., 2003), *Himantura bleekeri* (54.0%) (Le Nèchet *et al*., 2007), *R. bonasus*, *D. americana* and *A. narinari* (43.0, 38.2 and 41.2%, respectively) (Navarro *et al*., 2009), as well as shark liver (40.3%) (Navarro *et al*., 2000).

The fatty acid analyses of the lipid extracted from ray fish livers showed eighteen fatty acids that were considered abundant (Table 2). In spite of the complexity of fatty acid profiles from fish oils, their composition can be described based on 8 to 10 key fatty acids (Lambertsen, 1978). The present study concurs, since fatty acid analysis of ray fish liver oils demonstrated that C16:0 (4.74 - 23.44 g/100 g of liver oil) and C18:0 (3.10 - 10.71 g/100 g of liver oil) were the main saturated fatty acids (SFA), coinciding with has already been reported in liver lipids of *D. dipterura* and *R. steindachneri* captured off the Sonora state coast (Navarro *et al.*, 2004 a, b), for *R. bonasus*, *D. americana* and *A. narinari* (Navarro *et al.*, 2009) and for *R. marginata*, *D. marmorata* and *R. cemiculus* (Ould El Kebir *et al*., 2003), but also comparable to fatty acids in muscle of *Rachycentron canadum* (Liu *et al*., 2009) and *Raja clavata* (Turan *et al.*, 2007). Both, C16:0 and C18:0 can be used as energy sources. Additionally, they may serve as structural components of phospholipids (Perez *et al*., 1999). As for monounsaturated fatty acids (MUFA), the most abundant were C16:1 (1.74 - 11.62%) and C18:1 (2.86 - 17.61%) (Table 2), showing similar values to those reported for other Mexican ray fish species captured in different locations (Navarro-García *et al*., 2009; Navarro-García *et al*., 2004a, b). These fatty acids can be biosynthesized or obtained from the diet.

The n-3 LC-PUFA, particularly EPA and DHA have a significant therapeutic and nutritional value, and among other applications, they have been used for cardiovascular disease treatment (Kryzhanovskii and Vititnova, 2009), for babies brain development (Schuchardt *et al*., 2010) and as hypotensors (Chen *et al*., 2009). In general, the species in this study showed important concentrations of EPA and DHA (Table 2), although *D. dipterura* showed a DHA level (4.73%) lower than 5%. DHA values were higher than EPA values for the studied species, similarly to what has been reported for other ray fish (Navarro *et al*., 2009; Navarro *et al.*, 2004a, b) and some warm water species (Ackman *et al.*, 1980).

Unsaturated fatty acids (∑MUFA+∑PUFA+∑LC-PUFA) were a majority (58-69%), whereas the ratio ∑PUFA+∑LC-PUFA/∑SFA was higher for *R. steindachneri* (1.16). This ratio was over 0.50 in all remaining species (Table 3), which is the minimum

Table 1. Total lipid content in the liver of *U. chillensis*, *U. halleri*, *R. glaucostigma*, *R. steindachneri* and *D. dipterura*

Species	Lipid (%)
U. chilensis	$36.18^{ab} \pm 10.18$
U. halleri	$36.27^{ab} \pm 7.51$
R. glaucostigma	$31.83^{b} \pm 10.27$
R. steindachneri	$30.67^{b} \pm 4.84$
D. dipterura	$46.41^{a} \pm 4.98$

Tabla 2. Fatty acid composition of liver oil from the rajiforms *U. chilensis*, *U. halleri*, *R. glaucostigma*, *R. steindachneri* and *D. dipterura* (g/100 g of liver oil)

	U. chilensis		*U. halleri*		*R. glaucostigma*		*R. steindachneri*		*D. dipterura*	
Fatty acid	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
14:0	1.54	0.53	2.49	1.09	2.22	0.38	0.58	0.36	2.65	1.28
14:1	0.96	0.32	1.40	0.52	1.12	0.37	0.41	0.22	1.53	0.74
16:0	15.28	4.17	16.70	4.94	15.20	1.76	4.74	1.11	23.44	10.85
16:1	5.02	1.53	7.96	2.36	4.39	0.47	1.74	0.55	11.62	4.62
18:0	10.71	2.93	7.21	1.95	6.48	0.66	3.10	0.87	8.41	3.24
18:1	6.24	1.78	12.37	3.38	8.15	1.30	2.86	1.13	17.61	6.96
18:2n-6	1.73	0.40	1.79	0.63	1.44	0.31	0.61	0.27	2.12	1.04
18:3n-3	0.39	0.11	0.39	0.32	0.32	0.09	0.09	0.06	0.31	0.18
20:0	0.22	0.12	0.10	0.10	0.00	0.00	0.12	0.10	0.17	0.08
20:1	2.27	0.53	2.05	0.58	0.96	0.17	1.02	0.24	2.50	1.02
20:4n-6	3.24	0.85	3.10	0.87	2.86	1.21	1.30	0.24	2.88	0.95
20:5n-3	5.41	1.54	5.09	1.75	3.28	1.20	0.99	0.18	4.33	1.42
22:0	1.59	0.60	1.35	0.38	0.81	0.13	0.51	0.16	1.03	0.46
22:1	0.64	0.13	0.52	0.17	0.32	0.02	0.30	0.09	0.55	0.17
22:5n-3	2.27	0.41	2.21	0.62	1.21	0.23	1.10	0.41	1.85	0.55
22:6n-3	8.55	1.66	8.37	3.22	11.19	1.82	5.70	2.84	4.73	1.44
24:1	3.02	0.58	2.29	0.59	0.73	0.09	1.52	0.40	2.44	0.73
24:2	2.02	0.38	1.69	0.66	1.43	0.32	2.29	0.41	1.07	0.35

Table 3. Fatty acid sums (g/100 g of liver oil) and nutritional indexes of liver oil from the rajiforms *U. chilensis*, *U. halleri*, *R. glaucostigma*, *R. steindachneri* and *D. dipterura*

	U. chilensis		*U. halleri*		*R. glaucostigma*		*R. steindachneri*		*D. dipterura*	
Fatty acid	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
∑SFA	29.30	7.57	27.79	7.82	24.72	2.11	9.01	2.55	35.62	15.48
∑MUFA	18.15	4.30	26.47	6.53	15.67	2.06	7.84	2.49	36.25	13.71
∑PUFA+LC-PUFA	23.61	4.64	22.62	6.14	21.73	2.40	10.16	3.80	17.28	5.48
∑PUFA+LC-PUFA/∑SFA	0.82	0.11	0.83	0.14	0.88	0.12	1.16	0.41	0.51	0.10
∑n-3	16.62	3.38	16.05	4.35	16.00	1.97	5.95	3.82	11.21	3.33
∑n-6	4.97	1.17	4.88	1.42	4.30	1.15	1.91	0.05	5.00	1.93
∑n-3/∑n-6	3.39	0.38	3.32	0.47	4.03	1.60	3.08	1.90	2.32	0.36
EPA+DHA	13.95	2.95	13.45	3.73	14.47	1.87	4.79	3.83	9.06	2.71
AI	1.40		1.25		1.53		0.93		1.47	
IT	0.41		0.36		0.36		0.31		0.53	

SFA: Saturated Fatty Acids; MUFA: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids; LC-PUFA: Long Chain Polyunsaturated Fatty Acids; EPA: Eicosapentaenoic Acid; DHA: Docosahexaenoic Acid; AI: Atherogenicity index; IT: Index of Thrombogenicity.

Table 4. Matrix of holdout procedure calculated using all fatty acids

		Predicted membership				
		E1	E2	E3	E4	E5
Actual membership	E1	17	1	0	2	0
	E2	1	17	0	1	1
	E3	0	0	5	0	0
	E4	1	0	0	3	0
	E5	0	2	0	0	5

E1: *U. chilensis*; E2: *U. halleri*; E3: *R. glaucostigma*; E4: *R. steindachneri*; E5: *D. dipterura*

recommended ratio for cardiovascular disease prevention (Hunty, 1995) and comparable to the ratio reported for *R. clavata*'s oil (0.50) (Turan *et al.*, 2007).

The n-3 and n-6 polyunsaturated fatty acids have antagonistic effects in the human body. While n-3 fatty acids are precursors of vasodilators, platelet anti-aggregation and anti-inflammatory compounds, the n-6 are precursors of compounds with opposite effects. Thus, the n-3/n-6 ratio is an important indicator to determine the nutritional value of oils. Simopoulos (2000) proposed an optimal range of 0.5 - 1.0 for this ratio. The n-3/n-6 ratios determined for the five studied ray fish species ranged between 2.32 and 4.03, the highest corresponding to *R. glaucostigma*. Similar ratios have been determined for liver oils of *Sardinella lemuru* (2.26) (Khoddami *et al*., 2009) and tuna (6.5) (Jaturasitha *et al.*, 2009). Slightly lower n-3/n-6 ratios have been reported for some of these ray fish species and others, such as *R. steindachneri* (1.13), *A. narinari* (0.3), *R. bonasus* (1.33) and *D. dipterura* (1.21) (Perez *et al.*, 2008) that are probably a result of a dietary influence in the tissue's fatty acid profile.

Predicting the capacity to avoid cardiovascular accidents by consuming a particular kind of oil may be done through the atherogenicity (AI) and thrombogenicity (IT) indexes (Ulbricht and Southgate, 1991) determined from the fatty acid profile of the oil. The AI evaluates the effect of various fatty acids on the serum cholesterol. The

Table 5. Matrix of holdout procedure calculated using thirteen fatty acids*

		Predicted membership				
		E1	E2	E3	E4	E5
Actual membership	E1	18	1	0	1	0
	E2	0	20	0	0	0
	E3	0	0	5	0	0
	E4	0	0	0	3	0
	E5	0	1	0	0	6

*Fatty acids: 14:0, 14:1, 16:0, 16:1, 18:0, 18:1, 18:2n-6, 20:1, 22:0, 22:5n-3, 22:6n-3, 24:1, 24:2.
E1: *U. chilensis*; E2: *U. halleri*; E3: *R. glaucostigma*; E4: *R. steindachneri*; E5: *D. dipterura*

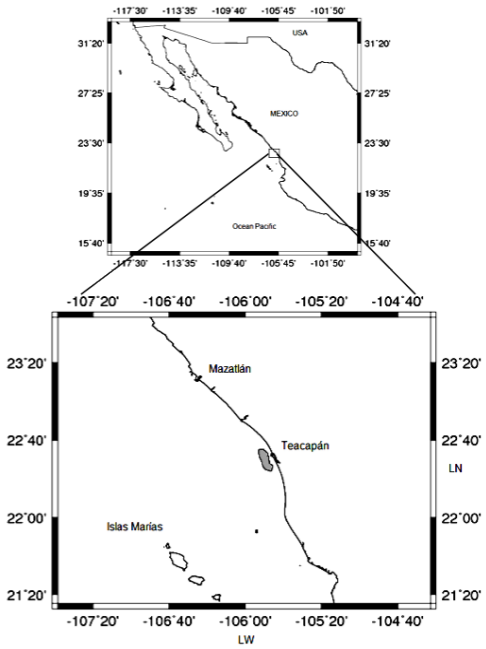

Figure 1. Study area and location of sampling stations in the coasts of the Gulf of California

saturated fatty acids C14:0 and C16:0 are four times more atherogenic, while unsaturated fatty acids do not contribute to the increment of the index. The IT allows us to know the degree of contribution of fatty acids to platelet aggregation raising the levels of esterified fatty acids, cholesterol, and phospholipids, which are factors that favor the development of thrombosis (Turan *et al.*, 2007). The determined IA (0.93 - 1.53) and IT (0.31 - 0.53) values for the liver oils of the evaluated ray fish were noticeably low in both cases (Table 3), which supports the evidence of the high quality of ray fish liver oil for cardiovascular disease prevention. Values for AI and IT for *R. clavata* (2.37; 0.63) (Turán *et al*., 2007), anchovy (0.45; 1.35), eel (0.37; 0.57), and rainbow trout (0.25; 0.45) (Valfré *et al*., 2003) have been reported.

Studies on the fatty acid profiles of oils from marine species not only provide information on their nutritional value, but also allow their classification through the application of multivariate statistical analysis. Some studies have reported that it is possible to differentiate different salmon species (Mjaavatten *et al.*, 1998) or species from the genus Sebastes (Joensen and Grahl-Nielsen, 2000) and

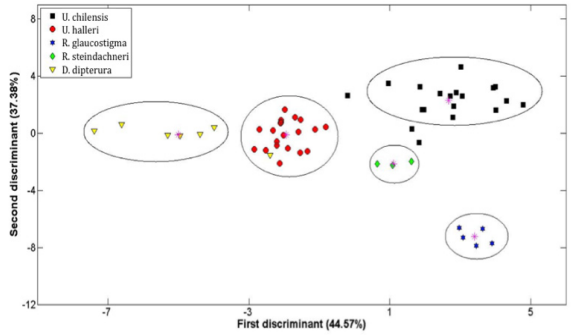

Figure 2. Ray fish species samples in discriminant space based on all fatty acids. The percentage of the dispersion of the group means along each of the discriminants may be observed as asterisks in the graph.

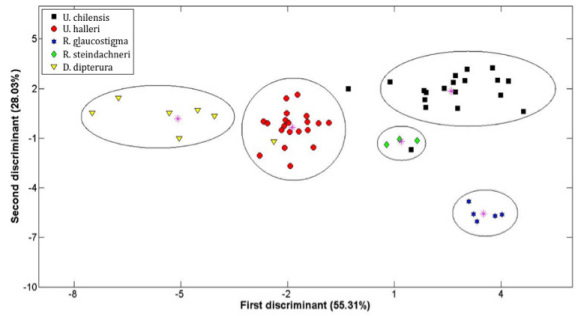

Figure 3. Ray fish Ray fish species samples in discriminant space based on thirteen fatty acids. The percentage of the dispersion of the group means along each of the discriminants may be observed as asterisks in the graph.

even tell apart a cultured or wild organisms (Tritt *et al.*, 2005). In the present paper, result from the multivariate statistical analysis showed the separation of five group means fully explained in the two-dimensional "discriminant space". The group means and the scatter of the individual observations in the discriminant coordinate system are shown in Figure 2. The separation is good, and the first and second discriminant functions, which taken together account for 81.95% of the dispersion of the group means, shows that they have the strongest power of discrimination of the four functions. The elements in Table 4 were generated using the holdout procedure, so the overall error rate (8/55 or 14.55%) is low. On the other hand, adopting the holdout estimate of the expected AER as our criterion in order to explore effective classification with fewer variables, it was observed that thirteen fatty acids (14:0, 14:1, 16:0, 16:1, 18:0, 18:1, 18:2n-6, 20:1, 22:0, 22:5n-3, 22:6n-3, 24:1, 24:2) produced an error rate of 5.45%, quite low (Table 5). A plot of the group means and individual observations using the first two discriminant scores is shown in Figure 3, where the separation is as good as in the previous figure. The first and second discriminant functions account for 83.34% of the dispersion of the group means. Thus the mean vectors lie largely in two dimension, and two discriminant functions suffice to describe most of the separation among the five ray fish species.

Conclusion

In conclusion, the value of multivariate analysis to determine the variation in the fatty acid composition of the oils was demonstrated. Total lipid content in the liver of all five species was relatively high, *D. dipterura* showed the highest total lipid content. All five species also showed important concentrations of n-3 LC-PUFA, particularly EPA and DHA, and R. glaucostigma showed the highest content of EPA+DHA. The AI and TI were noticeably low, supporting the evidence of the high quality of ray fish liver oil for cardiovascular disease prevention. Therefore, ray fish liver oil can be considered an important and interesting alternative to fish oil as a source of EPA and DHA.

References

A.O.C.S. 1992. Official methods and recommended practices of the American Oil Chemist's Society (4th eds). Champaign. AOCS.

Ackman, R. G., Sebedio, J. L. and Kovacs, M. I. P. 1980. Role of eicosenoic and docosenoic fatty acids in freswater and marine lipids. Marine Chemistry 9: 157-164.

Bonfil, R. 1994. Overview of world elasmo branch fisheries. FAO Fisheries Technical Paper. 341. Rome.

Bonfil, R.1997. Status of shark resources in the southern Gulf of Mexico and Caribbean: implications for management. Fisheries Research 29(2): 101-117.

Castillo-Géniz, J. L., Márquez-Farías, J. F., Rodríguez de la Cruz, M. C., Cortés, E., and Cid del Prado, A. 1998. The Mexican artisanal fishery in the Gulf of Mexico: towards a regulated fishery. Marine and Freshwater Research 49: 611-620.

Chen, Z.-Y., Peng, C., Jiao, R., Wong, Y. M., Yang, N., and Yu, H. 2009. Anti-Hypertensive nutraceuticals and functional foods. Journal of Agricultural and Food Chemistry 57: 4485-4499.

CONAPESCA. 2010. Comisión Nacional de Acuacultura y Pesca. Producción Pesquera y Acuícola 2010 (*Cifras definitivas*). Dowloaded from *http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_anuario_estadistico_de_pesca.*

Dobs, A. S., and Edelstein, D. 2008. Evaluating the Biological Activity and Effects on Human Health of Fish Oil and Its Omega-3 Fatty Acids. In De Mester, F. and Watson, R.R. (Eds.). Wild-Type Food in Health Promotion and Disease Prevention. p. 195-214. New Jersey: Humana Press Inc.

Flores, O. J., Rodríguez, M., Shimizu, M., and Machii, T. 1995. Evaluation of demersal fishery resources of the Gulf of California using Mexican shrimp trawlers. Journal of National Fisheries University 44(1): 9-19.

Folch, J., Lees, M., and Sloane-Stanley, G. H. 1957. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry 226: 497-509.

García-Caudillo, J. M., Cisneros-Mata, M. A. and Balmori, A. 2000. Performance of a bycatch reduction device in the shrimp fishery of the Gulf of California, México. Biological Conservation 92: 199-205.

González-Félix, M. L., Soller Dias da Silva, F., Davis, D. A., Samocha, T. M., Morris, T. C., Wilkenfeld, J. S. and Perez-Velazquez, M. 2010. Replacement of fish oil in plant based diets for Pacific white shrimp (*Litopenaeus vannamei*). Aquaculture 309: 152-158.

Harris, W. S., Kris-Etherton, P. M. and Harris, K. A. 2008. Intakes of long-chain omega-3 fatty acid associated with reduced risk for death from coronary heart disease in healthy adults. Current Atherosclerosis Reports 10: 503-509.

Hunty, A. 1995. The COMA report on nutritional aspects of cardiovascular disease: the scientific evidence. British Food Journal 97: 30-32.

Jaturasitha, S., Khiaosa-ard, R., Pongpiachan, P. and Kreuzer, M. 2009. Early deposition of n-3 fatty acids from tuna oil in lean and adipose tissue of fattening pigs is mainly permanent. Journal of Animal Science 87: 693-703.

Joensen, H. and Grahl-Nielsen, O. 2000. Discrimination of *Sebastes viviparus*, *Sebastes marinus* and *Sebastes mentella* from Faroe Islands by chemometry of the fatty acid profile in heart and gill tissues and in the skull oil. Comparative Biochemistry and Physiology 126B: 69-79.

Khoddami, A., Ariffin, A. A., Bakar, J. and Ghazali, H. M. 2009. Fatty acid profile of the oil extracted from fish waste (head, intestine and liver) (*Sardinella lemuru*). World Applied Sciences Journal 7(1): 127-131.

Kryzhanovskii, S. A. and Vititnova, M. B. 2009. ω-3 polyunsaturated fatty acids and the cardiovascular system. Human Physiology 35: 491-501.

Lambertsen, G. 1978. Fatty acid composition of fish Fats, comparisons based on eight fatty acids, Fisk. Dir. Skr. Set. Ernaering 1: 105-116.

Le Nèchet, S., Dubois, N., Gouygou, J. P. and Bergè, J. P. 2007. Lipid composition of the liver oil of the Ray, Himantura bleekeri. Food Chemistry 104: 559-564.

Liu, S. C., Li, D. T., Hong, P. Z., Zhang, C. H., Ji, H. W. and Gao, J. L. 2009. Cholesterol, lipid content, and fatty acid composition of different tisues of farmed cobia (*Rachycentron canadum*) from China. Journal of the American Oil Chemists' Society 86: 1155-1161.

Márquez-Farías, J. F. 2002. The artisanal ray fishery in the Gulf of California: development, fisheries research, and management issues. IUCN Shark Specialist Group. Shark News 14: 1-5.

Mjaavatten, O., Levings, C. D. and Poon, P. 1998. Variation in the fatty acid composition of juvenile chinook and coho salmon from Fraser river estuary determined by multivariate analysis; role of environment and genetic origin. Comparative Biochemistry and Physiology 120B: 291-309.

Navarro-Garcia, G., Bringas-Alvarado, L., Pacheco-Aguilar, R. and Ortega-García, J. 2004a. Oxidative resistance, carotenes, tocopherols and lipid profile of liver oil of the ray *Rhinoptera steindachneri.* Journal of Food Composition and Analisis 17: 699-706.

Navarro-García, G., Pacheco-Aguilar, R, Bringas-Alvarado, L. and Ortega-García J. 2004b. Characterization of the lipid composition and natural antioxidants in the liver oil of *Dasyatis brevis* and *Gymnura marmorata* rays. Food Chemistry 87: 89-96.

Navarro-García, G., Pacheco-Aguilar, R., Vallejo-Cordova, B., Ramírez-Suarez, J. C. and Bolaños, A. 2000. Lipid composition of the liver oil of shark species from the Caribbean and Gulf of California waters. Journal of Food Composition and Analysis 13: 791-798.

Navarro-García, G., Ramírez-Suárez, J. C., Ortega-García, J., García-Camarena, R., Márquez-Farías, J. F., Santos-Valencia, J. and Bringas-Alvarado, L. 2009. Lipid composition, natural antioxidants and physicochemical characteristics in liver oil from rajiforms from the Gulf of Mexico. Journal of the American Oil Chemists' Society 86: 323-328.

Ould El Kebir, M. V., Barnathan, G., Gaydou, E. M., Siau, I. and Miralles, J. 2007. Fatty acids in liver, muscle and gonad of three tropical rays including non-methylene-interrupted dienoic fatty acids. Lipids 42: 525-535.

Ould El Kebir, M. V., Barnathan, G., Siau, I., Miralles, J. and Gaydou, E. M. 2003. Fatty acid distribution in muscle, liver, and gonad of rays (*Dasyatis marmorata*, *Rhinobatos cemiculus* and *Rhinoptera marginata*) from the east tropical Atlantic Ocean. Journal of Agricultural and Food Chemistry 51(7): 1942-1947.

Pal, D., Banerjee, D., Patra, T. K., Patra, A. and Ghosh, A. 1998. Liver lipids and fatty acids of the sting ray *Dasyatis bleekeri* (Blyth). Journal of the American Oil Chemists' Society 75: 1373-1378.

Perez, J. A., Rodriguez C. and Henderson R. J. 1999. The uptake and sterification of radio labelled fatty acids by enterocytes isolated from rainbow trout (*Oncorhynchus mykiss*). Fish Physiology and Biochemistry 20: 125-134.

Perez-Velazquez, M., González-Félix, M. L., Navarro-García, G. and Valenzuela-Escalante, E., 2008. Nutritional Value of various ray fish liver oils to the pacific White shrimp *Liptopenaeus vannamei.* Lipids. 43: 1009-1016.

Riediger, N. D., Othman, R. A., Suh, M. and Moghadasian, M. H. 2009. A systemic review of the roles of n-3 fatty acids in health and disease. Journal of the American Dietetic Association 109: 668-679.

Schuchardt, J. P., Huss, M., Stauss-Grabo, M. and Hahn, A. 2010. Significance of long chain polyunsaturated fatty acids (PUFA) for the development and behaviour of children. European Journal of Pediatrics 169: 149-164.

Simopoulos, A. P. 2000. Human requirement for n-3

polyunsaturated fatty acids. Poultry Science 79: 961-970.

Tritt, K. L., O'bara, C. J. and Wells M. J. M. 2005. Chemometric discrimination among wild and cultured age-0 largemouth bass, black crappies, and white crappies based on fatty acid composition. Journal of Agricultural and Food Chemistry 53: 5304-5312.

Turan, H., Sönmez, G. and Kaya, Y. 2007. Fatty acid profile and proximate composition of the thornback ray (*Raja clavata* L. 1758) from the Sinop coast in the Black Sea. Journal of Fisheries Sciences 1(2): 97-103.

Ulbritcht, T. L. V. and Southgate, D. A. T. 1991. Coronary Heart Disease: Seven Dietary factors. The Lancet 338: 985-992.

Valfré, F., Caprino, F. and Turchini, G. M. 2003. The health benefit of seafood. Veterinary Research Communications 27: 507-512.

Wetherbee, B. M. and Nichols, P. D. 2000. Lipid composition of the liver oil of deep-sea sharks from the Chatham Rice, New Zealand. Comparative Biochemistry and Physiology 125B: 511-521.