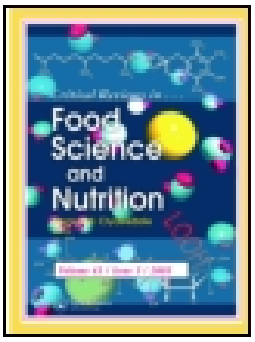

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REVIEW

Lipid nutritional quality of marine and freshwater bivalves and their aquaculture potential

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ABSTRACT

Omega-3 Long-chain polyunsaturated fatty acids (n-3 LC-PUFA) are beneficial to human health. Since the industrial revolution, with the tremendous increase of human population, the supply of natural n-3 LC-PUFA is far lower than the nutritional need of n-3 LC-PUFA. Therefore, a new alternative source of natural n-3 LC-PUFA is urgently needed to reduce the supply and demand gap of n-3 LC-PUFA. Mollusks, mainly bivalves, are rich in n-3 LC-PUFA, but the information of bivalves' lipid profile is not well organized. Therefore, this study aims to analyze the published fatty acid profiles of bivalves and reveal the potential of bivalve aquaculture in meeting the nutritional needs of human for n-3 LC-PUFA. There are growing evidence show that the nutritional quality of bivalve lipid is not only species-specific, but also geographical specific. To date, bivalve aquaculture has not been evenly practiced across the globe. It can be seen that aquaculture is predominant in Asia, especially China. Unlike fish aquaculture, bivalve aquaculture does not rely on fishmeal and fish oil inputs, so it has better room for expansion. In order to unleash the full potential of bivalve aquaculture, there are some challenges need to be addressed, including recurrent mass mortalities of farmed bivalves, food safety and food security issues. The information of this article is very useful to provide an overview of lipid nutritional quality of bivalves, and reveal the potential of bivalve aquaculture in meeting the growing demand of human for n-3 LC-PUFA.

KEYWORDS
Aquaculture; Bivalves; Challenges; Meta-analysis; n-3 LC-PUFA; Seafood

Introduction

Long-chain polyunsaturated fatty acids (LC-PUFA) refer to fatty acids with ≥3 double bonds and ≥20 carbon numbers, including the well-known n-6 series of arachidonic acid (20:4n-6, ARA), and the n-3 series of eicosapentaenoic acid (20:5n-3, EPA) and docosahexaenoic (22:6n-3, DHA). Since the publication of health assessment report in 1970, the importance of n-3 LC-PUFA has been elevated to a top priority. In that report, the incidence of low-density lipoprotein, plasma cholesterol, plasma triglycerides and heart disease in the Greenland Inuit (very high n-3 LC-PUFA consumption) were significantly lower than that in the Danes (low n-3 LC-PUFA consumption) (Nettleton 1995). Since then, there has been increasing evidence that n-3 LC-PUFA is beneficial to human health, including neurological development, cardiovascular protection, cancer prevention, and improved cognitive development and function (Berquin, Edwards, and Chen 2008; Sasazuki et al., 2011; Sawada et al., 2012). The requirement of n-3 LC-PUFA is affected by many factors, including genetics, age, gender, body weight, dietary habits, health status, daily activities, exposure to pollutants and toxins, medication use, etc (Teslovich et al. 2010). Different research groups and health organizations issued different recommended daily intake of n-3 LC-PUFA. For instance, in 2003, the International Society for the Study of Fatty Acids and Lipids recommended a daily intake of 500 mg EPA + DHA (International Society for the Study of Fatty Acids and Lipids (ISSFAL)), 2004), while the Japan Society for Lipid Nutrition recommended a daily intake of 1000 mg of EPA + DHA (Hamazaki and Okuyama 2003). In 2009, the World Health Organization/Food and Agricultural Organization (WHO/FAO 2010) and the European Food Safety Authority (European Food Safety Authority 2010) recommended that the daily intake of n-3 LC-PUFA account for 0.5 to 2.0% of the total daily energy (about 250 mg of EPA + DHA) for men and non-pregnant women. Other groups recommend a daily intake of EPA + DHA > 1000 mg/day (Flock, Harris, and Kris-Etherton 2013; Salem and Eggersdorfer 2015). Overall, most organizations include the Academy of Nutrition and Dietetics (Vannice and Rasmussen 2014), the Israel Heart Society (Israel Heart Society (IHS)), 2011), the National Heart Foundation of Australia (NHFA)) (2008), the Dietitians of Canada (Kris-Etherton and Innis 2007) and the International Society for the Study of Fatty Acids and Lipids (International Society

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for the Study of Fatty Acids and Lipids (ISSFAL)), 2004) recommended that healthy adults should consume 500 mg of EPA + DHA per day. Therefore, the term "recommended daily intake of EPA + DHA" used in this paper refers to 500 mg/day of EPA + DHA.

In just half a century, the human population has doubled from 3.7 billion in 1970 to 7.9 billion (Gerland et al. 2014; World Population Clock: 7.9 Billion People, 2021). The global survey of dietary n-3 LC-PUFA based on EPA + DHA intake data revealed that more than 80% of the world's population consumed less than 250 mg of n-3 LC-PUFA per day, and the global average intake of n-3 LC-PUFA was 163 mg/day (Micha et al., 2014). The consumption level of EPA + DHA is greatly affected by regional factors, in which 298 published data of relative weight percentage (%) of EPA + DHA in blood (n-3 index) show that the human population in most parts of the world, including the America, Europe, Middle East, Southeast Asia and Africa, has a low content of EPA + DHA in blood, which was <4% (considered as a cardiovascular risk factor), whereas high content of EPA + DHA in blood of >8% (good for health) was only observed in a few regions, including the Sea of Japan, Scandinavia, and areas with indigenous populations (Stark et al. 2016). At present, the global demand for EPA + DHA is estimated to be approximately 1.3 million tonnes/year (500 mg/day × 365 days × 7 billion) (Salem and Eggersdorfer 2015; Tocher 2015), while the global supply of EPA + DHA is only accounts for about 15% of the total demand (Stark et al. 2016). It is estimated that by 2100, the global human population will reach 11 billion or more (Gerland et al. 2014), which will widen the gap between supply and demand of n-3 LC-PUFA, resulting in more and more people worldwide to have inadequate EPA + DHA intake.

Mollusks, especially bivalves, are rich in n-3 LC-PUFA (Table 1). Lipid profiles of many marine and freshwater bivalves from different species and regions have been reported (e.g. Nguyen et al. 2017; Şereflişan and Altun 2018; Qin et al. 2018; Prato et al. 2019; Tan et al. 2020a, 2020b, 2021a). However, this information is not organized. In this context, this study aims to review the published fatty acid profiles of bivalves and reveal the potential of bivalve aquaculture to meet the nutritional needs of human beings for n-3 LC-PUFA. The information in this article can be used as a guide to identify potential bivalve species for aquaculture and unleash the full potential of bivalve aquaculture in the production of n-3 LC-PUFA to supply n-3 LC-PUFA at low price to meet some (if not all) of the global demand.

Fatty acid profiles in bivalve

Fatty acid profiles in marine mussels

In general, the lipid content of commercially important marine mussels is less than 3.00% wet weight (ww) (Table 2). The highest lipid content (2.98% ww) of marine mussels was *Modiolus barbatus* collected from Gulf of Taranto (Biandolino et al. 2019), followed by *Mytilus galloprovincialis* (2.18 ± 0.45% ww) (Dernekbaşı et al. 2015; Merdzhanova, Dobreva, and Panayotova 2017; Biandolino et al. 2019), *Perna viridis* (1.85 ± 0.21% ww) (Chakraborty et al. 2011) and *My. edulis* (1.28 ± 0.31% ww) (Lin et al. 2003; Alkanani et al. 2007). Marine mussels with the lowest lipid content of 0.50 to 0.60% ww, were recorded from samples of *Megangulus* collected from Hokkaido, Japan (Kawashima and Ohnishi 2003).

The fatty acid composition of most marine mussels is dominated by PUFA followed by saturated fatty acids (SFA), and then monounsaturated fatty acids (MUFA) (Ahn et al. 2000; Freites, Fernández-Reiriz, and Labarta 2002; Kawashima and Ohnishi 2003; Lin et al. 2003; Taylor and Savage 2006; Xu and Yang 2007; Alkanani et al. 2007; Chakraborty et al. 2011; Ruano, Ramos, and Quaresma 2012; Ezgeta-Balić et al. 2012; Dernekbaşı et al. 2015; Merdzhanova, Dobreva, and Panayotova 2017), except for *P. viridis* and *Mytilus galloprovincialis* collected from Kozhikode (Chakraborty et al. 2011) and Mar Grande of Taranto (Prato et al. 2010), respectively, in which SFA > PUFA > MUFA. It is worth noting that in some marine mussels, SFA content was only higher than PUFA and MUFA in winter. For example, in spring, summer and autumn, PUFA was the dominant fatty acid group in *Modiolus barbatus*, *My. galloprovincialis* and *P. canaliculus* collected from Gulf of Taranto (Biandolino et al. 2019), Mali Ston Bay (Ezgeta-Balić et al. 2012) and Stewart Island (Taylor and Savage 2006), respectively. However, the content of SFA increased drastically in winter and become the dominant fatty acid group.

The PUFA content of most marine mussels was >40.0%, except for *P. viridis* and *My. galloprovincialis* collected from Kozhikode (Chakraborty et al. 2011) and Mar Grande of Taranto (Prato et al. 2010), respectively and some *Modiolus barbatus* (Biandolino et al. 2019), *My. galloprovincialis* (Ezgeta-Balić et al. 2012) and *P. canaliculus* (Taylor and Savage 2006) collected in winter. The highest PUFA content (60.9 ± 18.5%) was documented in *Modiolus barbatus* (Ezgeta-Balić et al. 2012; Biandolino et al. 2019), which was significantly higher than that of other marine mussel species (ranging from 39.4 ± 9.2% to 46.5 ± 11.4%).

The highest EPA + DHA content was recorded in *Modiolus barbatus* (38.3 ± 14.5%) and *P. canaliculus* (38.6 ± 11.4%) collected from Mali Ston Bay (Ezgeta-Balić et al. 2012) and Stewart Island (Taylor and Savage 2006), respectively, which were significantly higher than that of other marine mussel species (ranged between 27.0 ± 6.9% and 28.2 ± 12.5%) (Ahn et al. 2000; Lin et al. 2003; Xu and Yang 2007; Alkanani et al. 2007; Prato et al. 2010; Chakraborty et al. 2011; Ezgeta-Balić et al. 2012; Dernekbaşı et al. 2015; Merdzhanova, Dobreva, and Panayotova 2017; Biandolino et al. 2019).

Most marine mussels have n-3/n-6 PUFA ratios greater than 1.00, except for *My galloprovincialis* collected from Mar Grande of Taranto (Prato et al. 2010). The highest n-3/n-6 PUFA ratio was recorded in farmed *P. canaliculus* (12.55 to 18.75) collected from the Marlborough Sounds (Mclean and Bulling 2005), followed by farmed *My edulis* (10.66 to 11.69) collected from the Marlborough Sounds (Mclean and

Bulling 2005), and farmed *Modiolus barbatus* (9.31) collected from the Mali Ston Bay (Ezgeta-Balić et al. 2012). The lowest n-3/n-6 LC-PUFA in marine mussel was recorded in *My galloprovincialis* (2.84 ± 2.07), which was significantly lower ($P < 0.05$) than that of other marine mussels (5.19 to 7.27).

The PUFA/SFA index of most marine mussels is greater than 1.00, except for *My. galloprovincialis* from Mar Grande of Taranto (Prato et al. 2010), *P. viridis* from Kozhikode (Chakraborty et al. 2011) and Cochin (Chakraborty et al. 2016), *Laternula elliptica* from King George Island (Ahn et al. 2000), *My. edulis* from Qingdao, China (Lin et al. 2003) and *P. canaliculus* from Stewart Island (Taylor and Savage 2006) as well as *Modiolus barbatus* and *My galloprovincialis* collected from Marlborough Sounds (Mclean and Bulling 2005), Mali Ston Bay (Ezgeta-Balić et al. 2012) and Gulf of Taranto (Biandolino et al. 2019) only in winter. Among them, only the PUFA/SFA (0.17 to 0.23) of *My galloprovincialis* collected from Mar Grande of Taranto was lower than the recommended value of 0.45.

Fatty acid profiles in marine clams

Marine clams are characterized with low lipid content, most of which report that the lipid content of marine clams is less than 2.00% ww, except for *Limaria tuberculata* (2.76% ww), *Astarte sulcata* (4.70% ww) and *Ruditapes decussatus* (2.31% ww) collected from Gulf of Taranto in winter (Biandolino et al. 2019), Møre and Romsdal in autumn and Lagunas de Baldaio in spring (Ojea et al. 2004), respectively. The was no significant ($P > 0.05$) difference in the average lipid content among marine clams (Table 3).

The fatty acid composition of most commercially important marine clams is dominated by PUFA, except for those clams collected from Gulf of Taranto in winter (Biandolino et al. 2019), Gulf of Tunisia in autumn (Chetoui et al. 2019), Caldeira de Tróia in summer, autumn and winter (Baptista et al. 2014), Lagunas de Baldaio in summer (Ojea et al. 2004), Marian Cove in winter (Ahn et al. 2000) and Gulf of Gdansk (Wenne and Polak 1989), in which SFA is dominant.

The PUFA content in *Arca noae* and *Ensis siliqua* was significantly higher ($59.6 \pm 14.7\%$) (Dupcoc Radic et al., 2014; Ezgeta-Balić et al. 2012) and lower ($21.1 \pm 14.5\%$) (Baptista et al. 2014), respectively, than those in other marine clams ($41.9 \pm 6.7\%$ to $45.1 \pm 13.5\%$) (Misra et al. 1985; Wenne and Polak 1989; Canuel et al. 1995; Ahn et al. 2000; Kawashima and Ohnishi 2003; Ojea et al. 2004; Orban et al. 2007; Biandolino et al. 2019; Chetoui et al. 2019). The highest EPA + DHA content (51.3%) and lowest EPA + DHA content (12.1%) of marine clam were recorded in *Arca noae* collected from Mali Ston Bay in winter (Ezgeta-Balić et al. 2012) and *Solen marginatus* collected from Gulf of Taranto in winter (Biandolino et al. 2019), respectively. The EPA + DHA content of *Arca noae* ($32.4 \pm 10.3\%$) (Ezgeta-Balić et al. 2012; Dupcoc Radic et al., 2014) and *Chamelea gallina* ($32.5 \pm 3.4\%$) (Orban et al. 2007) was significantly higher than that of *Mactra stultirum* ($18.5 \pm 5.3\%$) (Chetoui et al. 2019).

The n-3/n-6 LC-PUFA ratios of commercially important clams were all higher than 1.00, with the highest (10.80) and the lowest (1.96) n-3/n-6 LC-PUFA ratios recorded in *Chamelea gallina* collected from Rimini (Emilia-Romagna) and Pesaro (Marche) in winter (Orban et al. 2007), and *Macoma balthica* collected from Gulf of Gdansk in spring (Wenne and Polak 1989), respectively. It is worth noting that the n-3/n-6 LC-PUFA ratio of *Chamelea gallina* (7.54 ± 2.49) was significantly higher than that of other commercially important clams, ranging from 2.70 ± 0.58 and 5.20 ± 1.38.

The PUFA/SFA indexes of the commercially important clams were all higher than the recommended value of >0.45, except for *Ensis siliqua* collected from Caldeira de Tróia in summer (Baptista et al. 2014). The PUFA/SFA index of *Arca noae* (3.25 ± 2.71) and *Ensis siliqua* (0.64 ± 0.33) were the highest and the lowest, respectively, which were significantly higher and lower than those of other marine clam species (1.33 ± 0.59 to 1.59 ± 0.88).

Fatty acid profiles in marine scallops

The lipid content of scallops is relatively low, less than 1.50%, except for *Mimachlamys varia* (2.26%) and *Flexopecten glaber* (2.82%) collected from Gulf of Taranto in winter (Biandolino et al. 2019) and Bizerte lagoon in spring (Telahigue et al. 2013), respectively. The fatty acid composition of commercially important scallops is species dependent. Among them *Pecten maximus*, *Placopecten magellanicus* (Manthey-Karl et al. 2015), *Chlamys farreri* (Xu and Yang 2007) and *Chlamys nobilis* have lipid composition of PUFA > SFA > MUFA, while that the fatty acid composition of *Mimachlamys varia* (Biandolino et al. 2019) and *Flexopecten glaber* (Telahigue et al. 2013; Biandolino et al. 2019; Prato et al. 2019) was dominated by SFA (Table 4).

The highest ($51.1 \pm 3.1\%$) and the lowest ($26.9 \pm 9.1\%$) PUFA composition of commercially important scallop species was recorded in *Pecten maximus* (Manthey-Karl et al. 2015) and *Flexopecten glaber* (Telahigue et al. 2013; Prato et al. 2019; Biandolino et al. 2019), respectively, which was significantly higher and lower than that of other scallops species ($42.7 \pm 4.1\%$ and $45.0 \pm 2.1\%$) (Telahigue et al. 2013; Biandolino et al. 2019; Prato et al. 2019). The EPA + DHA content (34.4 to 46.2%) of *Pecten maximus*, *Placopecten magellanicus* and *Chlamys nobilis* was remarkably higher than of other scallops (8.0 to 22.6%). It is worth noting that *Pecten maximus* has the highest EPA + DHA content ($43.7 \pm 2.7\%$) (Manthey-Karl et al. 2015), while the lowest EPA + DHA content was observed in *Flexopecten glaber* ($14.04 \pm 6.24\%$) (Prato et al. 2019; Biandolino et al. 2019).

The n-3/n-6 PUFA ratio of all commercially important scallops were higher than 3.00. Among them, the *Pecten maximus* has the highest n-3/n-6 PUFA ratio of 12.27 ± 2.54 (Manthey-Karl et al. 2015), which was significantly higher than that of other scallops, including *Chlamys nobilis* (5.71 ± 0.11), *Chlamys farreri* (5.71 ± 0.08), and *Flexopecten*

Table 1. Lipid nutritional quality of seafood.

	Common name	Species	Lipid (% WW)	EPA + DHA (mg/ 100 g flesh)	n-3/n-6	PUFA /SFA	Amount of flesh (g) to supply 500 mg EPA + DHA	References
Marine mussels	Mediterranean mussel	*My. galloprovincialis*	2.18 ± 0.45	662.80 ± 194.20	2.84 ± 2.10	1.39 ± 0.80	75.44	Freites, Fernández-Reiriz, and Labarta (2002); Xu and Yang (2007); Prato et al. (2010); Ezgeta-Balić et al. (2012); Dernekbaşı et al. (2015); Merdzhanova, Dobreva, and Georgieva (2016, Merdzhanova, Dobreva, and Panayotova 2017); Biandolino et al. (2019)
	Blue mussel	*My. edulis*	1.32 ± 0.33	398.50 ± 206.90	6.59 ± 3.69	1.57 ± 0.65	125.48	Lin et al. (2003); Mclean and Bulling (2005); Alkanani et al. (2007); Redmond et al. (2010); Ruano, Ramos, and Quaresma (2012)
	Green mussel	*P. viridis*	1.92 ± 0.39	392.50 ± 70.10	4.25 ± 0.73	0.90 ± 0.24	127.38	Chakraborty et al. (2011, 2016)
	Green shell mussel	*P. canaliculus*	0.80 ± 0.56	292.30 ± 153.70	12.68 ± 4.32	1.64 ± 0.40	171.06	Mclean and Bulling (2005); Taylor and Savage (2006)
	Horse mussel	*Modiolus barbatus*	2.98	491.1	6.5	3.0	101.8	Biandolino et al. (2019)
Marine clams	Tellin clam	*Megangulus* spp.	0.55 ± 0.07	190.4 ± 38.0	6.62 ± 2.19	1.70 ± 0.05	262.6	Kawashima and Ohnishi (2003)
	Bent-nosed clam	*Macoma sp*	1.15 ± 0.92	204.60 ± 59.50	2.36 ± 0.57	2.41 ± 1.75	244.38	Misra et al. (1985); Wenne and Polak (1989)
	Sakhalin surf clam	*Spisula sachalinensis*	1.00	300.00	4.82 ± 1.07	2.18 ± 0.64	166.66	Tabakaeva and Tabakaev (2017)
	Noah's ark	*Arca noae*	1.18	170.00	3.95 ± 0.48	2.67 ± 0.95	294.12	Ezgeta-Balić et al. (2012); Dupcoc Radic et al. (2014); Biandolino et al. (2019)
	Striped venus clam	*Chamelea gallina*	1.17 ± 0.39	386.10 ± 141.40	7.54± 2.49	1.35± 0.19	129.54	Orban et al. (2007)
	Palourde clam	*Ruditapes decussatus*	1.76 ± 0.48	430.70 ± 146.80	5.20 ± 1.38	1.49 ± 0.55	116.1	Ojea et al. (2004)
Marine scallops	Smooth scallop	*Flexopecten glaber*	1.31 ± 0.76	162.60 ± 64.90	3.75 ± 1.26	0.56 ± 0.25	307.5	Telahigue et al. (2013); Prato et al. (2019); Biandolino et al. (2019)
	King scallop	*Pecten maximus*	0.97 ± 0.15	425.00 ± 91.30	12.27 ± 2.54	1.73 ± 0.14	117.7	Manthey-Karl et al. (2015)
	Variegated scallop	*Mimachlamys varia*	2.3	510.1	6.7	0.9	98	Biandolino et al. (2019)
	Atlantic deep-sea scallop	*Placopecten magellanicus*	0.6	182	18.2	1.7	274.7252	Manthey-Karl et al. (2015)
	Nan'ao golden scallop	*Chlamys nobilis (Golden)*	2	578	5.8	1.1	86.5052	Tan et al. (2020)
	Noble scallop	*Chlamys nobilis (brown)*	1.92	563	5.6	0.9	88.80994	Tan et al. (2020)
Marine oysters	Pean flat oyster	*Ostrea spp.*	1.97 ± 1.03	311.30 ± 195.90	3.86 ± 2.06	0.64 ± 0.06	160.62	Aziz et al. (2013); Biandolino et al. (2019)
	Rock oyster	*Saccostrea cucullata*	1.03 ± 0.60	168.60 ± 101.80	7.18 ± 1.96	0.78 ± 0.57	296.56	Mclean and Bulling (2005)
	Pacific oyster	*C. gigas*	1.10 ± 0.27	390.0 ± 105.3	5.50 ± 2.40	1.62 ± 0.71	128.2	Dridi, Salah Romdhane, and Elcafsi (2007); Zhu et al. (2018)

(*continued*)

Table 1. Continued.

	Common name	Species	Lipid (% WW)	EPA + DHA (mg/ 100 g flesh)	n-3/n-6	PUFA /SFA	Amount of flesh (g) to supply 500 mg EPA + DHA	References
	Indian oyster	*Crassostrea madrasensis*	3.25	1132.7	4.66	1.39	44.14	Asha et al. (2014)
Marine cockles	Malaysian cockle	*Tegillarca granosa*	1.87 ± 0.40	466.00 ± 101.50	4.40 ± 0.62	1.93 ± 0.32	107.3	Nguyen et al. (2017)
	Japanese cockle	*Fulvia mutica*	2.45 ± 0.64	1298.70 ± 319.10	19.18± 4.88	1.89 ± 0.02	40.84	Liu, Li, and Kong (2013)
	Blood cockle	*Anadara granosa*	1.93	545.3	3.8	1	91.7	Aziz et al. (2013)
Freshwater mussels	Zebra mussel	*Dreissena polymorpha*	1.00 ± 0.77	214.60 ± 195.70	2.13 ± 1.30	1.62 ± 0.57	233	Makhutova et al. (2011); Lazzara et al. (2012)
	River mussel	*Unio spp.*	0.61 ± 0.49	93.80 ± 94.40	1.28 ± 0.37	1.28 ± 0.18	533.04	Ersoy and Sereflisan (2010); Şereflişan and Altun (2018)
	Freshwater mussel	*Anodonta pseudodopsis*	0.77	112.8	1.11	1.13	443.26	Şereflişan and Altun (2018)
	Black river mussel	*Potamida littoralis*	0.11	11	1.4	1.07	4545.46	Ersoy and Sereflisan (2010)
Medium fat fish	Yellowtail amberjack	*Seriola lalandi*	4.59 ± 0.30	915.80	12.50	0.92	54.6	Rincón-Cervera et al. (2020)
	Mackerel	*Scomber japonicus*	6.44 ± 0.21	1370.70	7.14	0.92	36.4	Rincón-Cervera et al. (2020)
	Moonfish	*Trachinotus blochii*	6.89 ± 2.76	299.30	1.90	1.00	167.06	Aziz et al. (2013)
	Longtail shad	*Hilsa macrura*	23.15 ± 0.00	2210.50	0.80	0.40	22.62	Aziz et al. (2013)
	gilthead sea bream	*Sparus aurata*	4.33 ± 0.20	820.02	1.39	1.58	60.98	Nogueira, Cordeiro, and Aveiro (2013)
Low fat fish	Jack mackerel	*Trachurus murphyi*	3.77 ± 0.22	786.90	10.00	0.95	63.6	Rincón-Cervera et al. (2020)
	Chilean sandperch	*Pinguipes chilensis*	2.72 ± 0.11	507.60	5.88	0.8	98.6	Rincón-Cervera et al. (2020)
	Lesser amberjack	*Seriola fasciata*	2.58 ± 0.15	809.60	12.47	1.15	61.75859	Nogueira, Cordeiro, and Aveiro (2013)
	white sea bream	*Diplodus sargus*	3.82 ± 0.32	717.59	4.58	0.81	69.67796	Nogueira, Cordeiro, and Aveiro (2013)
	Atlantic chub mackerel	*Scomber colias*	3.17 ± 0.18	1132.96	10.18	1.47	44.13226	Nogueira, Cordeiro, and Aveiro (2013)
	Black pomfret	*Parastromateus niger*	2.33 ± 0.11	350.60	6.80	0.8	142.6127	Aziz et al. (2013)
	Silver pomfret	*Pampus argentus*	2.09 ± 0.93	264.30	2.50	0.7	189.179	Aziz et al. (2013)
	Sixbar grouper	*Epinephelus fasciatus*	3.46	298.60	3.70	0.9	167.4481	Aziz et al. (2013)
	Japanese threadfin bream	*Nemipterus japonicus*	2.70 ± 0.37	551.70	5.00	0.7	90.62897	Aziz et al. (2013)
	Yellowstripe scad	*Selaroides leptolepis*	2.12 ± 0.50	879.15	6.40	1.7	56.87312	Aziz et al. (2013)
	Gray eel-catfish	*Plotosus spp*	3.04 ± 0.59	234.60	1.10	0.6	213.1287	Aziz et al. (2013)
	Fourfinger threadfin	*Eleutheronema tetradactylum*	2.10 ± 0.25	149.30	1.30	0.5	334.8962	Aziz et al. (2013)
	Giant seaperch	*Lates calcarifer*	2.68 ± 0.79	234.90	2.90	0.7	212.8565	Aziz et al. (2013)
	Fringescale sardinella	*Clupea fimbriata*	3.00 ± 2.40	436.90	2.70	0.6	114.4427	Aziz et al. (2013)
Lean fish	Palm ruf	*Seriolella violacea*	1.71± 0.07	304.00	4.55	0.95	164.4	Rincón-Cervera et al. (2020)
	Red cusk-eel	*Genypterus chilensis*	0.69 ± 0.06	115.20	9.09	1.60	434.2	Rincón-Cervera et al. (2020)
	Croaker	*Cilus gilberti*	1.44 ± 0.05	294.60	11.11	1.15	169.8	Rincón-Cervera et al. (2020)
	Chilean hake	*Merluccius gayi gayi*	1.29 ± 0.08	309.40	11.11	1.52	161.6	Rincón-Cervera et al. (2020)
	Black scabbard	*Aphanopus carbo*	0.79 ± 0.11	239.40	41.81	1.34	208.86	Nogueira, Cordeiro, and Aveiro (2013)
	Fork-beard	*Phycis phycis*	0.81 ± 0.08	375.82	23.75	1.69	133.04	Nogueira, Cordeiro, and Aveiro (2013)
	Red scorpion fish	*Scorpaena scrofa*	0.76 ± 0.04	316.62	13.18	1.49	157.92	Nogueira, Cordeiro, and Aveiro (2013)
	Offshore rockfish	*Pontinus kuhlii*	0.88 ± 0.05	369.17	15.12	1.63	135.44	Nogueira, Cordeiro, and Aveiro (2013)
	Bluefish	*Pomatomus saltatrix*	1.12 ± 0.02	482.40	17.43	1.54	103.64	Nogueira, Cordeiro, and Aveiro (2013)
	Black tail comber	*Serranus atricauda*	1.07 ± 0.07	396.17	14.52	1.32	126.2	Nogueira, Cordeiro, and Aveiro (2013)

(*continued*)

Table 1. Continued.

	Common name	Species	Lipid (% WW)	EPA + DHA (mg/100 g flesh)	n-3/n-6	PUFA /SFA	Amount of flesh (g) to supply 500 mg EPA + DHA	References
	Pink dentex	*Dentex gibbosus*	0.74 ± 0.06	348.44	13.12	1.73	143.5	Nogueira, Cordeiro, and Aveiro (2013)
	Red porgy	*Pagrus pagrus*	0.73 ± 0.10	348.20	21.94	1.89	143.6	Nogueira, Cordeiro, and Aveiro (2013)
	Blue jack mackerel	*Trachurus picturatus*	1.87 ± 0.04	608.87	11.89	1.20	82.12	Nogueira, Cordeiro, and Aveiro (2013)
	White trevally	*Pseudocaranx dentex*	1.00 ± 0.04	341.85	10.06	1.44	146.26	Nogueira, Cordeiro, and Aveiro (2013)
	Hardtail scad	*Megalapsis cordyla*	1.53 ± 0.15	214.90	6.10	0.50	232.66	Aziz et al. (2013)
	Golden snapper	*Lutjanu sjohnii*	1.29 ± 0.41	25.90	3.40	1.20	1930.5	Aziz et al. (2013)
	Indian mackerel	*Rastrelliger kanagurta*	1.80 ± 0.62	76.90	2.60	0.30	650.2	Aziz et al. (2013)
	Indian threadfin	*Polynemus indicus*	0.85 ± 0.21	105.90	9.80	1.40	472.14	Aziz et al. (2013)
	Malabar red snapper	*Lutjanus argenti -meculatus*	1.37 ± 1.10	234.00	3.90	1.30	213.68	Aziz et al. (2013)
	Dorab woltherring	*Chirocentrus dorab*	1.22 ± 0.22	78.20	6.90	0.60	639.38	Aziz et al. (2013)
	Long-tailed butterfly ray	*Gymnura spp*	0.93 ± 0.12	11.70	13.30	1.30	4273.5	Aziz et al. (2013)
	Large-scale tongue sole	*Cynoglossusarel*	0.70 ± 0.10	121.70	7.80	1.10	410.84	Aziz et al. (2013)
	Spanish mackerel	*Scromberomorus guttatus*	1.05 ± 0.06	97.50	7.30	1.00	512.82	Aziz et al. (2013)
Crustacean	Red squat lobster	*Pleuroncodes monodon*	1.23 ± 0.08	189.80	7.70	1.68	263.4	Rincón-Cervera et al. (2020)
	Yellow squat lobster	*Cervimunida johni*	1.32 ± 0.07	162.90	5.88	1.81	307	Rincón-Cervera et al. (2020)
	Deep water shrimp	*Heterocarpus reedi*	1.35 ± 0.06	187.00	10.00	1.47	267.4	Rincón-Cervera et al. (2020)
	Stone crab	*Cancer edwardsi*	1.20 ± 0.16	205.60	10.00	2.10	243.2	Rincón-Cervera et al. (2020)
	Prawn	*Metapenaeus affinis*	1.06 ± 0.10	94.00	8.70	1.50	531.92	Aziz et al. (2013)
Echinoderm	Sea urchin	*Loxechinus albus*	7.23 ± 0.41	208.60	1.14	0.20	239.8	Rincón-Cervera et al. (2020)
Cephalopod	Sea squirt	*Pyura chilensis*	2.96 ± 0.25	522.70	9.09	1.31	95.6	Rincón-Cervera et al. (2020)
	Cuttlefish	*Sepia officinalis*	1.35 ± 0.28	206.90	15.30	0.90	241.66	Aziz et al. (2013)
Gastropod	Chilean abalone	*Concholepas concholepas*	0.87 ± 0.04	63.60	7.69	1.16	786	Rincón-Cervera et al. (2020)

glaber (3.75 ± 1.25) (Xu and Yang 2007; Telahigue et al. 2013; Manthey-Karl et al. 2015; Prato et al. 2019; Biandolino et al. 2019).

The PUFA/SFA index of most marine scallops was >0.45, except for *Flexopecten glaber* collected from Gulf of Taranto (Prato et al. 2019) and Bizerte lagoon (Telahigue et al. 2013) in autumn and spring, respectively. The PUFA/SFA index of *Pecten maximus* (1.73 ± 0.14) (Manthey-Karl et al. 2015) and *Flexopecten glaber* (0.56 ± 0.25) was significantly higher and lower, respectively than other scallops (ranging from 1.01 ± 0.10 to 1.19 ± 0.32) (Prato et al. 2019; Biandolino et al. 2019).

Fatty acid profiles in marine oysters

Commercially important marine oysters usually have a lipid content of less than 3.00% ww, with the exception of *Crassostrea madrasensis* collected from Moothakunnam (Asha et al. 2014) (Table 5). The fatty acid composition of the most commercially important marine oysters was dominated by PUFA, followed by SFA and MUFA, except for *C. hongkongensis* collected from Beihai, China, which showed SFA > PUFA > MUFA (Qin et al. 2018).

The PUFA content of most commercially important marine oysters was > 40.0%, except for *Ostrea edulis* and *C. hongkongensis* with PUFA content ranging from 31.6 to 39.6% (Qin et al. 2018; Biandolino et al. 2019). It is worth noting that the PUFA content of *C. hongkongensis* (35.3 ± 4.0) was the lowest, which was significantly lower than that of other oyster species (48.6 ± 8.0 to 51.5 ± 15.4).

Most commercially important marine oyster species are rich in EPA + DHA (>30.0%), with the exception of *C. hongkongensis*, which has an EPA + DHA value of 24.6 ± 3.3% (Qin et al. 2018). The n-3/n-6 LC-PUFA ratios of all commercially important oyster species are high (4.50 ± 0.54 to 5.98 ± 3.55), and there was no statistical difference in n-3/n-6 LC-PUFA ratios among different oyster species. The PUFA/SFA index of all commercially important oysters was higher than 0.6, and the highest PUFA/SFA index of 3.86 was recorded in *O. edulis* collected from Mali Ston Bay in

Table 2. Lipid nutritional quality of marine mussels.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild *Modiolus barbatus*	2.98 ± 0.20	–	43.7 ± 1.3	23.7 ± 01	32.6 ± 1.3	9.3 ± 0.2	7.2 ± 0.0	16.5	4.9	2.99 ± 0.14	0.75 ± 0.07	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *My. galloprovincialis*	2.15 ± 0.30	–	44.4 ± 1.1	18.0 ± 0.2	37.6 ± 1.3	11.7 ± 1.1	10.6 ± 2.1	22.3	4.8	7.36 ± 0.28	0.85 ± 0.07	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *My. galloprovincialis*	2.89 ± 0.10	–	28.1 ± 0.6	17.4 ± 0.3	54.5 ± 2.2	6.9 ± 0.2	30.4 ± 1.8	37.3	10.8	2.78 ± 0.02	1.94 ± 0.12	Kavarna	43.43	Spring	Merdzhanova, Dobreva, and Panayotova (2017)
Wild *My. galloprovincialis*	1.40 ± 0.08	–	25.6 ± 0.3	17.9 ± 0.2	56.5 ± 2.1	9.8 ± 0.2	27.3 ± 0.5	37.1	5.2	1.42 ± 0.01	2.21 ± 0.18	Kavarna	43.43	Summer	Merdzhanova, Dobreva, and Panayotova (2017)
Wild *My. galloprovincialis*	2.51 ± 0.12	–	31.0 ± 0.9	16.0 ± 0.2	53.0 ± 2.1	7.7 ± 0.9	26.0 ± 0.9	33.7	8.5	1.50 ± 0.02	1.71 ± 0.10	Kavarna	43.43	Autumn	Merdzhanova, Dobreva, and Panayotova (2017)
Wild *My. galloprovincialis*	2.32 ± 0.05	–	33.2 ± 1.9	13.2 ± 0.9	53.6 ± 2.8	4.7 ± 0.4	27.4 ± 1.6	32.1	7.4	1.61 ± 0.09	1.61 ± 0.07	Kavarna	43.43	Autumn	Merdzhanova, Dobreva, and Georgieva (2016)
Wild *My. galloprovincialis*	2.51 ± 0.06	–	31.3 ± 1.7	16.3 ± 1.0	52.5 ± 1.7	5.1 ± 0.5	26.4 ± 1.7	31.5	7.9	1.78 ± 0.15	1.68 ± 0.10	Kranevo	43.43	Autumn	Merdzhanova, Dobreva, and Georgieva (2016)
Wild *My. galloprovincialis*	1.85 ± 0.03	–	32.1 ± 2.0	13.0 ± 0.9	54.9 ± 2.1	7.1 ± 0.7	26.6 ± 1.6	33.7	6.2	1.90 ± 0.15	1.71 ± 0.12	Primorsko	42.27	Autumn	Merdzhanova, Dobreva, and Georgieva (2016)
Wild *P. viridis*	1.47 ± 0.10	–	39.6±	21.6±	25.4±	8.0±	9.6±	17.6	2.6	3.81	0.64	Cochin	9.97	–	Chakraborty et al. (2016)
Farmed *P. viridis*	2.63 ± 0.19	–	39.7±	17.9±	24.0±	7.4±	9.0±	16.4	4.3	4.20	0.61	Cochin	9.97	–	Chakraborty et al. (2016)
Wild *P. viridis*	2.00 ± 0.13	–	34.2±	24.0±	31.1±	12.7±	9.6±	22.3	4.5	5.30	0.91	Kozhikode	11.92	–	Chakraborty et al. (2016)
Cultured *P. viridis*	1.70 ± 0.16	–	29.6±	23.6±	34.6±	12.8±	9.9±	22.7	3.9	3.70	1.17	Kozhikode	11.92	–	Chakraborty et al. (2016)
Farmed *My. galloprovincialis*	2.30	–	28.5 ± 2.1	19.8 ± 1.0	50.7 ± 0.6	8.0 ± 0.3	14.4 ± 1.1	22.4	5.1	1.44 ± 0.03	1.78	Southern parts of the Black Sea coast	42.025	Autumn	Dernekbaşı et al. (2015)
Farmed *My. galloprovincialis*	2.40	–	27.1 ± 0.8	15.1 ± 1.2	55.6 ± 1.7	13.4 ± 3.3	16.2 ± 1.8	29.6	7.1	2.23 ± 0.19	2.05	Southern parts of the Black Sea coast	42.025	Winter	Dernekbaşı et al. (2015)
Farmed *My. galloprovincialis*	1.50	–	25.7 ± 0.8	17.5 ± 1.1	55.8 ± 1.3	12.8 ± 0.7	15.3 ± 1.0	28.1	4.2	1.99 ± 0.03	2.17	Southern parts of the Black Sea coast	42.025	Spring	Dernekbaşı et al. (2015)
Farmed *My. galloprovincialis*	2.10	–	29.2 ± 1.0	16.9 ± 0.6	53.0 ± 0.8	8.3 ± 0.3	18.6 ± 0.3	26.8	5.6	1.91 ± 0.02	1.81	southern parts of the Black Sea coast	42.025	Summer	Dernekbaşı et al. (2015)
Wild *My. edulis*	–	–	26.7±	19.5±	47.1±	15.7±	11.9±	27.5±	–	6.49	1.77	Albufeira coastal lagoon	37.09	Spring	Ruono et al. (2012)
	–	–	22.4 ± 0.8	11.8 ± 1.0	65.6 ± 1.8	18.1 ± 2.5	20.8 ± 2.9	38.9	–	7.82	2.93	Mali Ston Bay	42.87	Spring	

(*continued*)

Table 2. Continued.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Farmed *My. galloprovincialis*															Ezgeta-Balić et al. (2012)
Farmed *My. galloprovincialis*	–	–	39.9 ± 10.2	12.3 ± 2.5	47.6 ± 12.2	14.7 ± 2.8	15.0 ± 5.5	29.7	–	6.39	1.19	Mali Ston Bay	42.87	Summer	Ezgeta-Balić et al. (2012)
Farmed *My. galloprovincialis*	–	–	32.9 ± 3.4	17.4 ± 4.5	49.4 ± 7.1	19.8 ± 2.0	13.8 ± 8.2	33.6	–	5.3	1.50	Mali Ston Bay	42.87	Autum	Ezgeta-Balić et al. (2012)
Farmed *My. galloprovincialis*	–	–	51.4 ± 1.8	19.5 ± 2.4	28.9 ± 0.3	7.1 ± 0.4	11.7 ± 0.3	18.8	–	2.42	0.56	Mali Ston Bay	42.87	Winter	Ezgeta-Balić et al. (2012)
Farmed *Modiolus barbatus*	–	–	11.3 ± 1.3	14.4 ± 0.8	72.6 ± 1.7	23.6 ± 0.5	25.0 ± 0.8	48.5	–	9.31	6.40	Mali Ston Bay	42.87	Spring	Ezgeta-Balić et al. (2012)
Farmed *Modiolus barbatus*	–	–	24.2 ± 1.4	14.8 ± 0.7	59.5 ± 2.0	20.4 ± 1.0	18.2 ± 1.7	38.6	–	8.73	2.46	Mali Ston Bay	42.87	Summer	Ezgeta-Balić et al. (2012)
Farmed *Modiolus barbatus*	–	–	24.2 ± 2.8	14.0 ± 1.2	58.5 ± 2.2	15.5 ± 0.3	18.5 ± 1.2	34.1	–	5.47	2.42	Mali Ston Bay	42.87	Autum	Ezgeta-Balić et al. (2012)
Farmed *Modiolus barbatus*	–	–	7.6 ± 2.8	10.3 ± 0.9	81.5 ± 3.3	22.4 ± 1.8	31.5 ± 4.2	53.8	–	5.86	10.70	Mali Ston Bay	42.87	Winter	Ezgeta-Balić et al. (2012)
Wild *P. viridis*	2.00 ± 0.13	–	30.3	27.3	35.0	12.8 ± 1.0	9.9 ± 1.0	22.7	4.5	–	1.16	Kozhikode	11.9	–	Chakraborty et al. (2011)
Farmed P. viridis	1.70 ± 0.16	–	34.4	27.3	31.5	12.7 ± 1.2	9.6 ± 0.1	22.3	3.8	–	0.92	Kozhikode	11.9	–	Chakraborty et al. (2011)
Farmed *My. edulis*	–	–	37.1 ± 4.1	17.4 ± 1.2	45.4 ± 8.8	16.2 ± 3.9	17.9 ± 2.1	34.1	–	5.51	1.22	Austevoll	60.07	Autumn	Redmond et al. (2010)
Farmed *My. galloprovincialis*	–	24.70 ± 2.10	53.7	35.8	10.5	0.2	1.7	1.9	–	1.14	0.20	Mar Grande of Taranto	40.47	Summer	Prato et al. (2010)
Farmed *My. galloprovincialis*	–	8.00 ± 1.32	57.2	35.3	7.6	0.2	1.2	1.4	–	0.70	0.17	Mar Grande of Taranto	40.47	Autumn	Prato et al. (2010)
Farmed *My. galloprovincialis*	–	3.50 ± 0.80	57.1	33.2	9.7	1.1	2.2	3.3	–	3.94	0.20	Mar Grande of Taranto	40.47	Winter	Prato et al. (2010)
Farmed *My. galloprovincialis*	–	12.50 ± 2.01	49.3	39.6	11.2	0.4	1.6	2.0	–	1.93	0.23	Mar Grande of Taranto	40.47	Spring	Prato et al. (2010)
Wild *My. galloprovincialis*	–	–	28.2 ± 0.6	27.7 ± 0.2	37.6 ± 0.1	9.4 ± 0.3	5.3 ± 0.2	14.7	–	2.06	1.33	Jiaozhou Bay	36.00	Spring	Xu and Yang (2007)
Farmed *My. edulis*	1.62	–	25.4 ± 1.8	14.5 ± 3.0	61.9 ± 3.0	12.0 ± 2.2	21.5 ± 2.9	33.5	5.4	8.82 ± 1.60	2.44	Notre Dame Bay	49.5	One year round	Alkanani et al. (2007)
Farmed *My. edulis*	1.62	–	23.6 ± 2.3	17.7 ± 4.1	60.8 ± 4.0	17.0 ± 3.5	20.0 ± 4.3	37.0	6.0	8.02 ± 1.81	2.57	Notre Dame Bay	49.5	One year round	Alkanani et al. (2007)
Farmed *P. canaliculus*	–	8.19 ± 0.04	55.7 ± 0.7	21.3 ± 0.1	23.0 ± 0.6	11.7 ± 0.9	11.7 ± 0.9	23.4	–	3.89	0.41	Stewart Island	47	Winter	Taylor and Savage (2006)
Farmed *P. canaliculus*	–	8.29 ± 0.02	33.5 ± 0.4	18.4 ± 0.2	48.1 ± 0.3	26.1 ± 0.1	26.1 ± 0.1	52.2	–	9.46	1.44	Stewart Island	47	Spring	Taylor and Savage (2006)
Farmed *P. canaliculus*	–	8.45 ± 0.07	39.0 ± 0.8	16.2 ± 0.4	44.8 ± 0.8	23.2 ± 0.5	23.2 ± 0.5	46.4	–	8.35	1.15	Stewart Island	47	Summer	Taylor and Savage (2006)
Farmed *P. canaliculus*	–	8.00 ± 0.05	35.2 ± 0.2	14.2 ± 0.3	50.7 ± 0.2	21.2 ± 0.4	17.8 ± 0.3	39.0	–	8.2	1.44	Marlborough Sounds	41.57	Spring	Taylor and Savage (2006)
Farmed *P. canaliculus*	–	8.22 ± 0.14	41.0 ± 0.9	12.6 ± 0.9	46.1 ± 0.8	15.2 ± 0.4	17.0 ± 0.3	32.2	–	6.44	1.12	Marlborough Sounds	41.57	Summer	Taylor and Savage (2006)
Farmed *P. canaliculus*	0.60 ± 0.00	–	33.9	16.7	49.4	21.6	16.2	37.8	2.3	12.71	1.45	Marlborough Sounds	41.57	Spring	Mclean and Bulling (2005)

(*continued*)

Table 2. Continued.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Farmed *P. canaliculus*	0.50 ± 0.00	–	31.6	16.1	52.3	22.5	19.0	41.5	2.1	18.75	1.66	Marlborough Sounds	41.57	Summer	Mclean and Bulling (2005)
Farmed *P. canaliculus*	0.60 ± 0.00	–	31.0	16.1	52.8	18.7	23.7	42.4	2.5	12.94	1.70	Marlborough Sounds	41.57	Autumn	Mclean and Bulling (2005)
Farmed *P. canaliculus*	0.50 ± 0.00	–	30.9	16.5	52.6	19.2	22.3	41.6	2.1	12.55	1.70	Marlborough Sounds	41.57	Winter	Mclean and Bulling (2005)
Farmed *My. edulis*	1.30 ± 0.30	–	30.8	14.9	54.3	23.9	19.0	42.9	5.6	12.479	1.76	Marlborough Sounds	41.57	Spring	Mclean and Bulling (2005)
Farmed *My. edulis*	1.80 ± 0.30	–	29.2	14.2	56.5	25.1	18.4	43.5	7.8	11.69	1.93	Marlborough Sounds	41.57	Summer	Mclean and Bulling (2005)
Farmed *My. edulis*	1.70 ± 0.30	–	56.3	22.3	21.4	3.6	4.5	8.0	1.4	1.18	0.38	Marlborough Sounds	41.57	Autumn	Mclean and Bulling (2005)
Farmed *My. edulis*	0.90 ± 0.30	–	32.6	16.1	51.3	16.1	22.0	38.1	3.4	10.68	1.57	Marlborough Sounds	41.57	Winter	Mclean and Bulling (2005)
Wild *My. edulis*	1.42	–	52.4	11.0	27.4	7.5	6.8	14.3	2.0	3.03	0.52	Qingdao	36.07	Summer	Lin et al. (2003)
Wild *My. edulis*	0.93	–	37.1	14.8	36.7	5.3	9.1	14.4	1.3	2.21	0.99	Qingdao	36.07	Autumn	Lin et al. (2003)
Wild *My. edulis*	1.1	–	29.2	9.6	47.3	15.2	18.3	33.5	3.7	3.2	1.62	Qingdao	36.07	Winter	Lin et al. (2003)
Wild *My. edulis*	0.98	–	29.3	23.8	45.0	16.1	13.2	29.3	2.9	4.27	1.53	Qingdao	36.07	Spring	Lin et al. (2003)
Megangulus venulosus	0.50	–	28.4	16.4	49.2	16.4	16.3	32.7	1.6	5.07	1.73	Hokkaido	43.22	Spring	Kawashima and Ohnishi (2003)
Megangulus zyonensis	0.60	–	29.7	17.5	49.5	22.3	13.9	36.2	2.2	8.17	1.67	Hokkaido	43.22	Spring	Kawashima and Ohnishi (2003)
Mytilus galloprovincialis	–	–	26.7	17.4	34.3	10.4	8.9	19.3	–	2.02	1.28	Arosa Ria	42.59	Winter	Feites et al. (2002)
Wild *P. canaliculus*	1.80 ± 0.40	–	27.7 ± 0.9	48.5 ± 0.6	47.1 ± 1.3	17.9	13.5	31.4	5.7	6.43	1.70	New Zealand	40.9	Spring	Murphy et al. (2002)
Wild *My. edulis*	1.23 ± 0.40	–	30.5 ± 1.6	12.1 ± 2.5	58.7 ± 5.2	14.6	21.2	35.8	4.3	6.90	1.92	Tasmania, Australia	41.45	Spring	Murphy et al. (2002)
Laternula elliptica	6.60	–	47.0	17.3	31.7	14.1	7.0	21.1	13.9	5.74	0.67	King George Island	62.22	Winter	Ahn et al. (2000)

Table 3. Lipid nutritional quality of marine clams.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild Venus antiqua	1.47 ± 0.12	–	40.8 ± 1.1	16.1 ± 0.8	43.1 ± 1.0	19.9 ± 0.7	12.8 ± 0.5	–	214.34	11.1	1.06	Coquimbo Region, Chile	29.96	Summer	Rincón-Cervera et al. (2020)
Wild Mesodesma donacium	1.94 ± 0.07	–	36.4 ± 1. 2	14.9 ± 0.3	48.7 ± 1.2	18.0 ± 0.6	20.3 ± 1.2	–	216.96	25	1.34	Coquimbo Region, Chile	29.96	Summer	Rincón-Cervera et al. (2020)
Wild *Solen marginatus*	1.25 ± 0.10	–	43.7 ± 1.6	26.6 ± 0.7	29.7 ± 2.3	6.1 ± 0.6	6.0 ± 0.7	12.1	1.5	2.86 ± 0.44	0.68 ± 0.11	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *Limaria tuberculata*	2.76 ± 0.40	–	43.6 ± 3.2	22.9 ± 0.6	33.5 ± 3.8	7.1 ± 0.8	10.9 ± 2.7	18.0	5.0	5.77 ± 0.21	0.77 ± 0.51	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *Arca noae*	1.18 ± 0.01	–	45.3 ± 3.3	24.4 ± 1.0	30.4 ± 4.3	8.5 ± 1.0	6.0 ± 1.7	14.4	1.7	4.22 ± 0.65	0.68 ± 0.13	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *Mactra stultorum*	–	3.30 ± 0.20	38.4 ± 6.2	18.7 ± 3.3	38.6 ± 8.4	4.0 ± 0.6	9.8 ± 1.2	13.8	–	2.43 ± 0.23	1.01 ± 0.10	Gulf of Tunisia	37	Summer	Chetoui et al. (2019)
Wild *Mactra stultorum*	–	3.35 ± 0.18	39.0 ± 7.4	22.9 ± 5.3	35.1 ± 6.8	5.0 ± 1.0	9.2 ± 1.4	14.3	–	2.04 ± 0.87	0.90 ± 0.24	Gulf of Tunisia	37	Autumn	Chetoui et al. (2019)
Wild *Mactra stultorum*	–	3.3 ± 0.17	23.1 ± 6.4	17.5 ± 3.4	50.7 ± 10.0	9.6 ± 2.5	15.1 ± 2.3	24.7	–	2.94 ± 0.35	2.19 ± 0.95	Gulf of Tunisia	37	Winter	Chetoui et al. (2019)
Wild *Mactra stultorum*	–	3.5 ± 0.20	35.0 ± 5.9	17.7 ± 5.3	43.1 ± 10.3	6.2 ± 1.3	14.8 ± 2.8	21.0	–	3.38 ± 0.58	1.23 ± 0.36	Gulf of Tunisia	37	Spring	Chetoui et al. (2019)
Wild *Sinonovacula constricta*	–	10.9	32.8 ± 0.6	19.3 ± 0.2	47.9 ± 0.2	14.1 ± 0.0	4.1 ± 0.0	18.2	–	11.80	1.46	Yellow Sea	38.91	Summer	Wu et al. (2019)
Wild *Solen gouldi*	–	7.95	29.5 ± 0.5	15.7 ± 0.1	54.8 ± 0.4	13.8 ± 0.0	5.1 ± 0.0	18.9	–	1.97	1.86	Yellow Sea	38.91	summer	Wu et al. (2019)
Wild *Mactra chinensis*	0.40	–	22.4 ± 1.0	21.3 ± 1.0	52.6 ± 2.4	15.0 ± 0.7	15.9 ± 0.7	30.9	1.2	3.19	2.35	Okhotsk Sea, Japan	52.87	summer	Tabakaeva and Tabakaev (2018)
Wild *Spisula sachalinensis*	1.00 ± 0.05	–	24.4 ± 1.1	21.4 ± 1.0	53.2 ± 2.6	12.4 ± 0.6	17.6 ± 0.9	30.0	3.0	4.82	2.18	Okunevaya and Lazurnaya Bays	60.23	summer	Tabakaeva and Tabakaev (2017)
Wild *Ensis siliqua*	–	8.80	37.6 ± 6.1	19.7 ± 2.8	42.8 ± 9.3	9.5 ± 1.8	10.5 ± 2.1	20.1	–	5.21 ± 0.25	1.14	Caldeira de Tróia	38.48	Spring	Baptista et al. (2014)
Wild *Ensis siliqua*	–	4.00	29.2 ± 2.8	18.5 ± 1.6	13.8 ± 2.5	7.4 ± 1.2	13.8 ± 0.7	21.2	–	3.50 ± 0.28	0.47	Caldeira de Tróia	38.48	Summer	Baptista et al. (2014)
Wild *Ensis siliqua*	–	3.50	30.0 ± 6.5	17.6 ± 2.9	13.5 ± 3.4	7.4 ± 1.3	13.5 ± 0.4	20.9	–	3.49 ± 0.03	0.45	Caldeira de Tróia	38.48	Autumn	Baptista et al. (2014)
Wild *Ensis siliqua*	–	4.20	28.1 ± 2.9	17.7 ± 0.8	14.3 ± 0.1	7.5 ± 0.1	14.3 ± 0.0	21.9	–	3.90 ± 0.13	0.51	Caldeira de Tróia	38.48	Winter	Baptista et al. (2014)
Wild *Arca noae*	–	5	21.2 ± 4.8	17.2 ± 1.9	58.6 ± 7.2	11.7 ± 2.1	18.3 ± 5.4	30.0	–	4.20 ± 0.80	2.76	Mali Ston Bay	42.87	Winter	Dupcoc Radic et al. (2014)
Wild *Arca noae*	–	5	21.4 ± 3.2	18.1 ± 1.7	56.4 ± 4.7	13.1 ± 1.5	16.1 ± 3.8	29.2	–	4.40 ± 0.80	2.64	Mali Ston Bay	42.87	Spring	Dupcoc Radic et al. (2014)
Wild *Arca noae*	–	4	24.4 ± 4.3	19.5 ± 1.7	55.1 ± 3.8	9.6 ± 1.5	18.0 ± 5.0	27.6	–	3.60 ± 0.70	2.26	Mali Ston Bay	42.87	Summer	Dupcoc Radic et al. (2014)
Wild *Arca noae*	–	4.5	26.8 ± 4.1	17.8 ± 1.3	54.4 ± 4.7	8.4 ± 1.4	18.7 ± 5.5	27.1	–	2.90 ± 0.50	2.03	Mali Ston Bay	42.87	Autumn	Dupcoc Radic et al. (2014)
Wild *Venerupis pullastra*	–	–	28.2	17.7	49.0	16.2	14.1	30.3	–	5.22	1.74	Tagus estuary	38.82	May	Ruono et al. (2012)
Farmed *Arca noae*	–	–	15.5 ± 0.7	11.0 ± 0.5	73.3 ± 0.8	11.6 ± 0.5	29.3 ± 0.6	40.9	–	4.3	4.72	Mali Ston Bay	42.87	Spring	Ezgeta-Balić et al. (2012)
Farmed *Arca noae*	–	–	26.8 ± 5.4	9.3 ± 0.4	63.8 ± 5.4	9.1 ± 0.6	27.5 ± 3.8	36.6	–	4.22	2.38	Mali Ston Bay	42.87	Summer	Ezgeta-Balić et al. (2012)

(*continued*)

Table 3. Continued.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Farmed *Arca noae*	–	–	31.2 ± 2.8	9.2 ± 1.9	59.7 ± 3.4	6.5 ± 0.5	27.8 ± 4.8	34.3	–	3.64	1.92	Mali Ston Bay	42.87	Autumn	Ezgeta-Balić et al. (2012)
Farmed *Arca noae*	–	–	8.5 ± 0.3	6.8 ± 0.9	84.4 ± 0.8	10.6 ± 0.4	40.7 ± 0.5	51.3	–	4.05	9.89	Mali Ston Bay	42.87	Winter	Ezgeta-Balić et al. (2012)
Wild *Astarte sulcata*	4.70 ± 0.90	–	33.5	13.5	52.9	8.8	24.1	32.9	15.5	4.26	1.58	Møre and Romsdal	62.67	October	
Wild *Chamelea gallina*	1.55 ± 0.10	–	32.1 ± 0.6	20.4 ± 0.2	42.5 ± 0.7	18.9 ± 1.0	14.0 ± 0.5	32.9	5.1	9.07 ± 0.03	1.32	Rimini (Emilia-Romagna) and Pesaro (Marche)	44	Spring	Orban et al. (2007)
Wild *Chamelea gallina*	0.73 ± 0.08	–	39.3 ± 0.6	14.2 ± 0.1	41.6 ± 0.7	8.2 ± 0.4	19.8 ± 0.1	28.0	2.0	4.28 ± 0.05	1.06	Rimini (Emilia-Romagna) and Pesaro (Marche)	44	Summer	Orban et al. (2007)
Wild *Chamelea gallina*	1.16 ± 0.04	–	31.1 ± 0.8	15.8 ± 0.8	48.1 ± 0.1	20.0 ± 1.5	17.6 ± 1.2	37.6	4.4	6.77 ± 0.01	1.55	Rimini (Emilia-Romagna) and Pesaro (Marche)	44	Autumn	Orban et al. (2007)
Wild *Chamelea gallina*	1.59 ± 0.25	–	29.1 ± 0.5	23.4 ± 0.7	42.6 ± 2.9	19.5 ± 0.9	12.6 ± 3.4	32.1	5.1	10.80 ± 0.04	1.46	Rimini (Emilia-Romagna) and Pesaro (Marche)	44	Winter	Orban et al. (2007)
Wild *Chamelea gallina*	0.84 ± 0.05	–	33.8 ± 0.0	14.9 ± 0.3	46.4 ± 0.3	11.8 ± 0.1	20.3 ± 0.0	32.1	2.7	6.78 ± 0.06	1.37	Rimini (Emilia-Romagna) and Pesaro (Marche)	44	Spring	Orban et al. (2007)
Wild *Ruditapes decussatus*	1.58	–	25.4	19.3	54.4	8.5	15.1	23.6	3.7	7.26	2.14	Lagunas de Baldaio	41.17	Autumn	Ojea et al. (2004)
Wild *Ruditapes decussatus*	1.19	–	29.8	24.7	43.9	10.5	17.5	28.0	3.3	4.46	1.48	Lagunas de Baldaio	41.17	Winter	Ojea et al. (2004)
Wild *Ruditapes decussatus*	2.31	–	27.6	28.6	42.6	12.4	15.8	28.1	6.5	4.44	1.54	Lagunas de Baldaio	41.17	Spring	Ojea et al. (2004)
Wild *Ruditapes decussatus*	1.96	–	37.4	31.4	29.5	8.1	10.6	18.7	3.7	4.64	0.79	Lagunas de Baldaio	41.17	Summer	Ojea et al. (2004)
Wild *Megangulus venulosus*	0.5	–	28.4	16.4	55.2	16.4	16.7	33.1	1.7	5.07	1.94	Hokkaido	43.22	Spring	Kawashima and Ohnishi (2003)
Wild *Megangulus zyonoensis*	0.6	–	29.7	17.5	52.8	22.3	13.9	36.2	2.2	8.17	1.78	Hokkaido	43.22	Spring	Kawashima and Ohnishi (2003)
Wild *Laternula elliptica*	–	6.6	47.0	17.3	31.7	14.1	7.0	21.1	–	5.74	0.67	Marian Cove	62.22	Winter	Ahn et al. (2000)
Wild *Potamocorbula amurensis*	–	3.40	24.5	29.1	46.4	8.5	14.6	23.1	–	2.13	1.89	San Francisco Bay	62.22	Winter	Canuel et al. (1995)
Wild *Macoma balthica*	1.80	–	22.0	50.7	25.8	11.5	2.2	13.7	2.5	1.96	1.17	Gulf of Gdansk	54.6	Spring	Wenne and Polak (1989)
Wild *Macoma sp*	0.50	–	18.4	14.5	67.1	17.6	14.9	32.5	1.6	2.76	3.65	Sagar island	21.5	–	Misra et al. (1985)

Table 4. Lipid nutritional quality of marine scallops.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild *Mimachlamys varia*	2.26 ± 0.60	–	40.8 ± 2.8	21.2 ± 1.3	37.9 ± 6.2	8.2 ± 1.0	14.4 ± 4.3	22.6	5.1	6.65 ± 1.44	0.93 ± 0.13	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Wild *Flexopecten glaber*	1.04 ± 0.30	–	50.5 ± 2.1	23.9 ± 4.0	25.6 ± 6.1	6.5 ± 2.0	6.3 ± 2.2	12.8	1.3	2.66 ± 0.06	0.51 ± 0.14	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Farmed *Flexopecten glaber*	0.82	–	60.8	24.8	14.4	4.6	3.4	8.0	0.7	2.70	0.24	Gulf of Taranto	40.43	Autumn	Prato et al. (2019)
Farmed *Flexopecten glaber*	0.84	–	46.9	19.9	33.2	9.4	7.8	17.2	1.4	4.73	0.71	Gulf of Taranto	40.43	Winter	Prato et al. (2019)
Farmed *Flexopecten glaber*	1.14	–	42.1	20.1	37.8	9.9	11.4	21.4	2.4	5.37	0.90	Gulf of Taranto	40.43	Spring	Prato et al. (2019)
Farmed *Flexopecten glaber*	1.18	–	47.0	21.1	31.9	8.3	10.8	19.1	2.3	4.49	0.68	Gulf of Taranto	40.43	Summer	Prato et al. (2019)
Wild *Pecten maximus*	1.1	–	28.5 ± 0.3	7.3 ± 0.3	53.9 ± 0.5	20.0 ± 0.8	26.2 ± 0.7	46.2	5.1	10.90 ± 0.38	1.89	Frøya and Hitra	63.97	Autumn	Manthey-Karl et al. (2015)
Wild *Pecten maximus*	1.00	–	30.7 ± 0.5	6.8 ± 0.4	51.6 ± 1.2	18.0 ± 0.9	25.9 ± 0.5	43.9	4.4	10.70 ± 0.62	1.68	Brittany and Normandy coast	49.37	Autumn	Manthey-Karl et al. (2015)
Wild *Pecten maximus*	0.80	–	29.3 ± 1.1	7.4 ± 0.4	47.8 ± 2.6	14.8 ± 1.0	26.1 ± 1.8	40.9	3.3	15.20 ± 2.52	1.63	Frozen	–	–	Manthey-Karl et al. (2015)
Wild *Placopecten magellanicus*	0.60	–	27.8 ± 1.2	9.4 ± 0.8	47.0 ± 1.1	20.3 ± 1.0	21.3 ± 1.8	41.6	2.5	18.20 ± 0.44	1.69	Frozen	–	–	Manthey-Karl et al. (2015)
Wild *Flexopecten glaber*	2.82 ± 0.09	–	59.7 ± 9.9	21.9 ± 3.1	18.4 ± 1.9	4.4 ± 0.8	1.4 ± 0.3	5.8	1.6	2.54	0.31	Bizerte lagoon	37.17	Spring	Telahigue et al. (2013)
Farmed *Chlamys farreri*	–	–	24.8 ± 1.4	31.5 ± 1.3	38.3 ± 0.4	14.4 ± 0.9	2.6 ± 0.2	17.0	–	5.73	1.55	Jiaozhou Bay	36.00	Spring	Xu and Yang (2007)
Farmed *Chlamys nobilis (Golden)*	–	0.50 ± 0.01	43.0 ± 1.3	10.5 ± 0.4	46.5 ± 1.4	14.6 ± 0.4	22.1 ± 1.3	36.7	–	5.78 ± 0.43	1.18	Nan'ao Island	23.35	–	Unpublish data
Farmed *Chlamys nobilis (brown)*	–	0.48 ± 0.01	46.6 ± 2.2	10.0 ± 0.4	43.4 ± 1.8	13.8 ± 0.3	20.6 ± 1.3	34.4	–	5.63 ± 0.11	0.99	Nan'ao Island	23.35	–	Unpublish data

Table 5. Lipid nutritional quality of marine oysters.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Farmed *C. gigas*	–	–	46.1 ± 1.0	17.8 ± 0.0	36.1 ± 1.0	15.1 ± 1.1	12.5 ± 0.3	27.6	–	7.60 ± 0.01	0.80 ± 0.01	Nan'ao Island, China	23.43	Winter	Tan et al. (2020)
Farmed *C. gigas*	–	–	35.9 ± 0.3	11.5 ± 0.0	52.6 ± 0.2	20.0 ± 0.3	17.7 ± 0.0	37.7	–	5.90 ± 0.12	1.50 ± 0.01	Nan'ao Island, China	23.43	Spring	Tan et al. (2020)
Farmed *C. gigas*	–	–	40.5 ± 0.2	14.9 ± 0.2	44.6 ± 0.1	22.2 ± 0.1	10.1 ± 0.1	32.2	–	5.60 ± 0.11	1.10 ± 0.02	Nan'ao Island, China	23.43	Summer	Tan et al. (2020)
Farmed *C. gigas*	–	–	42.1 ± 0.3	13.4 ± 0.5	44.6 ± 0.2	21.1 ± 0.0	12.3 ± 0.1	33.4	–	5.50 ± 0.03	0.90 ± 0.01	Nan'ao Island, China	23.43	Autumn	Tan et al. (2020)
Farmed *C. angulata*	–	–	41.7 ± 1.5	17.9 ± 0.4	36.6 ± 3.4	15.3 ± 0.6	12.3 ± 0.7	27.6	–	7.60 ± 1.82	0.90 ± 0.10	Nan'ao Island, China	23.43	Winter	Tan et al. (2020)
Farmed *C. angulata*	–	–	33.3 ± 1.1	9.2 ± 0.5	57.5 ± 0.5	21.7 ± 0.3	21.0 ± 0.1	42.7	–	6.80 ± 0.13	1.70 ± 0.12	Nan'ao Island, China	23.43	Spring	Tan et al. (2020)
Farmed *C. angulata*	–	–	41.3 ± 0.4	15.1 ± 0.0	43.6 ± 0.4	19.1 ± 1.6	11.4 ± 1.0	30.5	–	4.80 ± 0.03	1.10 ± 0.02	Nan'ao Island, China	23.43	Summer	Tan et al. (2020)
Farmed *C. angulata*	–	–	42.1 ± 0.3	13.4 ± 0.5	44.6 ± 0.2	21.1 ± 0.0	12.3 ± 0.1	33.4	–	6.10 ± 0.14	1.10 ± 0.03	Nan'ao Island, China	23.43	Autumn	Tan et al. (2020)
Wild *Ostrea edulis*	2.70 ± 0.30	–	48.1 ± 5.5	19.1 ± 0.3	32.8 ± 5.8	7.5 ± 1.5	9.2 ± 4.4	16.7	4.5	5.31 ± 0.98	0.68 ± 0.28	Gulf of Taranto	39.89	Winter	Biandolino et al. (2019)
Farmed *C. gigas (black)*	–	4.96 ± 0.52	39.8 ± 2.0	15.6 ± 0.9	44.6 ± 1.2	17.8 ± 0.4	21.1 ± 0.6	38.9	–	7.78 ± 0.22	1.12	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. gigas (Purple)*	–	4.80 ± 0.44	40.2 ± 1.9	14.5 ± 0.5	45.2 ± 2.0	18.7 ± 0.7	21.1 ± 0.6	39.8	–	8.11 ± 0.24	1.13	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. gigas (Orange)*	–	3.58 ± 1.57	41.1 ± 3.8	15.8 ± 0.6	43.1 ± 3.6	17.2 ± 1.3	20.1 ± 1.7	37.4	–	7.30 ± 0.63	1.05	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. gigas (Golden)*	–	5.04 ± 1.85	40.5 ± 4.5	16.6 ± 0.7	42.9 ± 4.1	17.9 ± 1.7	18.8 ± 1.5	36.7	–	6.35 ± 0.50	1.06	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. gigas (White)*	–	5.15 ± 0.68	39.7 ± 1.5	15.4 ± 0.3	44.9 ± 1.8	18.0 ± 0.7	21.2 ± 0.7	39.1	–	7.71 ± 0.30	1.13	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. gigas (common)*	–	4.95 ± 0.62	42.2 ± 2.1	15.6 ± 0.8	42.3 ± 3.1	17.8 ± 1.3	18.5 ± 1.5	36.3	–	6.61 ± 0.50	1.00	Rushan Bay	53.4	Winter	Zhu et al. (2018)
Farmed *C. hongkongensis (Diploid)*	–	–	58.7	9.5	31.6	10.5	11.3	21.8	–	3.71	0.54	Beihai	21.48	Summer	Qin et al. (2018)
Farmed *C. hongkongensis (Triploid)*	–	–	52.2	9.2	39.6	14.3	14.3	28.6	–	4.7	0.76	Beihai	21.48	Summer	Qin et al. (2018)
Farmed *C. hongkongensis (Diploid)*	–	–	58.3	8.9	32.2	13.4	8.6	22.0	–	4.64	0.55	Beihai	21.48	Autumn	Qin et al. (2018)
Farmed *C. hongkongensis (Triploid)*	–	–	55.3	9.1	37.7	15.1	10.9	26.0	–	4.94	0.68	Beihai	21.48	Autumn	Qin et al. (2018)
Farmed *C. madrasensis*	3.25 ± 0.32	–	32.2 ± 0.8	13.7 ± 0.1	44.8 ± 0.3	19.2 ± 0.4	15.7 ± 0.2	34.9	11.3	4.66	1.39	Moothakunnam	10		Asha et al. (2014)
Wild *Ostrea spp.*	1.24	–	57.4	8.4	34.2	5.5	8.4	13.9	1.7	2.4	0.6	Straits of Mallaca	4.66		Aziz et al. (2013)
Farmed *Crassostrea angulate*	–	–	31.1	19.1	46.9	15.8	10.2	26.0	–	10	1.51	Sado estuary	38.82	Nov	Ruono et al. (2012)
Farmed *O. edulis*	–	–	18.5 ± 1.8	9.5 ± 0.6	71.5 ± 2.7	26.5 ± 2.2	30.2 ± 2.2	56.7	–	7.82	3.86	Mali Ston Bay	42.87	Spring	Ezgeta-Balić et al. (2012)
Farmed *O. edulis*	–	–	32.5 ± 8.9	11.8 ± 2.3	54.9 ± 11.2	19.3 ± 4.6	20.8 ± 7.9	40.1	–	6.39	1.69	Mali Ston Bay	42.87	Summer	Ezgeta-Balić et al. (2012)
Farmed *O. edulis*	–	–	26.3 ± 1.4	10.8 ± 1.2	62.2 ± 2.6	20.8 ± 0.8	22.9 ± 1.6	43.7	–	5.26	2.36	Mali Ston Bay	42.87	Autum	Ezgeta-Balić et al. (2012)
Farmed *O. edulis*	–	–	22.8 ± 2.1	16.5 ± 0.6	53.5 ± 2.5	17.6 ± 3.7	16.5 ± 6.3	34.1	–	8.36	2.35	Mali Ston Bay	42.87	Winter	Ezgeta-Balić et al. (2012)

(continued)

Table 5. Continued.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Farmed *C. virginica*	–	–	25.8	15.1	59.1	12.1	18.4	30.5	–	3.28	2.29	Baie de Saint Simon	46.72	May	Pernet, Gauthier-Clerc, and Mayrand (2007)
Wild *C. gigas*	–	6.2 ± 3.0	23.7	12.4	61.8	12.2	20.4	32.6	–	3.15	2.61	Bizert lagoon	37.13	Winter	Dridi, Salah Romdhane, and Elcafsi (2007)
Wild *C. gigas*	–	7.5 ± 2.4	23.1	12.4	61.1	11.0	21.9	32.9	–	2.7	2.64	Bizert lagoon	37.13	Spring	Dridi, Salah Romdhane, and Elcafsi (2007)
Wild *C. gigas*	–	4.8 ± 2.3	23.1	12.9	53.7	10.7	17.7	28.4	–	2.45	2.32	Bizert lagoon	37.13	Summer	Dridi, Salah Romdhane, and Elcafsi (2007)
Wild *C. gigas*	–	8.0 ± 2.1	26.4	15.8	55.8	11.4	21.2	32.7	–	2.83	2.12	Bizert lagoon	37.13	Autumn	Dridi, Salah Romdhane, and Elcafsi (2007)
Wild *C. gigas*	–	–	30.0 ± 1.6	27.4 ± 0.2	39.0 ± 0.1	11.5 ± 1.2	6.4 ± 0.4	17.9	–	2.81	1.30	Jiaozhou Bay	36.00	Spring	Xu and Yang (2007)
Wild *Saccostrea cucullata*	0.90 ± 0.10	–	63.4	24.3	12.4	1.0	1.0	2.0	0.2	5.25	0.20	Tasman Bay	41.57	Spring	Mclean and Bulling (2005)
Wild *Saccostrea cucullata*	1.90 ± 0.10	–	52.6	24.4	23.1	6.0	6.4	12.4	2.4	5.75	0.44	Tasman Bay	41.57	Summer	Mclean and Bulling (2005)
Wild *Saccostrea cucullata*	0.60 ± 0.10	–	33.4	17.8	48.8	13.9	23.5	37.3	2.2	9.13	1.46	Tasman Bay	41.57	Autumn	Mclean and Bulling (2005)
Wild *Saccostrea cucullata*	0.70 ± 0.10	–	40.5	17.3	42.2	10.9	17.3	28.2	2.0	8.60	1.04	Tasman Bay	41.57	Winter	Mclean and Bulling (2005)

Table 6. Lipid nutritional quality of marine cockles.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild *Tegillarca granosa*	1.80 ± 0.10	–	26.8 ± 0.5	24.7 ± 0.1	47.8 ± 0.8	12.2 ± 0.0	11.3 ± 0.1	23.5	4.2	3.90 ± 0.10	1.80 ± 0.80	Yeosu	34.76	Autumn	Nguyen et al. (2017)
Wild *Tegillarca granosa*	1.50 ± 0.10	–	23.3 ± 0.4	22.3 ± 0.1	54.0 ± 0.4	14.9 ± 0.1	11.3 ± 0.1	26.2	3.9	4.20 ± 0.20	2.30 ± 0.40	Yeosu	34.76	Winter	Nguyen et al. (2017)
Wild *Tegillarca granosa*	2.30 ± 0.20	–	27.2 ± 0.5	25.7 ± 0.8	46.2 ± 1.3	17.3 ± 0.1	8.0 ± 0.1	25.3	5.8	5.10 ± 0.50	1.70 ± 0.60	Yeosu	34.76	Spring	Nguyen et al. (2017)
Wild *Cerastoderma edule*	–	–	41.4 ± 6.2	12.3 ± 1.9	45.0 ± 6.6	22.9 ± 1.8	13.0 ± 3.6	35.9	–	22.54	1.09	São Jacinto	40.65	Spring	Ricardo et al. (2015)
Wild *Cerastoderma edule*	–	–	33.6 ± 4.2	13.3 ± 1.2	48.4 ± 5.8	21.2 ± 2.2	16.0 ± 3.4	37.1	–	17.03	1.44	Mira	40.63	Spring	Ricardo et al. (2015)
Wild *Cerastoderma edule*	–	–	29.5 ± 6.7	13.0 ± 1.2	56.0 ± 7.3	22.5 ± 1.6	18.7 ± 4.0	41.2	–	11.73	1.90	Ilhavo	40.63	Spring	Ricardo et al. (2015)
Wild *Cerastoderma edule*	–	–	28.4 ± 10.8	12.6 ± 2.0	58.0 ± 14.1	24.1 ± 3.7	22.1 ± 8.5	46.1	–	18.31	2.04	Espinheiro	40.65	Spring	Ricardo et al. (2015)
Wild *Fulvia mutica*	2.90 ± 0.10	–	31.1 ± 1.6	10.7 ± 1.4	58.2 ± 3.1	22.5 ± 1.6	31.7 ± 1.3	54.2	15.7	24.6	1.87	Weihai	36.68	Winter	Liu, Li, and Kong (2013)
Wild *Fulvia mutica*	2.70 ± 0.09	–	34.1 ± 1.1	9.8 ± 1.2	56.1 ± 4.4	19.2 ± 1.4	32.1 ± 2.0	51.3	11.0	21.2	1.64	Weihai	36.68	Spring	Liu, Li, and Kong (2013)
Wild *Fulvia mutica*	2.70 ± 0.10	–	30.5 ± 1.4	11.3 ± 1.2	58.2.9 ± 3.6	19.3 ± 1.1	32.7 ± 1.8	51.9	7.2	13.2	1.90	Weihai	36.68	Summer	Liu, Li, and Kong (2013)
Wild *Fulvia mutica*	1.50 ± 0.02	–	28.4 ± 2.0	10.7 ± 1.4	60.9 ± 4.1	20.8 ± 1.0	35.0 ± 2.0	55.8	4.6	17.7	2.14	Weihai	36.68	Autumn	Liu, Li, and Kong (2013)
Wild *Anadara granosa*	1.93	–	39.0	24.0	37.0	20.8	7.5	28.3	5.5	3.8	1	Straits of Mallaca	4.66	–	Aziz et al. (2013)
Wild *Cerastoderma edule*	–	–	31.1	18.8	47.8	13.1	10.0	23.1	–	3.45	1.54	Sado estuary	38.82	May	Ruono et al. (2012)

Table 7. Lipid nutritional quality of freshwater mussels.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild *Anodonta pseudodopsis*	0.77 ± 0.03	–	29.1	23.1	32.9	8.1	6.6	14.7	1.1	1.11	1.13	Lake Gölbaşı	39.8	–	Şereflişan and Altun (2018)
Wild *Unio tigridis*	0.96 ± 0.06	–	28.1	21.8	39.6	9.6	7.2	16.7	1.6	1.01	1.41	Lake Gölbaşı	39.8	–	Şereflişan and Altun (2018)
Wild *Limnoperna fortunei*	–	–	35.7 ± 1.4	21.9 ± 1.3	33.9 ± 2.4	7.4 ± 0.8	9.4 ± 0.3	16.8	–	2.36	0.95	southern China	23.13	March to Nov	Zhang et al. (2017)
Wild *Batissa violacea*	10.66	–	54.0	23.9	22.1	2.2	2.4	4.6	4.9	1.06	0.41	NORTH MOROWALI	1.63	–	Jamaluddin, Septiawan, and Yuyun (2016)
Wild *Lamellidens marginalis*	–	1.02 ± 0.20	49.4 ± 0.5	22.2 ± 0.0	28.6 ± 0.0	3.4 ± 0.1	9.6 ± 0.1	13.0	–	1.38	0.58	West Bengal	22.99	–	Haldar et al. (2014)
Wild *Unio tumidus*	–	–	32.6 ± 0.1	25.9 ± 0.3	34.1 ± 3.1	4.3 ± 0.3	1.6 ± 0.1	5.9	–	0.71	1.05	Kanevskoe Reservoir	50.33	Summer	Makhutova et al. (2013)
Wild *Dreissena polymorpha*	–	–	35.2 ± 0.2	22.8 ± 0.5	35.0 ± 2.2	6.4 ± 0.3	8.0 ± 0.4	14.4	–	1.96	0.99	Kanevskoe Reservoir	50.33	Summer	Makhutova et al. (2013)
Wild *Dreissena bugensis*	–	–	33.3 ± 0.2	23.5 ± 0.1	35.0 ± 3.4	7.7 ± 0.7	5.1 ± 0.4	12.8	–	2.88	1.05	Kanevskoe Reservoir	50.33	Summer	Makhutova et al. (2013)
Wild *Dreissena polymorpha*	0.83 ± 0.09	–	25.8 ± 1.1	25.3 ± 0.4	48.9 ± 1.2	8.4 ± 0.5	9.1 ± 0.4	17.5	1.5	1.87	1.90	Ebro River	41.85	Autumn	Lazzara et al. (2012)
Wild *Dreissena polymorpha*	0.87 ± 0.06	–	23.7 ± 1.1	25.2 ± 0.1	51.1 ± 1.2	11.1 ± 0.3	11.5 ± 0.3	22.6	2.0	2.20	2.16	Ebro River	41.85	Winter	Lazzara et al. (2012)
Wild *Dreissena polymorpha*	2.07 ± 0.21	–	29.9 ± 1.3	23.2 ± 1.4	47.0 ± 2.6	12.0 ± 0.5	11.6 ± 1.2	23.6	4.9	3.80	1.57	Ebro River	41.85	Spring	Lazzara et al. (2012)
Wild *Dreissena polymorpha*	0.23	–	41.4 ± 1.9	21.3 ± 0.4	34.7 ± 1.6	5.0 ± 0.2	7.2 ± 0.3	12.2	0.3	0.66	0.84	Rybinskoe reservoir	58.05	Summer	Makhutova et al. (2011)
Wild *Dreissena bugensis*	0.19	–	39.7 ± 1.9	17.8 ± 0.5	39.3 ± 1.8	8.3 ± 0.3	7.6 ± 0.5	15.9	0.3	1.05	0.99	Rybinskoe reservoir	58.05	Summer	Makhutova et al. (2011)
Wild *Unio elongatulus*	–	–	27.1 ± 1.2	34.5 ± 1.3	39.2 ± 1.4	4.3 ± 0.2	0.7 ± 0.0	5.0	–	0.41	1.44	Mardin	37.05	Spring	Ekin, Bashan, and Sesen (2011)
Wild *Unio elongatulus*	–	–	28.4 ± 1.2	34.3 ± 1.3	37.4 ± 1.3	3.2 ± 0.2	1.0 ± 0.2	4.2	–	0.38	1.32	Diyarbakır	37.92	Spring	Ekin, Bashan, and Sesen (2011)
Wild *Unio elongatulus*	–	–	29.0 ± 1.2	32.2 ± 1.3	39.5 ± 1.4	5.1 ± 0.4	0.3 ± 0.0	5.4	–	0.32	1.36	Diyarbakır	37.72	Spring	Ekin, Bashan, and Sesen (2011)
Wild *Unio elongatulus*	–	–	26.8 ± 1.3	29.4 ± 1.2	44.5 ± 1.4	6.1 ± 0.5	0.7 ± 0.0	6.8	–	0.40	1.66	Mardin	37.42	Spring	Ekin, Bashan, and Sesen (2011)
Wild *Unio elongatulus*	–	–	31.7 ± 1.4	47.1 ± 2.1	21.1 ± 1.4	7.0 ± 0.5	7.2 ± 0.6	14.2	–	1.03	0.66	Diyarbakr	37.92	Summer	Ekin and Bashan (2010)
Wild *Amblema plicata*	–	4.7 to 5.7	38.5	20.2	41.3	5.1	1.8	6.9	–	0.81	1.07	North America	54.53	Summer	Newton et al. (2013)
Wild *Actinonaias ligamentina*	–	4.5 to 6.2	37.3	23.5	39.1	4.3	2.0	6.4	–	0.79	1.05	North America	54.53	Summer	Newton et al. (2013)
	0.26 ± 0.1	–	32.1 ± 0.1	19.6 ± 0.0	37.1 ± 0.0	3.3 ± 0.0	7.1 ± 0.0	10.4	0.3	1.54	1.15	Lake Gölbaşı	39.8	–	

(*continued*)

Table 7. Continued.

	TLC (% WW)	TLC (% DW)	SFA (%)	MUFA (%)	PUFA (%)	EPA (%)	DHA (%)	EPA + DHA (%)	EPA + DHA (mg/g)	n-3/ n-6	PUFA/SFA ratio	Location	Latitude	Analysis Period	References
Wild *Unio terminalis*															Ersoy and Sereflisan (2010)
Wild *Potamida littoralis*	0.11 ± 0.0	–	30.2 ± 0.1	22.8 ± 0.2	32.4 ± 0.1	4.1 ± 0.1	5.9 ± 0.1	10.0	0.1	1.40	1.07	Lake Gölbaşı	39.8	–	Ersoy and Sereflisan (2010)
Wild *Anadonta piscinalis*	–	1.03 to 1.05	18.9	25.9	55.2	0.7	3.1	3.7	–	1.47	2.92	River Volga	47.5	–	Dembitsky, Rezanka, and Kashin (1993)
Wild *Diplodom patagonicus*	–	–	34.1	19.9	46.0	2.7	1.6	4.3	–	0.45	1.35	Lake of Nahuel Huapi	40.93	Autumn	Pollero, Brenner, and Gros (1981)
Wild *Diplodom patagonicus*	–	–	36.5	20.9	42.6	3.5	0.8	4.3	–	0.46	1.17	Lake of Nahuel Huapi	40.93	Winter	Pollero, Brenner, and Gros (1981)
Wild *Diplodom patagonicus*	–	–	41.1	21.5	37.4	2.5	1.2	3.7	–	0.44	0.91	Lake of Nahuel Huapi	40.93	Spring	Pollero, Brenner, and Gros (1981)
Wild *Diplodom patagonicus*	–	–	32.3	25.6	42.1	3.5	1.5	5.0	–	0.61	1.30	Lake of Nahuel Huapi	40.93	Summer	Pollero, Brenner, and Gros (1981)

spring (Ezgeta-Balić et al. 2012). In general, the PUFA/SFA index of *C. hongkongensis* (0.63 ± 0.11) (Qin et al. 2018) was significantly lower than that of other oysters.

Fatty acid profiles in marine cockles

The lipid content of commercially important marine cockles was less than 3.0%, and the highest lipid content (2.90% ww) was recorded in *Fulvia mutica* collected from Weihai, China in winter (Liu, Li, and Kong 2013) (Table 6). The average lipid content of *Fulvia mutica* (2.45 ± 0.66% ww) was significantly higher than that of other cockle species (1.87 to 1.93% ww) (Aziz et al. 2013; Nguyen et al. 2017).

All reported commercially important cockles have similar fatty acid composition of PUFA > SFA > MUFA. The PUFA content of *Anadara granosa* (37.1 ± 6.5) (Aziz et al. 2013) was significantly lower than that of other cockles (49.3 ± 4.1 to 58.3 ± 2.0) (Ruono et al., 2012; Liu, Li, and Kong 2013; Ricardo et al. 2015; Nguyen et al. 2017). The EPA + DHA content of *Cerastoderma edule* and *Fulvia mutica* (53.3 ± 2.1% to 33.9 ± 6.3%) was significantly higher than that of other cockle species (Liu, Li, and Kong 2013; Ricardo et al. 2015).

The commercially important cockle species has a n-3/n-6 LC-PUFA ratio ranging from 3.80 (*Tegillarca granosa* collected from Yeosu in autumn) (Nguyen et al. 2017) to 22.54 (documented in *Fulvia mutica* collected from Weihai in winter) (Liu, Li, and Kong 2013), with n-3/n-6 LC-PUFA ratio of *Cerastoderma edule* (14.61 ± 7.34) and *Fulvia mutica* (19.18 ± 4.88) was significantly higher than other cockles (Ruono et al., 2012; Aziz et al. 2013; Nguyen et al. 2017). The PUFA/SFA index of all commercially important marine cockle species was greater than 1.00, with the highest (2.30) and the lowest (1.00) PUFA/SFA index documented in *Tegillarca granosa* collected from Yeosu in winter (Nguyen et al. 2017) and *Anadara granosa* collected from Straits of Mallaca (Aziz et al. 2013), respectively. There was no significant difference in PUFA/SFA index among cockles.

Fatty acid profiles in freshwater mussels

The lipid content of freshwater mussels is usually less than 1.00% ww, except for *Dreissena polymorpha* (2.07% ww) collected from Ebro River, Spain in spring (Lazzara et al. 2012). The average lipid content of *Dreissena polymorpha* (1.00 ± 0.77) (Makhutova et al. 2011; Lazzara et al. 2012) was significantly higher than that of other freshwater mussels, including *Anodonta pseudodopsis*, *Unio spp.* and *Potamida littoralis* (0.11 to 0.77) (Ersoy and Sereflisan 2010; Makhutova et al. 2011; Lazzara et al. 2012; Şereflişan and Altun 2018).

The fatty acid composition of most freshwater mussels is dominated by PUFA, with the exception of *Diplodom patagonicus* collected from Lake of Nahuel Huapi (Pollero, Brenner, and Gros 1981), *Unio elongatulus* collected from Diyarbakr (Ekin and Bashan 2010), *Dreissena* spp collected from Kanevskoe Reservoir and Rybinskoe reservoir (Makhutova et al. 2011, 2013), *Lamellidens marginalis* collected from West Bengal (Haldar et al. 2014), *Batissa violacea* collected from North Morowali (Jamaluddin, Septiawan, and Yuyun 2016), and *Limnoperna fortunei* collected from southern China (Zhang et al. 2017), in which SFA was dominated.

The PUFA content of most freshwater mussels was >30.0%, except for *Batissa violacea*, *Lamellidens marginalis* and *Unio elongatulus* collected from North Morowali, West Bengal and Diyarbakr, respectively (Ekin and Bashan 2010; Haldar et al. 2014; Jamaluddin, Septiawan, and Yuyun 2016). The EPA + DHA content of most freshwater mussels have a below 20.0%, except for *Dreissena polymorpha* collected from Ebro River during spring (23.6%) and winter (22.6%) (Lazzara et al. 2012).

Half of the reported marine mussels had n-3/n-6 LC-PUFA ratios <1.00, with the lowest ratios recorded in *Unio elongatulus* (0.32 to 0.41) collected from Spain (Ekin, Bashan, and Sesen 2011), followed by *Diplodom patagonicus* (0.45to 0.61) collected from Lake of Nahuel Huapi (Pollero, Brenner, and Gros 1981). The highest n-3/n-6 LC-PUFA ratio of freshwater mussels was 3.80, which was recorded in *Dreissena polymorpha* collected from Ebro River (Lazzara et al. 2012).

The PUFA/SFA index of all freshwater mussels was higher than the recommended value of 0.45, except for *Batissa violacea* collected from North Morowali (Jamaluddin, Septiawan, and Yuyun 2016). The average PUFA/SFA index of *Dreissena polymorpha* (1.62 ± 0.57) (Makhutova et al. 2011; Lazzara et al. 2012) was significantly higher than that of other freshwater mussel species (1.07 to 1.28) (Ersoy and Sereflisan 2010; Şereflişan and Altun 2018).

Discussion

Comparison of lipid nutritional quality of marine bivalves and other aquatic animals

In recognition of the importance of n-3 LC-PUFA to our health, food choices rich in n-3 LC-PUFA are preferable by consumers. Comparing the nutritional quality of lipid between marine and freshwater bivalves, the lipid content, total EPA + DHA and n-3/n-6 LC-PUFA of most marine bivalves were significantly higher than those of freshwater bivalves (Table 7), indicating that marine bivalves are the better source of n-3 LC-PUFA. This is because the content of n-3 LC-PUFA of freshwater phytoplankton (food of freshwater bivalve) is much lower than that of marine phytoplankton (the n-3/n-6 LC-PUFA ratio of in freshwater phytoplankton and marine phytoplankton is 1.0 to 7.6 and 11.6 to 22.4, respectively) (Brett, Muller-Navarra, and Presson 2009; Perhar, Arhonditsis, and Brett 2012).

The total EPA + DHA content and n-3/n-6 LC-PUFA of marine bivalves are significantly lower than that of many low to medium fat fishes (EPA + DHA content= 508-1371 mg/100 g flesh; n-3/n-6 LC-PUFA = 5.0-12.5), including *Seriola lalandi*, *Scomber japonicas*, *Trachurus murphyi* and *Pinguipes chilensis* from the Southern Pacific (Rincón-Cervera et al. 2020), *Sparus aurata*, *Seriola fasciata*, *Diplodus sargus* and *Scomber colias* from Northern Atlantic (Nogueira, Cordeiro, and Aveiro 2013), and *Nemipterus japonicas* and *Selaroides leptolepis* from the South China Sea (Aziz et al. 2013). However, the EPA + DHA content of most marine bivalves is comparable (or even higher) to that of many lean fish (Nogueira, Cordeiro, and Aveiro 2013; Aziz et al. 2013; Rincón-Cervera et al. 2020) and most low and medium fat fish caught from tropical regions (Aziz et al. 2013). It is worth noting that with the exception of *Seriola fasciata*, *Scomber colias* and *Selaroides leptolepis*, most low and medium fat marine fish have significantly lower PUFA/SFA than that of most marine bivalves (Nogueira, Cordeiro, and Aveiro 2013; Aziz et al. 2013). All these observations indicate that marine bivalves are a good alternative for n-3 LC-PUFA.

Compared with other seafood, although the lipid content of bivalves is much lower than that of sea urchins, the n-3/n-6 LC-PUFA and PUFA/SFA of bivalves are significantly higher than those of sea urchins (Rincón-Cervera et al. 2020). This observation can be explained by the much lower SFA, and higher n-3 LC-PUFA content in bivalves, which indicates that bivalves are more healthy seafood than sea urchins. On the other hand, n-3/n-6 LC-PUFA and PUFA/SFA of most marine bivalves are comparable to those of crustaceans, gastropods and cephalopods (Aziz et al. 2013; Rincón-Cervera et al. 2020, Tan, Zhang, and Ma 2021b). It is worth noting that except for squid (Rincón-Cervera et al. 2020), the EPA + DHA content of most marine bivalves is significantly higher than that of most other seafood, which indicates that marine bivalves are a good source of n-3 LC-PUFA.

The lipid composition of bivalves is greatly affected by latitude and season. On the one hand, 12 months lipid profile analysis of bivalves revealed that the average LC-PUFA content and the average EPA + DHA content of *My. Galloprovincialis* (Prato et al. 2010; Dernekbaşı et al. 2015; Merdzhanova, Dobreva, and Georgieva 2016), *My. Edulis* (Lin et al. 2003; Mclean and Bulling 2005), *P. viridis* (Chakraborty et al. 2011, 2016) and *C. gigas* (Dridi, Salah Romdhane, and Elcafsi 2007; Tan et al., 2020) were positively associated with latitude. For example, annual average of LC-PUFA and EPA + DHA content of *My. Galloprovincialis* were much higher at 43.43 °N (LC-PUFA= 54.01 ± 1.57%; EPA + DHA= 34.34 ± 2.72%) (Merdzhanova, Dobreva, and Panayotova 2017) compared with lower latitudes of 40.47 to 42.03 °N (LC-PUFA= 9.73 ± 1.57% to 53.77 ± 2.44%; EPA + DHA= 2.12 ± 0.79% to 26.71 ± 3.10%) (Prato et al. 2010; Dernekbaşı et al. 2015). Another example is that the EPA + DHA content of *Mytilus edulis* sampled from high latitude area of Notre Dame Bay (49.5 °N) contains much higher EPA + DHA (571.21 ± 40.09 mg/g) (Alkanani et al. 2007) than that of bivalves collected (248.00 ± 101.86 mg/g) form low latitude area of Qingdao (36.7 °N) (Lin et al. 2003). This can be partly explained by the higher content of LC-PUFA in microalgae (food of bivalves) in higher latitudes, which is crucial for maintaining membrane fluidity and function at low temperature (Steinrucken et al. 2017). There are similar reports on fish, where the n-3 LC-PUFA of high latitude cold-water fish is usually higher than that of lower latitude tropical fish (Dunstan, Olley, and Ratkowsky 1999; Bahurmiz, Adzitey, and Ng 2017).

On the other hand, although there are some mixed trends in the seasonal variations of n-3 LC-PUFA and EPA + DHA content, most of the data (especially in the high latitudes) show that the LC-PUFA and EPA + DHA in most of the marine bivalves, including *My. galloprovincialis* (Ezgeta-Balić et al. 2012; Dernekbaşı et al. 2015), *C. gigas* (Tan et al., 2020), *C. angulata* (Tan et al., 2020), *O. edulis* (Ezgeta-Balić et al. 2012) were the highest in spring and the lowest in winter. This observation can be explained by the food availability and reproductive cycle of bivalves, where phytoplankton in temperate and sub-polar regions usually bloom in spring (Rumyantseva et al. 2019). Since lipids and LC-PUFA are essential for the development of mature gonads (Fearman, Bolch, and Moltschaniwskyj 2009), high food abundance induce the dramatic increase in n-3 LC-PUFA composition in bivalves (Tan et al., 2020). For instance, the gonadal index of *My. galloprovincialis* from Biscay (Basque Country, 45.5 °N) was the highest in spring (April) and the lowest in autumn and winter (August) (Azpeitia et al. 2017). The gonadal index of *My. edulis* from north-western Iceland (65.57 to 65.72 °N) peaked from April-May (Spring) and reached its lowest value from October to November (Autmn) (Thorarinsdottir et al. 2013).

Prospect of marine bivalve aquaculture as a sustainable source of n-3 PUFA

Our meta-analysis clearly reveals that marine bivalves are excellent sources of n-3 LC-PUFA. For cultivation purposes, it is important to select bivalves that can accumulate high levels of EPA + DHA (n-3 LC-PUFA). Among them, there are at least 2 marine mussels (*My. Galloprovincialis* and *Modiolus barbatus*), 1 marine clam (*Ruditapes decussatus*), 3 marine scallops (*Pecten maximus*, *Mimachlamys varia* and *Chlamys nobilis*), 2 marine oysters (*C. madrasensis* and *C. gigas*) and 3 marine cockles (*Tegillarca granosa*, *Fulvia mutica* and *Anadara granosa*) are highly recommended for aquaculture, as consumer only need to consume about 100 g to meet the daily needs of n-3 LC-PUFA. Caution through, many studies do not provide information on total lipid content, thus the absolute content of EPA + DHA cannot be calculated in this study. Therefore, there may be more bivalve species with higher absolute EPA + DHA concentration, which makes them potential bivalve species for commercial cultivation. It is strongly recommended that in addition to relative abundant of fatty acids (%), researchers should also provide information on absolute content (mg/g) or at least total lipid content in future studies.

Bivalve aquaculture is an environmentally sustainable method to produce protein and n-3 LC-PUFA (Tan, Zhang, and Zheng 2020c; Tan and Zheng 2021). Unlike finfish, bivalves are non-fed species, which makes bivalve aquaculture more environmental friendly. In 2016, the world's aquaculture mollusk production reached 17,139 thousand tonnes (21.4% of total aquaculture production), of which *Crassostrea* spp., *Ruditapes philippinarum* and *Pectinidae* accounted for 30.72%, 26.71% and 11.75% of the total mollusk production, respectively (Food and Agriculture Organisation (FAO), 2020). Bivalve aquaculture is primarily predominant in tropical and subtropical regions, with temperate regions accounting for only about 10% of the total production of farmed bivalve (De Silva and Soto 2009; Food and Agriculture Organisation (FAO), 2020). In 2016, Asia (mainly China) was by far the largest producer of farmed bivalves (15,835 thousand tonnes, accounting for 92.39% of the total bivalve production from aquaculture), and its contribution was more than 25 times that of Europe (613 thousand tonnes), and Europe was the second largest producer of farmed bivalves. Since the early 1990s, the production of farmed bivalves in China has increased by more than 7 times (2 million tonnes per year in 1992 and more than 14.57 million tonnes in 2016) (Food and Agriculture Organisation (FAO), 2020). The dramatic increment of farmed bivalve production was driven by the improvement of living standards and the growth of population in China. In other countries, the production of farmed bivalves has remains consistent or even decreased (Wijsman et al. 2018). For instance, in Europe, the production of farmed bivalves decreased by about 22.5% in 2015 compared with 1998, with the most significant reduction (over 50%) was in the production of bottom culture mussels in the Netherlands due to inconsistent natural seed supply and occasional recruitment failures (Food and Agriculture Organisation (FAO), 2020). Gentry et al. (2017) estimated the global capacity for increased marine aquaculture production based on physiology, allometry and growth theory. It was found that vast areas (1.5 million km^2) in nearly every coastal country are suitable for bivalve aquaculture, and the development potential of bivalve aquaculture are far exceeds the predicted global seafood demand in the future. Notably, many countries with the greatest potential do not currently produce large quantities of marine aquaculture (Food and Agriculture Organisation (FAO), 2015, 2018).

Challenges in bivalve aquaculture

Mass mortalities of farmed bivalve

Over the past few decades, repeated episodes of bivalve mass mortalities caused by environmental stress (e.g. Renault et al. 2002; Washington State Blue Ribbon Panel on Ocean Acidification 2012; Tan et al. 2019; Tan et al. 2020d), and the spread and proliferation of deadly diseases (e.g. Wendling and Wegner 2013; Queiroga et al. 2015) have been documented around the world. These repeated episodes of bivalve mass mortalities have been analyzed, and it was found that most mass mortality outbreaks were associated with changes of ocean conditions induced by global climate change. The driving factors of global climate change, including ocean warming, ocean acidification, salinity changes, and dissolved oxygen changes, altered the physiology of bivalves and increased their susceptibility to environmental stressors or pathogens (Tan and Ransangan 2019; Tan and Zheng 2019, 2020). Mass mortality outbreaks of farmed bivalves have resulted in severe economic losses in many regions. For example in France, since 2008, the Ostreid Herpes-virus mutant species (*OsHV1-µVar*) outbreaks have caused recurrent mass mortality outbreaks (up to 80 to 100% per year) of juvenile oysters in oyster farms (Guillotreau, Le Bihan, and Pardo 2018). Another good example is that in the Pacific Northwest of the United States, the recurrent mass mortalities of bivalves resulting in an annual economic loss of $270 million (Washington State Blue Ribbon Panel on Ocean Acidification 2012).

On the one hand, a number of management strategies have been proposed to mitigate the impact of climate change. Among them, integrated multi-trophic aquaculture (IMTA) appears to be the most promising approach, and provides some successful examples (Chopin 2015). For example, high photosynthetic rates in tropical seagrass meadows resulted in an increase in seawater pH from 7.9 to 8.9, of which increase the calcification rate of calcareous animals in Chwaka Bay, Tanzania (Semesi, Beer, and Bj€Ork 2009). The most interesting part is that IMTA can be applied to bivalve hatchery system, in which the input seawater is first stored in large macroalgae or microalgae tanks (buffer low pH seawater), and then supplied to bivalve larvae tanks. On the other hand, genetic selection in selective breeding programs has great potential to improve the health and survival rate of farmed bivalves by cumulatively improving environmental sensitivity and resistance to diseases (Dégremont et al. 2005, Dégremont, Nourry, and Maurouard 2015; Frank-Lawale, Allen, and Dégremont 2014; Thompson et al. 2015; de Melo, Durland, and Langdon 2016; Tan, Zhang, and Zheng 2020c, Tan et al. 2020d). With the rapid development of genetic tools, the application of modern genetic technology, including marker-assisted selection (MAS) and genomic selection (GS), can significantly improve the accuracy and effectiveness of selection for robustness in commercially important bivalves to changing ocean conditions. Briefly, MAS uses molecular markers to assist phenotypic selections, while GS refers to the use of new markers-based whole-genomic prediction models for genetic evaluation. Although these technologies have not been implemented in bivalve selective breeding program, MAS and GS have been successfully implemented in many livestock and crop breeding programs (Poland et al. 2012; Kumar et al. 2012; Moen et al. 2015; Abdelrahman et al. 2017; Bangera et al. 2018; Verbyla, Kube, and Evans 2018).

Food safety

Bivalves are filter feeders that consume plankton togather with microorganisms and toxins. Not all bivalves are safe for human consumption, because some (particularly non-farmed bivalves) growing in polluted water can accumulate pathogens, heavy metals, toxins or chemical pollutants in their tissues to the levels that is harmful to human health (Tan and Ransangan 2015). Warning though, heavy metals and some marine biotoxins are inorganic compounds and will not be destroyed during cooking or freezing. Therefore, the consumption of contaminated bivalves has potential public health issues, including infectious diseases, heavy metals or marine biotoxins intoxication (Tan and Ransangan 2015; Venugopal and Gopakumar 2017).

In response to food safety issues, most countries have implemented sanitary control on the bivalve aquaculture industry, including clean aquaculture environment, sanitary processing and safety of final products (Anon 2005; García, Nascimento, and Barardi 2015). All new bivalve farms need to conduct sanitation surveys to provide an in-depth assessment of water quality in bivalve aquaculture area. In addition, regular inspections are required to assess the health status of the farms to ensure that all bivalve farms meet high sanitary standards. During harvest, the level of contaminants in farmed bivalves will be assessed. If any contaminants exceed the permissible limits, the harvested bivalves are usually kept in an indoor tank with clean seawater for depuration until contaminants dropped to below the permissible limits (Lees, Younger, and Dore 2010). As a result, farmed bivalves are generally more hygienic and safer than many other wild caught seafood.

Many surveys have shown that the level of contaminants in shellfish in the United State (Groth 2010) and United Kingdom (Rose et al. 2010; Li et al. 2018) are too low to pose serious hazards. For example, Li et al. (2018) revealed that the contaminant level of farmed mussels in Scottish is far lower than that of wild caught seafood around the coast of the United Kingdom, as well as the permissible limit sets by European Union (EU) (Fernandes et al. 2008). It is important to note that not all regions have adequate sanitation control. For example, Sivaperumal, Sankar, and Viswanathan (2007) revealed that the contamination level of heavy metals in bivalves in a popular seafood market in India reached the maximum levels prescribed by the EU and the FDA. Moreover, there are more than 50,000 intoxication incidents associated with bivalve consumption every year around the world (Tan and Ransangan 2015). Therefore, food safety is one of the biggest challenges for the rapid development of bivalve aquaculture. Food safety can only be ensured to a great extent in the near future through combination of well managed hygiene control that met the stringent quality standards and continuous vigilance by regulatory bodies.

Food security

Food security is defined as "a situation in which all people, at all times, can obtain sufficient, safe and nutritious foods to meets their dietary needs and for a healthy life" (Barrett 2010). Food security is increasingly concerned around the world, and the number of undernourished people has been increasing, from 785.4 million in 2015 to 821.6 million in 2018 (Food and Agriculture Organisation (FAO), 2020). Among them, about 700 million people (9.2% of the world's population, especially in Africa and Latin America) suffered from serious food insecurity in 2018, which means that they are facing a reduction in the quantity and quality of food consumed to the extent that they suffer malnutrition.

It is estimated that the global demand for seafood products in 2030 will be about 39% (about 607,200 thousand tonnes) higher than in 2016 (Food and Agriculture

Organisation (FAO), 2020). Gentry et al. (2017) believe that bivalve aquaculture is a promising solution to improve global food security, where almost every coastal country is suitable for bivalve aquaculture, and the potential production of bivalve aquaculture far exceeds the predicted seafood demand. In fact, except for China, the current production of bivalve aquaculture in other coastal countries, including Europe (613 thousand tonnes), Americas (574 thousand tonnes) and Oceania (112 thousand tonnes) is far lower than its potential production (Wijsman et al. 2018). It is worth noting that Africa, Asia and South America are the countries with the highest percentage of areas suitable for bivalve aquaculture, but bivalve aquaculture of these regions (except for China) are less developed or undeveloped (Gentry et al. 2017). Therefore, the development of inexpensive non-fed bivalve aquaculture can easily meet the needs of its own domestic seafood demand by producing nutritious and inexpensive animal protein, which can significantly improve the national food security and nutrition in these regions

Special attention should be given to rural populations with a much higher risk of food insecurity due to financial and transportation constrains, which result in a limited supply of fresh and affordable food (Thompson and Amoroso 2014). Rural shoppers may rely on expensive and less nutritious foods from nearby gas station convenience stores, or may have to travel far to a town with a supermarket or grocery store. Bivalves are an ideal aquaculture species for local production. They have a low maintenance cost and do not require an external food supply because they feed directly by filtrating their surrounding growing medium. It is worth noting that in the 1970s, the construction of aquaculture ponds in the inland or coastal farming in coastal areas of China played an important role in solving the problem of "difficulty in buying seafood" in rural populations (Wijsman et al. 2018).

Conclusion

In a nutshell, due to the unsustainable supply of fish meal and fish oil in finfish aquaculture and the continuous growth of human population, bivalve aquaculture plays an increasingly important role in filling the supply gap of n-3 LC-PUFA for human consumption. In general, the lipid nutritional quality of bivalves is of species-specific and geographical-specific. Bivalve aquaculture seems to be a promising option for protein and lipid sources of farmed aquatic animal. Therefore, encouraging populations to increase consumption of farmed bivalves may be a feasible strategy to increase EPA and DHA intake. The fast growing bivalve aquaculture is facing some challenges that require special attention, including the recurrent mass mortalities of farmed bivalves, food safety and food security issues.

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