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Review Article

Nutritional quality of the fresh and processed grey mullet (Mugilidae) products: a short review including data concerning fish from freshwater

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Abstract – This short review compiles the data concerning the quality of flesh, processed roe and smoked fillets of grey mullets (Mugilidae), including when available the data concerning the fish from freshwater and in particular those from Tunisian reservoirs. The biochemical and mineral composition of the fish, the nutritional benefits and the potential health risks related to the consumption of fish products are discussed with regard to human health, taking into consideration the nutritional recommendations and normative toxicological limits defined by leading health authorities. Flesh proximal compositions of fish from freshwater are relatively scarce, but the few available lipid data are within the very large proximal range (from less than 1% to more than 11%) reported for grey mullets in general. Most of the studies reveal the predominance of unsaturated fatty acids with a substantial proportion ω3 type not only for fish from marine environment but also for those from freshwater. Flesh constitutes a source of essential amino acids and mineral nutrients too. The mullets are generally reported to be safe for human consumption except the fish from heavily contaminated zones. Globally, it should be regarded as an interesting contribution to a healthy diet. The mullets are also greatly appreciated for the production of salted and dried roe as well as smoked fillets, which allow increasing their economic value while preserving products health beneficial attributes. Data concerning processing mullet's roe from freshwater are missing, but it may be supposed that these roes have acceptable texture, taste and flavour as they are highly sought by connoisseurs. It is recommended to perform studies on the qualities of freshwater mullet's roe and to look for labelling the origin for both the roes and the smoked fillets of mullet from Tunisian reservoirs dedicated to the production of drinking water as it would guarantee that the fish come from unpolluted environments.

Keywords: Mullets / quality / proximal composition / roe / smoked fillet / freshwater

1 Introduction

The grey mullets (Mugilidae) were well known and have been highly appreciated since antiquity. These fish species are well presented in different historical and archaeological archives, including literature and the sculptured friezes of the ancient civilizations from the Mediterranean area (Nash and Shehadeh, 1980). Nowadays, their commercial importance depends on the country, ranging from highly esteemed food in Tunisia, Egypt and Taiwan to being considered of little value in parts of Spain, France and Australia (Whitfield et al., 2012). In North Carolina, Alabama and Louisiana, the main mullet-producing states of the United States, there is little demand for mullet for human consumption due to its oiliness. But most commercial exploitation in these states targets roe-carrying females (for roe processing and export) and fish for mullet bait fisheries (Simon, 2016; Spring, 2016). However, in most of the producing countries, including those where mullets are undervalued fish species, there is an increasing interest for mullets during the spawning seasons. At that period, there is a demand for mullets for the exploitation of their roe, which becomes a highly value-added product when salted and dried. Worldwide, fish roe products are extremely valuable, and demand is growing at both international and domestic markets (Bledsoe et al., 2003).

Production statistics reported by the official authorities of producing countries do not systematically differentiate between the marine or freshwater origin of the fish and the variety of their environments, including lagoon, open sea,

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lakes or rivers. Moreover, it is often not specified whether the products were wild catches or produced by aquaculture. Nevertheless, in the reports of the Food and Agriculture Organization (FAO) of the United Nations concerning the annual nominal catches, there is often a differentiation between flathead grey mullet (*Mugil cephalus*) and the other Mugilidae species (FAO, 2011), which are generally grouped under mullets NEI (not elsewhere included). Indeed, among the family Mugilidae, the flathead grey mullet is the most widespread species; it is capable of living in a wide range of habitats, i.e. in (i) waters ranging from fresh to hyperhaline, (ii) both transparent and turbid waters, (iii) sandy or muddy habitats, and (iv) within a wide range of dissolved oxygen levels. The widespread occurrence together with its foraging at the base of the food web enables this species to be abundant and attain high biomass in many parts of its distribution range (Whitfield et al., 2012). It has been reported that *M. cephalus* comprised 29% of the world mullet capture fisheries production in 2013, although this appears to be an underestimation as a large part of the production reported as mullets NEI also includes this species. Hence, on a global scale *M. cephalus* probably constitutes almost 50% of mullet production, for both capture fisheries and aquaculture (Crosetti, 2016). For the main producing countries, more detailed statistical data can be obtained. Saleh (2008) reported that in Egypt the production of mullets reached 186,000 tonnes in 2005, among which aquaculture accounted for about 156,000 tonnes while harvest accounted for about 30,000 tonnes with a strong contribution (81.6%) from lakes and coastal lagoons. He also indicated that *Liza ramada* constituted an average of 58% of the catch while the flathead grey mullet *M. cephalus* was 23%. In Tunisia, the Ministry of Agriculture and Hydraulic Resources publishes every year the statistics concerning specifically the production of mullets in freshwater. The landings from catches in marine areas (sea and coastal lagoons) use to be around 2100–2400 tonnes/yr while those from freshwater used to vary between 260 and 360 tonnes/yr. The national production of freshwater fish, all species included, reached about 1200 metric tonnes in 2015 with mullets thus representing about 30%. However, despite the socioeconomic contribution of inland fisheries in terms of food security, employments and incomes, the sector is often neglected in national and international development discussion forums; the inland fishery sector is often sidelined in the competition for freshwater resources by the other better organized sectors such as agriculture (FAO, 2016). Overall, with a few exceptions, concerning the mullets produced in freshwater, there is a paucity of data and lack of worldwide comparable statistics.

Since a long time, there has been a large interest in studies concerning mugilids and a diversity of subjects. These have included the biology of the mullets (De Silva, 1980; Crosetti and Cataudella, 1995; Whitfield et al., 2012; Cardona, 2016; González-Castro and Minos, 2016; Ibáñez, 2016), the acclimation of mugilid to low salinities (Chervinski, 1977; Nordlie et al., 1982; El Cafsi et al., 2003; Khériji et al., 2003; Rabeh et al., 2010, 2015; Nordlie, 2016) the development of the early stages (Zouiten et al., 2008; Ben Khemis et al., 2013; Koutrakis et al., 2016), or the pollution and biomonitoring (Waltham et al., 2013) or stock enhancement and fisheries (Losse et al., 1991; Vidy and Franc, 1992; Crosetti, 2016; Leber et al., 2016) in the environments where they occur as well as aquaculture (Nash and Shehadeh, 1980; El-Sayed, 1991; Ben Khemis et al., 2006; Besbes et al., 2010; Crosetti, 2016; Gisbert et al., 2016; Altunok and Özden, 2017). Reviews on different topics related to biology, ecology and culture of grey mullet taxonomy have been compiled recently in a book edited by Crosetti and Blaber (2016). The quality of Mugilidae fish products (fish flesh or roe) also received some attention (Beddih et al., 2004; Rosa et al., 2009; Baptista et al., 2013; Mostafa and Salem, 2015), including the fish from freshwater (Huang et al., 2008; Yilmaz, 2009; Bouzgarrou et al., 2016; Bouzgarrou and Sadok, 2017; Ben Khemis et al., 2017). This study compiles the data regarding the quality of fresh and processed mullets products (dried salted roe and smoked fillets), including the data concerning fish from freshwater and in particular those from Tunisian reservoirs when available. The biochemical and the mineral composition of the fish, the nutritional benefits and the potential health risks related to the consumption of fish products are discussed with regard to human health taking into consideration the nutritional recommendations and normative toxicological limits defined by leading health authorities.

2 Nutritional quality of fresh mullet products (including fish from freshwater)

Some proximal compositions reported in the literature for flathead grey mullet (*M. cephalus*), the thin-lipped grey mullet (*L. ramada*), golden grey mullet (*Liza aurata*) and thick-lipped grey mullet (*Chelon labrosus*) are compiled in Table 1 with specification of water type. The data concerning the fish from freshwater are relatively scarce and do not allow a comparative study, although their compilation gives an insight into the present state of knowledge.

In mullets like in all fish species, proximal composition may be highly variable owing to a variety of factors, including diet, season, sex, age etc. These factors have an effect on the physiological status of the fish. Flathead grey mullet are among the fish showing the largest variation in fat content depending not only upon the season and geographic location of the catch but also upon the sexual maturity of the fish (Gooch et al., 1987). According to the data of these authors, the range of lipid contents may vary up to more than 10-fold. The few lipid data reported for the mullets from freshwater environments (Tab. 1) are within this very large proximal range. Nevertheless, it has to be kept in mind that at present *M. cephalus* is considered as a "species complex" (Whitfield et al., 2012; Durand, 2016), and therefore the comparisons between samples collected in different regions (Shen and Durand, 2016; Turan, 2016; Tran et al., 2017) of the world may have limited value.

Fat content is the most relevant discriminating aspect between species for the quality of the fish flesh (Lazo et al., 2017). As reported earlier, several populations do not appreciate mullets for consumption due to the oiliness of its flesh (Simon, 2016; Spring, 2016). Important aroma compounds characteristic of fresh fish are lipid-derived volatile compounds. These compounds are mainly generated by oxidative enzymatic reactions and autoxidation of lipids. In wild flathead grey mullet, a large number of key aroma-active components and a very low antioxidant activity value have been identified in the flesh (Cayhan and Selli, 2011). In

Table 1. Proximal compositions reported in the literature, for flathead grey mullet (*Mugil cephalus*), thin lipped grey mullet (*Liza ramada*), golden grey mullet (*Liza aurata*) and thick lipped grey mullet (*Chelon labrosus*).

Specie/Country	Locality Water type	Fish biometrics (weight; size)	Protein content (%)	Lipid content (%)	Moisture content (%)	Reference
Mugil cephalus						
Spain	Bay of Cadiz – earthen ponds **M**	500g – 1 kg	21.4 ± 0.7	0.6 ± 0.0	76.5 ± 1.1	Lazo et al., 2017
Tunisia	Wed Abid Lake **F**	_	_	6.9 ± 0.9	_	Bouzgarrou et al., 2016
Egypt	Nile Delta (Tanta) **B**	_	18.5 ± 0.00	8.4 ± 0.2	71.9 ± 0.1	Mostafa and Salem, 2015
India	Chittagong Coast **M**	_		9.9		Rowshan-Ali et al., 2014
India	Parangipettai Coast **M**	_	17.6 ± 0.2	2.4 ± 0.2	75.3 ± 0.1	Kumaran et al., 2012
Turkey	Mediterranean **M**	_	_	2.1 ± 0.1	_	Özogul and Özogul, 2007
US	Atlantic (Charleston) **M**	1150 g ; 41 cm	19.6 (17.3–20.8)	6.1 (0.9–11.8)	75.1 (64.6–79.9)	Gooch et al., 1987
Liza ramada						
Tunisia	Wed Abid Lake **F**	_	17.9 ± 0.4	4.6 ± 0.4	78.3 ± 0.5	Bouzgarrou and Sadok, 2017
Turkey	Mersin Gulf **M**		16.9 ± 0.2	0.4 ± 0.0	81.4 ± 0.2	Kalay et al., 2008
Liza aurata						
Italy	Mediterranean **M**	42 g; 19 cm	_	5.9 ± 0.1	_	Prato and Biandolino, 2012
Iran	Caspian Sea **M**	632g; 39 cm	_	4.5 ± 0.21	_	Hedayatifard and Youssefian, 2010
Iran	Caspian Sea **M**	875g; 42 cm	_	9.3	_	Hedayatifard, 2009
Chelon labrosus						
Tunisia	Experimental conditions					Rabeh et al., 2015
	F	30-40 g	_	4.9 ± 0.1	56.0 ± 0.2	
	M	30-40 g	_	1.8 ± 0.0	63.0 ± 0.1	

F – Freshwater; **B** – Brakish water; **M** – Marine water; _ – not indicated.

addition, grey mullet flesh has been often characterized by bitter flavour (Lazo et al., 2017). Chemical compounds occurring in the environment also may impair the flavour of fish (Per-Edvin, 1984) and mullets are among the sensitive fish species that may accumulate such compounds in their flesh. Indeed, grey mullets like eutrophic waters and often school at wastewater effluents or in harbours, feeding on both the surface water and the bottom (Cardona, 2016). This often leads to the flesh developing a bad flavour and justifies the bad reputation of the species among consumers. A kerosene-like taint in the flesh of mullets from hydrocarbons polluted zones has been reported (Connell, 1978), while freshwater caught mullets are frequently described as having a muddy or sulfide-like taste (Thulasi and Lakshmi, 2016).

The fatty acids profiles also show variations between the different studies (Tab. 2). However, it is not possible to strictly relate these changes or a part of them to the living conditions in freshwater. Comparatively to saturated fatty acids (SFA), most of the studies reveal the predominance of unsaturated fatty acids, including mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA). They also show that within PUFAs, the fatty acids of the ω3 type generally account for a substantial proportion. These include eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in particular, both of which are essential in human nutrition. This is the case not only for the flesh of fish from marine environment but also true for the flesh of fish from freshwater, although in freshwater the DHA level seems relatively moderate (Bouzgarrou et al., 2016). The weekly needs in EPA + DHA for maintaining a good cardiovascular function have been estimated by the WHO (World Health Organization) and the EFSA (European Food Safety Authority) and resulted in recommendations of about 1.5 g per week for an adult. Hence, according to the data reported, a portion of 150 g of mullet flesh may largely or totally cover this weekly need (Mostafa and Salem, 2015; Bouzgarrou et al., 2016; Bouzgarrou and Sadok, 2017).

Table 2. Proportions of fatty acid types reported in the literature for fresh flathead grey mullet (*Mugil cephalus*) and golden grey mullet (*Liza aurata*).

Specie/FAO area or country	Locality Water type	SFAs content (%)	MUFAs content (%)	PUFAs content (%)	Processed or raw	Reference
Mugil cephalus						
Tunisia	Wed Abid Lake	28.7 ± 0.3	28.3 ± 0.2	26.7 ± 0.3	Raw	Bouzgarrou et al., 2016
	F	32.4 ± 0.3	36.5 ± 1.5	22.1 ± 0.1	Smoked	
Egypt	Nile Delta (Tanta)	36.9	22.6	33	Raw	Mostafa and Salem, 2015
	B					
India	Parangipettai Coast	40.2 ± 0.2	33.5 ± 0.3	26.3 ± 0.3	Raw	Kumaran et al., 2012
	M					
Turkey	Mediterranean	32.8	25.8	24.8	Raw	Özogul and Özogul, 2007
	M					
US	Atlantic (Charleston)	35.7 to 39.4	11.3 to 29.2	16.6 to 40.4	Raw	Gooch et al., 1987
	M					
Liza ramada						
Tunisia	Wed Abid Lake	48.6 ± 0.9	24.1 ± 1.5	17.8 ± 0.1	Raw	Bouzgarrou and Sadok, 2017
	F	54.8 ± 3.9	19.5 ± 1.9	19.6 ± 1.3	Salted	
		47.9 ± 1.7	23.2 ± 1.4	20.5 ± 0.4	Smoked	
Liza aurata						
Italy	Mediterranean	39.8 ± 0.9	31.4 ± 1.4	27.7 ± 0.5	Raw	Prato and Biandolino, 2012
	M					
Iran	Caspian Sea	35.2 ± 0.6	46.4 ± 1.4	7.1 ± 0.3	Raw	Hedayatifard and Youssefian, 2010
	M	31.7 ± 1.2	45.3 ± 1.3	15.2 ± 0.4	Salted	
Iran	Caspian Sea	22.5	34.4	21.9	Raw	Hedayatifard, 2009
	M					

SFAs – Saturated Fatty Acids; **MUFAs** – Mono Unsaturated Fatty Acids; **PUFAs** – Poly Unsaturated Fatty Acids
B – Brakish water; **M** – Marine water; _ – not indicated;

Overall, the reported fatty acids profiles confer excellent nutritional properties to mullets flesh in terms of indices of lipid quality, i.e. the ω3/ω6 ratio (ratio of unsaturated fatty acids types) as well as the IA index (index of atherogenicity) and the IT index (index of thrombogenicity). These indices are calculated from the data on the fatty acid composition using specific mathematical formulas (Ulbritch and Southgate, 1991) expressing relationships between SFAs (which are considered as having pro-atherogenic and pro-thrombogenic properties) and MUFAs and PUFAs (which are considered as having anti-atherogenic and anti-thrombogenic properties). The value of IA indicates if the lipids have the tendency to adhere to cells of the immunological and circulatory system or inversely if they inhibit the aggregation of plaque and diminish the levels of esterified fatty acid, cholesterol and phospholipids, thereby preventing the appearance of micro- and macrocoronary diseases; the value of IT shows the tendency to form clots in the blood vessels (Garaffo et al., 2011). In the study of *M. cephalus* from freshwater by Bouzgarrou et al. (2016), the IA and IT values were reported to be 0.93 and 0.44, respectively. The calculated ω3/ω6 ratio corresponded to a value of 2.6, which is within the range of the values established for Mediterranean fish in general and clearly confer anti-thrombotic and anti-inflammatory properties to mullet flesh (Din et al., 2004). In flathead grey mullet (*M. Cephalus*), seasonal increases of fat contents were due to the increase in muscle fat storage rather than increase in muscle phospholipids; hence, these lipids consisted mainly of triglycerides, which comprise proportionally less PUFAs than phospholipids (Gooch et al., 1987). These authors concluded, therefore, that the negative correlation between fat content and long-chain PUFAs levels for these species is not surprising (Gooch et al., 1987).

In addition to their lipid contents and fatty acids profiles, mullet flesh constitutes a source of amino acids that is interesting for human nutrition. Ten of these amino acids are considered essential amino acids for human healthy nutrition: phenylalanine, valine, tryptophan, threonine, isoleucine, methionine, histidine, arginine, leucine and lysine (Kumaran et al., 2012). Similarly, mullet flesh from both marine or freshwater is also an interesting supply of essential mineral nutrients, including P, K, Na, Ca, Fe, Zn, Mn, Mg and Se (Kumaran et al., 2012; Ben Khemis et al., 2017). The calculated provisional intakes (PIs) from a standard fish portion of 150 g of flesh per meal are all far below the upper limits (ULs) established by medical authorities and comparatively to the recommended daily allowances (RDAs) or the adequate intakes (AIs). Mullet consumption would substantially (>15% of daily requirements) contribute to cover the nutritional requirements and thus should also be considered an interesting contribution to a healthy diet in regard to mineral content (Ben Khemis et al., 2017).

Table 3. Proximal compositions reported in the literature, for flathead grey mullet (*Mugil cephalus*) and golden grey mullet (*Liza aurata*) raw or processed roe.

Specie/FAO area or country	Locality Water type	Protein content (%)	Lipid content (%)	Moisture content (%)	Processed or raw	**Reference**
Mugilcephalus						
Turkey	Homa Lagoon- **B**	41.8 ± 0.6	13.3 ± 1.5	26.3 ± 0.5	Dried	Çelik et al., 2012
		25.7 ± 0.4	13.1 ± 0.2	50.2 ± 0.2	Raw	
Eastern Central Atlantic (34)	Atlantic – **M**	_	22.9 ± 1.5	_	Salted & dried	Rosa et al., 2009
South West Atlantic (41)	Atlantic – **M**	_	32.5 ± 1.5	_		
Egypte	Mediterranean – **M**	_	27.7	51.4	Raw	Assem et al., 2008
Japan	Nagasaki – **M**	38.7 ± 2.1	33.1 ± 2.5	23.4 ± 1.7	Salted & dried	Itoh et al., 2006
	Nagasaki – **M**	28.1 ± 0.3	20.3 ± 2.0	50.2 ± 6.0	Raw	
Australia	_	26.4 ± 0.7	20.1 ± 0.3	53.2 ± 0.6	Raw	
Formosa	_	44.2	26.2	25.2	Salted & dried	
Italy	_	42.8	29.7	25.2	Salted & dried	
Mauritania	Atlantic – **M**	44.4	31.7	_	Salted & dried	Beddih et al., 2005
Mauritania	Atlantic – **M**	_	30.9	_	Salted & dried	Beddih et al., 2004
Tunisia	Mediterranean – **M**	_	27.4	_	Salted & dried	
Liza aurata						
Iran	Caspian Sea	_	10.3	_	Raw	Hedayatifard, 2009

3. Nutritional quality of processed mullet products (*including fish from freshwater*): smoked fillets and salted-dried roe

The flathead grey mullet, *M. cephalus*, is greatly appreciated late during the reproduction season, which corresponds to the end of summer and autumn in the Mediterranean area, for the production of salted and dried roe. The latter is known as bottarga (Italian) or boutargue/poutargue (French) from the Arab boutharkha (dried fish eggs), and sold at high prices (up to more than 200 €/kg) as a delicacy of the Mediterranean gastronomic tradition (FAO, 2015a; Crosetti, 2016). The dried roe may also be produced from *L. ramada* in winter or spring (Saleh, 2008). Mullets are highly fecund, relatively short-lived, with a low age at maturity, making them resilient to heavy fishing pressure (Simon, 2016). Nevertheless, during the last two decades, drastic reductions of annual nominal catches have been reported in the Western Central Atlantic as well as the Mediterranean and the Black Sea (FAO, 2011). Both these regions were historically major mullet-producing zones. The major reasons explaining the drastic reduction of mullet fry availability are increased production of dried mullet roe and excessive seed fishing activities, which include the illegal activities for farming and lakes restocking. These activities have indeed a negative impact on fish recruitment: as each migrating ripe female killed to extract its ovaries corresponds to the loss of 2–4 million eggs and at least many hundreds of thousands of seeds (Saleh, 2008).

Information about the annual production of mullet roe is often scarce, since part of the production is sold directly as a traditional local product. These local products do not go through the wholesale traders' circuit and are, therefore, often not officially recorded (Crosetti, 2016). According to Blaise (2017), few Tunisian producers import frozen roe from Senegal or even from Florida, Australia or Brazil, in order to provide enough products all over the year and in particular during the end-of-year festive period. For the roe of mullets from freshwater, the data are totally missing. But for Sidi Salem reservoir, the largest and most important producing Tunisian reservoir, main wholesalers informed us (personal communication) that mullet females are highly sought during late August and September for their developing roe by a few connoisseurs. This suggests that these roe from mullets of freshwater origin have acceptable texture, taste and flavour for processing, although the freshwater origin of the fish has never been mentioned for these local market products. Hence, we strongly recommend for performing studies on the qualities of the roe in freshwater mullets. Such studies may also contribute to diversifying the commercialization and creating opportunities for increasing the economic value of freshwater mullet production. Even if it has been demonstrated that *M. cephalus* starts its reproductive development in freshwater (Tamaru et al., 1994; McDonough et al., 2005), we need to keep in mind that this species does not ovulate naturally in freshwater (Abraham et al., 1967; Shireman, 1975). Tamaru et al. (1994) reported that only 30% of the females maintained in freshwater reached the state of maturity at which spawning could be artificially induced (i.e. when the oocyte diameter is at least 600 μm). Females at the fourth (gravid) or fifth (spawning) gonad maturity stage according to the Kesteven's scale are preferred for roe processing (Katselis et al., 2005). In freshwater, oocyte diameters generally remain smaller than 350–400 μm (Tamaru et al., 1994; Assem et al., 2015), which corresponds to the third gonad maturity stage. In ripe *M. cephalus* females, the gonado-somatic index (GSI) is highly variable (Kurma and Ramesh, 2016). Nevertheless, it commonly attains 16–17% (Katselis et al., 2005, Macdonough et al., 2005) and even much higher values up to a maximum of 22–25% have also been reported (Assem et al., 2008, 2015). For the females from a freshwater Egyptian fish farm, only a slight increase in GSI values up to 2.3% maximally has been reported by Assem et al. (2015).

Table 4. Proportions of fatty acid types reported in the literature for flathead grey mullet (*Mugil cephalus*) and golden grey mullet (*Liza aurata*) raw or processed roe.

Specie/FAO area or country	Locality – Water type	SFAs content (%)	MUFAs content (%)	PUFAs content (%)	Processed or raw	Reference
Mugil cephalus						
Turkey	Homa Lagoon – **B**	41.8 ± 0.6	13.3 ± 1.5	26.3 ± 0.5	Dried	Çelik et al., 2012
		25.7 ± 0.4	13.1 ± 0.2	50.2 ± 0.2	Raw	
Eastern Central Atlantic (34)	Atlantic – **M**	15.8 ± 0.5	29.9 ± 0.2	43.1 ± 0.3	Salted & dried	Rosa et al., 2009
South West Atlantic (41)	Atlantic – **M**	17.4 ± 0.5	45.3 ± 0.1	26.7 ± 0.3	Salted & dried	
Egypte	Mediterranean – **M**	_	27.7	51.4	Raw	Assem et al., 2008
Mauritania	Atlantic – **M**	17.9	39.4	28.8	Salted & dried	Beddih et al., 2004,2005
Tunisia	Mediterranean – **M**	2.8	41.4	39.0	Salted & dried	
Turkey	Sufa lagoon **- B**	17.5 ± 0.1	42.9 ± 0.7	39.3 ± 0.4	Salted & dried	Sengör et al., 2003
		11.19 ± 0.2	42.9 ± 0.7	39.3 ± 0.4	Raw	
Liza aurata						
Iran	Caspian Sea	10.9	40.5	27.8	Raw	Hedayatifard, 2009

SFAs – Saturated Fatty Acids; **MUFAs** – Mono Unsaturated Fatty Acids; **PUFAs** – Poly Unsaturated Fatty Acids
B – Brakish water; **M** – Marine water; _ – not indicated.

The mullet's roes are very rich in lipids (Assem et al., 2008; Hedayatifard 2009) and similar to flesh, the contents show variations according to season and geographic origin as indicated by the compiled proximal compositions (Tab. 3) concerning raw and processed roe of flathead grey mullet (*M. cephalus*). The raw and dried roe also show variable fatty acids profiles, but the different studies generally highlight elevated unsaturated fatty acids content, although the relative proportions of MUFAs and PUFAs also may be variable between products (Tab. 4). The lipid content in the dried roe is higher compared to the raw product because of the moisture loss. However, the raw and the corresponding dried roe exhibit similar relative levels of the different lipid components (fatty acids types: SFA, MUFA and PUFA) with generally high contents in long chain fatty acids within PUFAs. According to Sengör et al. (2003), the amounts of docosadienoic acid (C22:2) and DHA (C22:6) of raw and bees waxed caviar oils were nearly 1.5–2.9 times higher than those of the fish fillets. Rosa et al. (2009) investigated the susceptibility of mullet roe lipids to oxidative degradation induced by the process (salting, drying and sometimes grating). They reported that the *n*-3 PUFA showed a high stability and very minor oxidation during processing and storage, indicating that mullet roe may be regarded as stable natural source of *n*-3 PUFA and, therefore, beneficial for human health. Other results showed interesting anti-tumour properties of bottarga lipids, and qualify this fish product as a food with nutraceutical properties and potential benefits in colon cancer prevention (Rosa et al., 2013).

The mullet roe from the Missolonghi-Aitoliko lagoon (Greece) called "Avgotaracho Messolonghiou" is one of the few seafood products that proudly benefits from a "protected designation of origin" (PDO) label (FAO, 2015a). Authentication of the product origin, using PCR-RFLP analysis of 16s rRNA-mtDNA segment, was developed (Klossa-Kilia et al., 2002). It might be interesting to look for such labelling of origin for both the roe and the smoked fillets of mullet from Tunisian reservoirs dedicated to the production of drinking water. Indeed, the drastic environmental protection and controls performed in such reservoirs to guarantee its suitability for the production of drinking waters in compliance to the standards of the WHO also provides a guarantee that the fish comes from an unpolluted environment. Nevertheless, particular attention might be necessary to check risk of off-flavour contamination of products by compounds derived from microorganisms. These compounds include geosmin and 2-methylisoborneol, which are potentially frequent in freshwater and give a muddy/musty smell and flavour to the flesh of the fish (Angioni et al., 2015).

Ripe females from which ovaries are removed to be salted and dried (FAO 2015a, Crosetti 2016) or more generally mullet fish (Efiuvwevwere and Iweanoge, 1991; Antoine et al., 2000) may be filleted, salted and smoked to become an attractive value-added fish product with good nutritional attributes and improved storage potential. Recently, in Tunisia, such processes were also applied to fillets of both flathead grey mullet (*M. cephalus*) and thin-lipped grey mullet (*L. ramada*) from freshwater (Bouzgarrou et al., 2016; Bouzgarrou and Sadok, 2017). In the smoked fillet, the lipid content significantly increases comparatively to the fresh product. This change, which is related to muscle water loss during processing, may reach a twofold increase according to the data reported by Bouzgarrou et al. (2016). However, only few changes are generally reported in the relative levels of the different lipid components and fatty acids profiles after processing. In addition, the sensory attributes, the health benefit indices, the spoilage indicators, or the bacterial loads of smoked products showed excellent levels and normally remain within good intervals during shelf life storage. In Orbetello Lagoon (Italy), the smoked mullet fillets are sold as a nice high-priced product (36€/kg). Hence the smoking of ripe females from which ovaries are removed is considered an excellent method to provide added value to a by-product of roe processing (Crosetti, 2016). In Tunisia, a successful innovation consisting in the addition of a natural polyphenol extract (from

quince fruit *Cydoniaoblonga* Miller) was tested to improve the preservation of the smoked freshwater fish product (Bouzgarrou et al., 2016). In this study, 60 inexperienced juries, representing Tunisian consumers, assessed the attributes of the smoked product by scoring flavour, door, juiciness and texture using a four-point hedonic scale. The smoked fillets of mullet (*M. cephalus*) from freshwater and treated by a low dose of polyphenols received an excellent global score, indicating their appreciation by local consumers. However, such products are not yet available on local markets. According to Lazo et al. (2017), flathead grey mullet (described with bitter flavour) should be used in product processing that can mask their peculiar characteristics which are undesirable for some consumers in specific markets.

3 Health risks related to consumption of mullet products

Mullets flesh, dried roe or smoked fillets are perishable feed like all fish and processed fish products (Huss, 1993). They may be involved in the transmission of pathogenic microorganisms and toxins as well as foodborne illness (Brandas et al., 2015; Mostafa and Salem, 2015) and a risk of contamination and growth of pathogenic bacteria cannot be excluded. Thus, sanitary microbiological control of the fish and the working space of the workers processing the fish is essential. Therefore, the Hazard Analysis Critical Control Point (HACCP) system must be applied rigorously in any fish industry dealing with mullet products. Golden grey mullet stored in ice and in a refrigerator showed that sensory attributes positively correlated with microbial load and that the shelf life was 10 days in ice and about 14 days in the refrigerator, which are similar to the trends generally observed for chill storage of fish (Bahmani et al., 2011).

In addition to spoilage and microbial risk health, the fish and their processed products, including those from freshwater, are considered to be among the food categories that contribute the most to dietary human exposure to a large variety of contaminants (WHO, 2011a,b). Heavy metals, dioxins and PCBs (polychlorinated biphenyls), pesticides and PAHs (polycyclic aromatic hydrocarbons) are among the contaminants considered as the most dangerous. Hence, maximum levels or provisional tolerable intakes for such contaminants are strictly regulated by safety standards concerning fish (EC, 2006). There is a widespread interest in using mullet fish, and in particular the flathead grey mullet (*M. cephalus*), in biomonitoring studies (Altındag and Yigit, 2005; Ben ameur et al., 2013; Waltham et al., 2013; Bozcaarmutlu et al., 2014; Ben Khemis et al., 2017). These studies include rivers and reservoirs. The mullets are generally reported to be safe for human consumption (Baptista et al., 2013), with an exception for the fishes harvested from heavily contaminated marine (Dural et al., 2006; Waltham et al., 2013) and freshwater (Yilmaz, 2009; Djedjibegovic et al., 2012) environments.

PAHs are combustion by-products that display a range of toxic, mutagenic and carcinogenic effects. Their concentrations are generally higher in smoked foods than in the corresponding non-smoked foods (EC, 2006; Forsberg et al., 2011). During smoking, an increased risk of accumulation of PAHs may be related to the elevated lipid content of the fish, as the PAHs are lipophilic compounds. Hence, the smoked lipid-rich fish products can thus be of concern for public health. Nevertheless, despite the high lipid content of mullet flesh, both hot and cold smoking processes have been reported to be safe. Indeed, the resultant contents of benzo(*a*)pyrene and the sum of the four PAHs (chrysene, benzo[*b*]fluoranthene, benz[*a*]anthracene and BaP) always remained far below the normative limit even though they showed much higher levels than fresh unprocessed mullet flesh (Bouzgarrou et al., 2016; Bouzgarrou and Sadok, 2017).

4 Conclusions and ecological considerations

Responsible stocking and culture-based fisheries, including in dam lakes and reservoirs, are considered examples of "Blue growth" interventions (FAO, 2015b). They contribute to food security, as well as to creation of economic resources and employment in remote regions where working opportunities are generally scarce (Steenfeldt et al., 2015). Several fish species may be concerned with such practices, but the grey mullets are certainly among the best candidates with regard to their ecological profile, their commercial importance and the potential processing of highly value-added product. At present mullet stocking and aquaculture still rely mainly on capture of wild fry because mass production of hatchery juveniles are not yet available. Therefore, the major drive for the future sustainable development of mullet production is definitely dependent on shifting from harvesting wild fry to supply of "hatchery-reared fry" for stocking. Large efforts are spent in that sense among others in the frame of federated research projects such as DIVERSIFY, a EU funded project, or the "Stock Enhancement and Production of the Grey Mullet Fry – A Sustainable Choice" a USAID-MERC funded project.

A second major drive for maintaining and even increasing fry stocking and thus fisheries in freshwater reservoirs is achieving good quality of fresh and processed products of mullets from such environments. This short review was based on the compilation of the data regarding the quality of fresh and processed (roe and smoked fillets) mullet products, including when available the data concerning the fish from freshwater and in particular those from Tunisian reservoirs. It appeared from the few available data that proximal compositions are within the very large proximal ranges generally reported for mullets. In addition, the reported fatty acids profiles of the mullets show that the flesh confers excellent nutritional properties for human consumption that is shown by the indices of lipid quality, i.e. the ω3/ω6 ratio (ratio of unsaturated fatty acids types), as well as the index of atherogenicity or the index of thrombogenicity. A portion of 150 g of mullet flesh may largely or totally cover the weekly needs in essential fatty acids, namely (EPA + DHA) estimated to be 1.5 g per week by health authorities. Mullet flesh should also be considered for its contribution to a healthy diet since it may represent an interesting supply of amino acids and essential mineral nutrients.

The consumption of mullet is sometimes not appreciated due to the oiliness of the fish flesh or the off-flavour of flesh or roe by compounds derived from microorganisms (geosmin or 2-methylisoborneol which give a muddy/musty smell) or from

hydrocarbons in polluted zones (which give a kerosene-like taint to the flesh). Except the fish from heavily contaminated zones in marine and freshwater environments, the mullets are generally reported to be safe for human consumption.

The grey mullets are also greatly appreciated for the production of salted and dried roe as well as smoked fillets, which allow increasing its economic value by diversification of products. It has been demonstrated that in freshwater environments, flathead grey mullet starts its reproductive development but does not ovulate naturally as the fish does not achieve a final maturation of its gonads. Data concerning processing of mullet's roes from freshwater are missing, but it may be supposed that these roes have acceptable texture, taste and flavour as they are highly sought by few connoisseurs. It might be interesting to look for labelling the origin for both the roes and the smoked fillets of mullet from Tunisian reservoirs dedicated to the production of drinking water as it would guarantee that the fish come from unpolluted environments.

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