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Quality parameters of wild white trevally (*Pseudocaranx dentex*) natural spawn kept in captivity

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ABSTRACT

The white trevally (*Pseudocaranx dentex* Bloch & Schneider, 1801) is a widely distributed carangid, commercially exploited in both the Pacific and eastern Atlantic. Most published works refer to the use of hormonal induction with gonadotropin-releasing hormone for egg supply with generally low fecundities and of poor quality. This study aimed to contribute for a better knowledge on the husbandry conditions that allow for natural spawning of white trevally in captivity. Wild white trevallies were kept in captivity for four years until natural spawning occurred. Nine breeders were kept in a $10m^3$ concrete tank at a density of 5 Kg/m^3, under natural photoperiod and natural water temperature fluctuations. Spawning started when water temperature reached 19 °C and lasted for two months. Viability rates varied between 35 and 79% and the average number of spawned eggs *per* female was of 280×10^3. Egg total lipids (16%DW) and fatty acid profile (expressed as a % total detected) remained constant throughout the spawning season and were not correlated with any egg viability parameters. Neutral lipids, a major energy source in marine fish eggs and larvae, accounted for 50% of lipid classes, followed by glycolipids and phospholipids. Within lipid fractions, the neutral lipids presented high amounts of mono-unsaturated fatty acids followed by equally high contents of polyunsaturated fatty acids. Docohexaenoic acid (DHA) was mainly found in the phospholipids fraction, though it was present in high amounts in all lipid classes. However, no significant correlations were observed between the DHA content and the egg viability parameters. The percentage of arachidonic acid (Ara) (< 0.1%) was low, possibly due to a deficiency of this fatty acid in the broodstock diet. Polyunsaturated fatty acids content, mostly represented by DHA and eicosapentaenoic acid (EPA), was positively correlated with hatching rate. Correlations observed between chemical composition of the eggs and viability parameters highlight the fact that egg quality is deeply influenced not only by environmental factors but also by broodstock management techniques.

1. Introduction

There is a worldwide increasing demand for more sustainable and profitable aquatic products. Thus, the development of new and competitive products is of paramount importance if aquaculture is to boost production in Europe. Carangids have received attention in various parts of the world during the past 30 years as potential new species for aquaculture diversification. The white trevally (*Pseudocaranx dentex* Bloch & Schneider, 1801) is a widely distributed carangid, commercially exploited in both the Pacific and eastern Atlantic (Masuda and Tsukamoto, 2000; Scandol and Rowling, 2007; Smith-Vaniz et al., 2015). In Japan, there is a long history of white trevally off-shore cultivation and sea-ranching (FAO, 2006–2017; Harada, 1970; Harada et al., 1984; Kuwada et al., 2008) and induced spawning performance of white trevally kept in captivity fed different artificial diets has been previously described (Table 1). In Europe, white trevally culture is still in an embryonic status (Andrade et al., 2012; Roo et al., 2012) and a major constraint is the lack of a regular egg supply and most importantly good quality eggs. Roo et al. (2012) referred to the use of hormonal induction with gonadotropin-releasing hormone (GnRh) for egg supply, resulting in low fecundities and low hatching rates. Nevertheless, the collection of fertilized eggs obtained from natural spawning is a routine technique in aquaculture which minimizes the handling stress of broodstock fish (Bromage et al., 1994) and until now very few cases of white trevally spontaneous spawning under captivity have been reported (Andrade et al., 2012;Murai et al., 1987).

Good quality eggs have been generally defined as those exhibiting low mortalities at fertilization, hatching and first feeding (Bromage et al., 1992). More recently, Bobe and Labbe (2010) defined fish egg quality as the ability of the egg to be fertilized and subsequently

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Table 1
Published literature on spawning performance of white trevally kept in captivity (nd, no available data; temp., temperature; RF, raw fish mix; DP, dry pellets).

	Captivity conditions			
	System type	Breeders weight (Kg)	Density (Kg/m^3)	Diet
Watanabe et al. (1998) & Vassallo-Agius et al. (1998)	Net cage (5 × 5 × 5 m), then moved to 65m^3 tanks	4.8 ± 0.8	0,42 (4♀) 0,46 (5♀)	RF Soft-dry pellets (SDP)
Vassallo-Agius et al. (2001c)	Net cage (5 × 5 × 5 m), then moved to 65m^3 tanks	3.6 ± 0.5	0,29 (5♀)	RF Squid DP Fish-squid-krill DP
Vassallo-Agius et al. (2001a)	Net cage (5 × 5 × 5 m), then moved to 65m^3 tanks	3.5 ± 0.4	0,56 (7♀)	RF Squid meal + Astax suppl. DP
Vassallo-Agius et al. (2001b)	Net cage (5 × 5 × 5 m), then moved to 65m^3 tanks	3.7 ± 0.6	0,30 (4♀RF; (5♀ DP; Astax DP)	RF Steam DP Astaxanthi suppl. DP
Vassallo-Agius et al. (1999)	Net cage (5 × 5 × 5 m), then moved to 65m^3 tanks	nd	0,40 (4♀)	RF Soyabean + spirulin screw extruded DP

	Reproductive performance				
	Spawning	Production (avg number of eggs/female/day)	Egg diameter (μm)	Oil droplet diameter (μm)	Eggs total lipids
Watanabe et al. (1998) & Vassallo-Agius et al. (1998)	Induced by temp. change (22 °C)	113.9×10^3 213.2×10^3	970 ± 20 968 ± 21	256 ± 8 256 ± 8	14,9 24,1
Vassallo-Agius et al. (2001c)	Induced by temp. change (22 °C) + HCG	233×10^3 114×10^3 122×10^3	977 ± 14 972 ± 26 976 ± 23	246 ± 9 243 ± 12 247 ± 9	25,93 23,75 26,96
Vassallo-Agius et al. (2001a)	Induced by temp. change (22 °C)	48.5×10^3[a] 51.5×10^3[a]	997 ± 18 994 ± 15	258 ± 8 252 ± 8	nd
Vassallo-Agius et al. (2001b)	Induced by temp. change (22 °C) + HCG	203×10^3 68×10^3 139×10^3	984 ± 23 990 ± 26 980 ± 22	247 ± 11 250 ± 10 253 ± 11	22,34 23,74 22,6
Vassallo-Agius et al. (1999)	Induced by temp. change (22 °C)	55.9×10^3[a] 37.2×10^3[a]	951 ± 22 985 ± 24	251 ± 22 256 ± 7	nd

[a] Avg number of egg/Kg.female/day.

develop into a normal embryo, while Çoban et al. (2011) considered the potential of an egg to hatch into a viable larva. Despite the different definitions, it is accepted that numerous factors affect egg quality in fish, such as environmental parameters (Lahnsteiner and Kletzl, 2012); broodstock diet (Almansa et al., 1999; Bromage et al., 1992; Furuita et al., 2002; Izquierdo et al., 2001; Zakeri et al., 2009); husbandry practices (Bromage, 1995) and the domestication level of the species (Bobe and Labbe, 2010; Migaud et al., 2013). Several physical, biological and biochemical parameters are used as indicators of broodstock reproductive performance and egg quality (Bromage, 1995). Besides fertilization and hatching rates, parameters such as buoyancy, egg size, distribution of lipid droplets and blastomere morphology have been cited as reliable indicators of egg quality (Aristizabal et al., 2009; Kohn and Symonds, 2012; Mansour et al., 2008). In addition, biochemical parameters, such as eggs fatty-acid composition, in particular n-3 HUFA concentrations (Almansa et al., 1999; Bruce et al., 1999; Fernández-Palacios et al., 1995; Furuita et al., 2002; Navas et al., 1997) and n-3/n-6, DHA/ArA, EPA/ArA ratios (Bell and Sargent, 2003; Pickova et al., 1997; Tveiten et al., 2004) were suggested to affect egg quality and larval survival in several species. The fatty-acid composition of white trevally eggs obtained by induced spawning after hormonal treatments and/or water temperature manipulation has been characterized and compared between broodstocks fed different formulated diets in Japan (Vassallo-Agius et al., 1998, 1999, 2001a, 2001b, 2001c; Watanabe et al., 1998).

If white trevally is to be seen as a candidate for the European aquaculture diversification, the ability to control eggs production and quality is a major requirement for the sustainable cultivation of this species. A full control of sexual maturation and spawning under captivity is a primary requirement for broodstock management and good farming practice and it is often achieved through environmental manipulation (Bromage, 1995). The knowledge of environmental conditions allowing for spontaneous spawning under captivity and the characterization of egg quality under such conditions may be a useful reference to establish a protocol for environmental manipulation towards the control of reproduction of Eastern Atlantic white trevally. As mentioned above, egg quality is deeply influenced not only by environmental factors and broodstock management techniques, but also by the aquaculture system used and the domestication level of the species or the population and these factors may act in a species-dependent manner. The present study was not a nutritional trial but rather sought to associate and characterize white trevally natural spawning performance under standard operating procedures in a marine hatchery using morphological and chemical analyses as indicators of egg quality, further increasing knowledge on white trevally culture techniques.

2. Material and methods

2.1. Broodstock and rearing system

White trevally individuals (*Pseudocaranx dentex*) were captured off the south coast of Madeira Archipelago (Portugal) and transported to the Mariculture Center of Calheta, a Governmental Marine Hatchery Center. Fish were kept in a 10m^3 concrete tank under natural photoperiod with constant water renewal. Salinity was 36‰ and temperature ranged from 18 to 24 °C year-round. Fish were fed near satiation once a day, six days a week with a moist pelleted diet- Lansy Breed Maturation, INVE (Table 2), supplemented twice a week with a mixture of low commercial value diet, mainly chub mackerel (*Scomber japonicus*), european squid (*Loligo vulgaris*) and blue mussel (*Mytilus edulis*) at a ratio of 2:2:1. All the individuals were weighted every year before the spawning season. After four years in captivity, natural spawning occurred and the broodstock was kept at a density of 5.073 kg/m^3, with a total of nine breeders (4Males:5Females).

Table 2
Proximate composition of Lansy Breed Maturation moist pelleted diet.

Moisture	22%
Crude protein	40%
Crude ash	12%
Crude lipids	15%
Crude fiber	1%
Phosphorus	1.3%
Vit. A	11.000 IU/Kg
Vit. D3	2.100 IU/Kg
Vit. E	2.100 IU/Kg
Vit. C	4.100 IU/Kg
DHA/EPA	2
Σω3HUFA	36 mg/g dwt

2.2. Reproductive performance

Broodstock reproductive performance was evaluated by the total number of spawning events, total number of eggs, proportion of viable (buoyant) and unviable (sinking) eggs, fertilization rate and hatching rate. During the spawning season, an egg collector tank (100 L), with an 800 μm mesh size bag, was placed by the side opening of the broodstock tank. Floating eggs were collected by overflow and stocked in the collector tank with flowing water and air supply. The collector tank was monitored every morning, at 9 am. Whenever spawning had occurred, the eggs were collected, placed in a 5 L bucket with saltwater for total number and viability estimation. In each spawning event, the total number of spawned eggs and viability rates were estimated according to Fernández-Palacios et al. (1995). Ten samples of 5 mL were observed under the stereoscope. In each 5 mL sample, two fractions could be distinguished: a fraction of viable buoyant eggs and a second fraction of sinking eggs (non-viable). Viable fertilized eggs were described as the percentage of morphologically normal buoyant eggs at the morula stage and described as transparent, perfectly spherical with clear, symmetrical early cleavages (Kjørsvik et al., 1990).

The total numbers of viable eggs (TVE), unviable eggs (TUE), spawned eggs (TE), egg viability rate (EVR, %) and fertilization rate (EFR, %) were calculated as:

$$TVE = (\text{bucket volume} \times \text{Mean total viable egg}) \times 5\ mL$$

$$TUE = (\text{bucket volume} \times \text{Mean total unviable egg}) \times 5\ mL$$

$$TE = TVE + TUE$$

$$EVR\ (\%) = (TVE \times 100)/TE$$

$$EFR\ (\%) = (\text{number of normal and fertilized eggs} / \text{Total viable buoyant fraction}) \times 100$$

The hatching rate (HR, %) was evaluated once a week, in triplicate. One hundred viable (buoyant) eggs were disinfected with 1.5 mL/L of formaldehyde for 5 min and stocked in three 2 L aquariums filled with filtered water and gentle aeration. Dead eggs were counted and removed daily until hatching (approximately 48 h). Hatching rate (HR, %) was calculated as:

$$HR\ (\%) = \text{number of hatched larvae} \times 100 / \text{number of viable (buoyant) eggs}$$

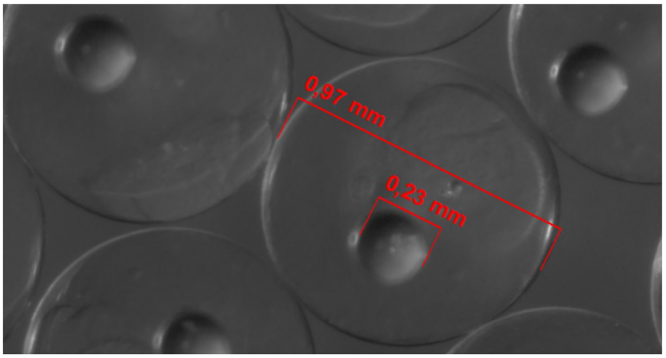

Fig. 1. Measurement of white trevally egg and oil droplet diameters.

2.3. Egg measurements

Weekly samples of thirty eggs were collected, placed under the stereoscope (Zeiss DV4) and photographed. Egg and oil droplet diameters were measured, using Axio Vision L.E. 4.3 (Carl Zeiss Micro Imaging GmbH), with a precision of 0.1 mm (Fig. 1).

2.4. Biochemical analyses

In order to perform biochemical analysis, approximately 1 g (WW) of eggs was collected once a week, using a 75-μm mesh filter. The egg pool was snap frozen in liquid nitrogen and stored at −80 °C until further analysis. All the samples were freeze-dried until residual water percentage was below 3%. The lipid content was determined according to Bligh and Dyer (1959) and described in Fernandes et al. (2016). From each freeze-dried egg pool, 100 mg were weighted and added 3 mL of a solution containing methanol/chloroform/BHT (2:1:0.01%) and 400 μL of saturated solution of potassium chloride. Two mL of chloroform and 2 mL of distilled water were then added and the mixture was placed under agitation for 20 min. The organic phase was collected and the solvent removed using a rotary evaporator at 40 °C. The lipid content was determined gravimetrically and the results expressed in percentage of dry weight (DW).

Total lipid extracts were analysed for their fatty acid composition as fatty acid methyl esters (FAMEs) as previously described by Lepage and Roy (1986), modified by Cohen et al. (1988). Briefly, the fatty acids were converted to FAMEs by adding a mixture of ethyl acetate-methanol (1:19 v/v) to total lipid aliquots that were after submitted at 80 °C for 1 h. FAMEs were analysed by gas chromatography (Agilent HP 6890) equipped with a mass selective detector (Agilent 5973) and a fused silica capillary column SupelcowaxTM 10 (30 m × 0.25 mm inner diameter, 0.25 μm film thickness) from Supelco. The chromatographic conditions were: initial temperature, 40 °C for 5 min; temperature gradient, 2 °C min^{-1}; final temperature, 250 °C for 5 min; injector temperature, 260 °C; transfer-line temperature, 260 °C; split ratio, 1:100. Helium was used as the carrier gas with a flow of 1.0 mL min^{-1}. The FAMEs were identified through comparison of retention times and mass spectra obtained with two standard samples: “bacterial acid methyl esters CP mix” and “Supelco 37 component FAME mix” and spectra library Wiley-NIST. Heneicosanoic acid as an internal standard. The results were expressed in percentage of total FA detected, being the quantification made according to the response factor determined for each FA present in the standards, in comparison with the heneicosanoic acid (internal standard).

Five egg samples were used for determination of lipid classes (neutral lipids, glycolipids and phospholipids), according to Fernandes et al. (2016). Previously extracted lipids were solubilized in dichloromethane and fractionated in activated silica chromatography column (at 100 °C). The separation of lipid classes was made in the following elution sequence: 5 mL of dichloromethane (neutral lipids, NL), 5 mL of acetone (glycolipids, GL) and, 10 mL of methanol (phospholipids, PL). All chemical analyses were carried out at least in duplicate.

2.5. Data analyses

The statistical analyses followed previously reported methods (Zar, 2010) and IBM SPSS Statistics 23 was the software used for all the statistical analysis performed. All data were tested for normality using a Kolmogorov-Smirnov (whenever $n > 30$) or Shapiro-Wilk (whenever $n < 30$) test, and for homogeneity of variance using a Levene's test. Biochemical data were log transformed to fit a normal distribution and all the percentage data were arcsine transformed prior to analyses. Means and back-transformed means are presented and the standard errors are those obtained from untransformed variables. The differences between weeks in egg quality parameters, total lipids, total fatty acids content, lipid classes (neutral lipids, phospholipids and glycolipids) and each class fatty acids content were tested by a one-way ANOVA, followed by Tukey's multiple comparison test. A Pearson's coefficient correlation was applied to establish the relationship between the egg morphological and performance parameters and biochemical composition. Significant levels were set at $P < 0.05$.

3. Results

The natural spawning of wild white trevally kept in captivity lasted approximately two months (from May 5th to June 29th), when water temperatures ranged from 19.5 °C to 21.9 °C and photoperiod was of 16 h of light. There were 20 spawning events and the total number of eggs collected was estimated at 10.8 million (10 789 780), of which 42.90% were unviable (sinking) eggs and 56.63% were viable (buoyant) eggs. The number of eggs collected at each event varied between 15.600 and 1.430.400 with an average number of eggs per batch of 674.361. The egg production, mean viability rate and fertilization rate are shown in Fig. 2. The total number of eggs and the viability rate were highly variable and there was no clear trend throughout the spawning season. Still, hatching rate variations correlated to water temperature (Table 3). Hatching rate was also correlated to total monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids contents (Table 3). The fertilization rate was always higher than 95% (Fig. 2).

The white trevally eggs were spherical, non-adhesive and pelagic with a mean diameter of 0.969 ± 0.027 mm and an oil globule of 0.279 ± 0.017 mm. The mean weekly egg diameter fluctuated without significant differences between weeks ($P > 0.05$). However, the average egg size declined towards the end of the season (Fig. 3) and was negatively correlated with water temperature (Table 3).

Lipid content was fairly constant throughout the spawning season with a mean value of 16.63 ± 1.01% DW (Table 4). There were no correlations between the eggs lipid content and the number of viable eggs, the egg size or oil droplet size. Fatty acid (FA) profile was also fairly constant throughout the spawning season. Polyunsaturated fatty acids (PUFA) were the major component of total lipids, representing > 40% of total detected FA, followed by saturated fatty acids (SFA, 27–29%) and monounsaturated fatty acids (MUFA,

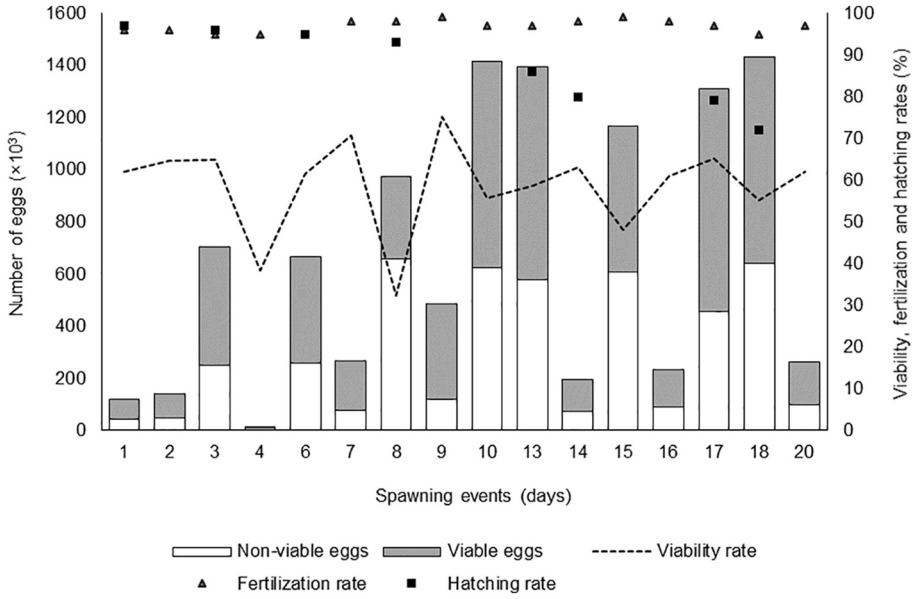

Fig. 2. Total number of spawned viable (buoyant) and unviable (sinking) eggs (left Y-axis), viability, fertilization, hatching rate (%) (right Y-axis) throughout the reproductive season of white trevally.

Table 3
Correlations (Pearson's coefficients) for temperature, eggs morphological and performance parameters and biochemical composition (monounsaturated fatty acids – MUFA, polyunsaturated fatty acids - PUFA, and docosahexaenoic acid – DHA - contents, proportion of total lipids). Pearson's coefficients (r) and corresponding significance level (P) and number of entries (n) are presented for each correlation. Statistical significance was set at $P < 0.05$.

	Temperature	Viable eggs	Egg diam.	Hatching rate	MUFA	PUFA	DHA
Temperature	–						
Viable eggs	P = 0.044, r = 0.202 (n = 210)	–					
Egg diam.	P = 0.040, r = −0.197 (n = 210)	ns	–				
Hatching rate	P = 0.001, r = −0.993 (n = 100)	ns	ns	–			
MUFA	P = 0.017, r = 0.941 (n = 11)	ns	ns	P = 0.040, r = −0.894 (n = 11)	–		
PUFA	Ns	ns	ns	P = 0.032, r = 0.909 (n = 11)	P = 0.030, r = −0.802 (n = 11)	–	
DHA	P = 0.042, r = −0.892 (n = 11)	ns	ns	Ns	P = 0.007, r = −0.887 (n = 11)	ns	–

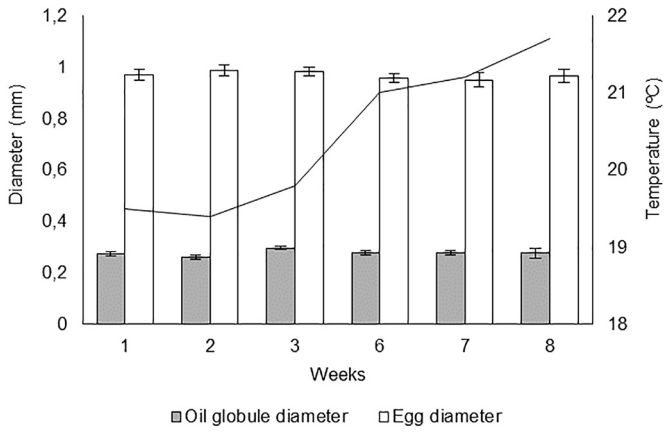

Fig. 3. Egg and oil globule diameter (left Y-axis) and temperature (right Y-axis) throughout the reproductive season of white trevally. Values are means ± s.d. (n = 30). No statistitical differences (P > 0.05, 1 way-ANOVA) were found between weeks.

24–27%) with no significant differences being detected between weeks (Fig. 4). Within each major fatty acid group, palmitic acid (16:0) accounted for 52.58% of SFA, oleic acid (18:1) accounted for 73.61% of MUFA and DHA (22:6ω3) and EPA (20:5 ω6) accounted for 50.11 and 13.32% of PUFA, respectively.

Lipids class composition in white trevally eggs was fairly constant throughout spawning season (P > 0.05) (Fig. 5). Neutral lipids (NL) fraction accounted for > 49% of total lipids during the entire spawning season, followed by glycolipids (GL) (23.5–26.5%) and polar lipids (18.6–22.8%). Again, no correlation was observed between lipid classes and other egg quality parameters. The fatty acid profile varied between lipids classes: whereas MUFA were mostly represented in the neutral and glycolipid fractions (Tables 5, 6), SFA were mostly abundant in PL (Table 7). GL fraction presented the lowest amount of PUFA, particularly EPA and DHA (Table 6), which were mostly abundant in the PL fraction (Table 7).

4. Discussion

In fish, egg quality is a key factor to the successful production of

Table 4
Fatty acids and fatty acid groups (% detected) in the eggs of white trevally throughout spawning season. Data are expressed as mean ± SD (n = 2–4). Different letters within the same row represent statistical differences (P < 0.05).

	Weeks							
	1	2	3	4	5	6	7	8
Total lipids (%DW)	16.37 ± 1.45	16.79 ± 1.23	16.87 ± 1.29	16.40 ± 1.26	17.63 ± 0.98	15.74 ± 0.36	17.57 ± 0.27	16.14 ± 1.22
Fatty acids (%)								
C14:0	1.76 ± 0.09^{a}	1.80 ± 0.013^{a}	1.77 ± 0.02 ^{a}	1.88 ± 0.38 ^{ab}	1.81 ± 0.03^{a}	1.77 ± 0.02^{a}	1.89 ± 0.01^{ab}	2.04 ± 0.06^{b}
C16:0	14.65 ± 0.49	14.38 ± 0.10	14.48 ± 0.59	15.10 ± 0.22	13.99 ± 0.36	14.50 ± 0.02	14.49 ± 0.20	14.48 ± 0.25
C18:0	3.72 ± 0.16	3.74 ± 0.10	3.70 ± 0.28	3.92 ± 0.04	3.60 ± 0.11	3.87 ± 0.05	3.62 ± 0.10	4.00 ± 0.25
Others	7.41 ± 1.23	7.14 ± 0.07	8.39 ± 1.33	6.99 ± 0.15	7.30 ± 0.07	8.64 ± 0.01	7.51 ± 0.19	6.47 ± 0.47
Total – SFA	27.54 ± 1.62	27.06 ± 0.06	28.34 ± 1.46	27.90 ± 0.07	26.69 ± 0.43	28.79 ± 0.05	27.50 ± 0.10	27.00 ± 0.35
C16:1n-9	5.53 ± 0.38	5.33 ± 0.04	5.40 ± 0.10	5.60 ± 0.05	5.27 ± 0.04	5.25 ± 0.01	5.51 ± 0.07	5.60 ± 0.12
C18: 1n-9	17.57 ± 1.36 ^{a}	18.69 ± 0.15^{a}	17.83 ± 0.88^{a}	18.90 ± 0.14^{a}	18.16 ± 0.20^{a}	18.61 ± 0.10^{a}	19.73 ± 0.51^{b}	19.50 ± 0.24^{b}
C20:1	0.83 ± 0.08^{ab}	0.89 ± 0.01^{a}	0.98 ± 0.05^{bcd}	0.92 ± 0.01^{b}	1.03 ± 0.01^{d}	0.97 ± 0.01^{c}	1.11 ± 0.04^{e}	1.13 ± 0.03^{e}
Others	0.133 ± 0.02	0.10 ± 0.00	0.31 ± 0.22	0.10 ± 0.00	0.13 ± 0.00	0.10 ± 0.00	0.13 ± 0.00	0.41 ± 0.29
Total – MUFA	24.06 ± 1.64	24.98 ± 0.20	24.53 ± 0.79	25.51 ± 0.19	24.60 ± 0.24	24.93 ± 0.13	26.49 ± 0.63	26.64 ± 0.54
C18:2n6	5.58 ± 1.89^{a}	6.20 ± 0.08^{ac}	6.47 ± 0.08^{ac}	5.88 ± 0.03^{ab}	5.98 ± 0.07^{abc}	6.15 ± 0.01^{ac}	6.76 ± 0.15^{ad}	6.27 ± 0.27^{ac}
C18:3n3	0.69 ± 0.00^{a}	0.71 ± 0.00^{b}	0.77 ± 0.02^{c}	0.69 ± 0.00^{a}	0.71 ± 0.01^{b}	0.70 ± 0.01^{ab}	0.74 ± 0.01^{c}	0.73 ± 0.02^{bc}
C18:4n3	2.85 ± 0.02^{a}	2.91 ± 0.03^{b}	3.00 ± 0.09^{bd}	2.75 ± 0.04^{c}	2.98 ± 0.02^{d}	2.86 ± 0.01^{a}	3.02 ± 0.02^{d}	2.68 ± 0.12^{c}
C20:4n6	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
C20:4n3	0.69 ± 0.01^{a}	0.67 ± 0.01^{ab}	0.70 ± 0.02^{ac}	0.66 ± 0.01^{b}	0.75 ± 0.04^{c}	0.67 ± 0.01^{ab}	0.68 ± 0.03^{abc}	0.68 ± 0.02^{ab}
C20:5n3 – EPA	6.16 ± 0.18^{c}	5.36 ± 0.02^{ab}	5.54 ± 0.38^{b}	5.42 ± 0.04^{b}	5.37 ± 0.11^{b}	5.42 ± 0.01^{b}	5.08 ± 0.12^{a}	5.43 ± 0.26^{b}
C22:5n6	0.47 ± 0.12	0.54 ± 0.01	0.52 ± 0.08	0.51 ± 0.01	0.56 ± 0.02	0.55 ± 0.02	0.47 ± 0.01	0.50 ± 0.03
C22:5n3	0.94 ± 1.08	1.67 ± 0.01	0.91 ± 0.05	1.64 ± 0.02	1.78 ± 0.08	0.96 ± 0.01	1.71 ± 0.04	1.70 ± 0.04
C22:6n3- DHA	22.39 ± 1.52	20.70 ± 0.05	20.89 ± 1.07	20.21 ± 1.70	21.59 ± 0.51	20.91 ± 0.03	19.58 ± 0.40	19.59 ± 0.63
Others	2.75 ± 0.19^{ab}	2.94 ± 0.01^{bc}	2.69 ± 0.08^{a}	2.99 ± 0.04^{c}	2.93 ± 0.06^{bc}	2.86 ± 0.03^{bc}	2.91 ± 0.05^{c}	2.58 ± 0.13^{a}
Total – PUFA	42.65 ± 3.21	41.89 ± 0.01	41.67 ± 2.13	40.94 ± 0.30	42.83 ± 0.44	40.34 ± 0.02	41.14 ± 0.84	40.35 ± 0.54
Σn3	35.45 ± 3.03	33.81 ± 0.05	33.30 ± 2.57	33.14 ± 0.28	34.85 ± 0.48	32.27 ± 0.01	32.39 ± 0.67	32.27 ± 0.71
Σn6	6.64 ± 0.34^{b}	7.47 ± 0.07^{e}	7.72 ± 0.43^{ade}	7.12 ± 0.01^{c}	7.27 ± 0.05^{d}	7.42 ± 0.04^{e}	8.02 ± 0.17^{a}	7.37 ± 0.33^{cde}
Σn3/Σn6	5.33 ± 0.19^{b}	4.52 ± 0.05^{e}	4.34 ± 0.57^{cde}	4.66 ± 0.04^{c}	4.79 ± 0.10^{c}	4.35 ± 0.02^{d}	4.04 ± 0.01^{a}	4.39 ± 0.28^{de}
DHA/EPA	3.66 ± 0.14^{b}	3.87 ± 0.01^{c}	3.77 ± 0.08^{ab}	3.73 ± 0.01^{b}	4.02 ± 0.18^{a}	3.86 ± 0.01^{ac}	3.86 ± 0.01^{ac}	3.61 ± 0.11^{b}

Limit of detection for all fatty acids: 0.1%; n = 22. SFA- saturated fatty acids; MUFA- monounsaturated fatty acids; PUFA- polyunsaturated fatty acids.

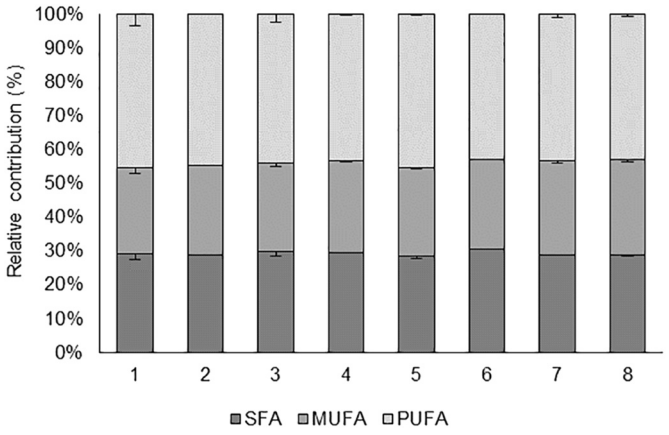

Fig. 4. Fatty acids groups, as a proportion of total lipids (% detected) in white trevally eggs throughout spawning season. Values are means ± s.d. (n = 10). No statistical differences (P > 0.05, 1 way-ANOVA) were found for each group between weeks.

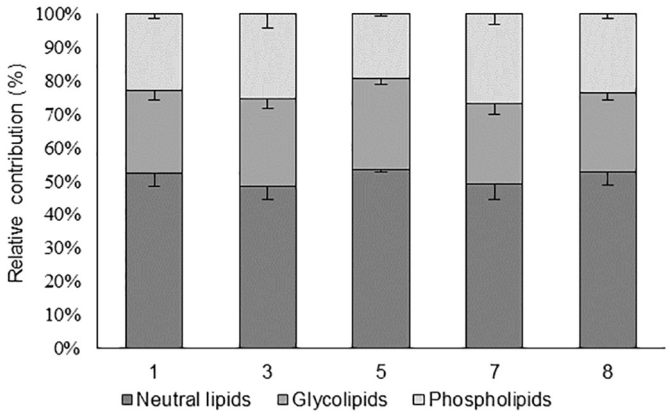

Fig. 5. Lipid class composition (% detected) in white trevally eggs throughout spawning season. Values are means ± s.d. (n = 10). No statistical differences (P > 0.05, 1 way-ANOVA) were found for each class between weeks.

viable offspring in marine teleosts (Jia et al., 2014). The present study aimed to describe the husbandry conditions and characterize the reproductive performance and egg quality of white trevally obtained by natural spawning in captivity.

Reference for the optimum temperatures for hatching and newly-hatched larval rearing of white trevally are between 20 and 22 °C (Kawabe et al., 1991; Murai et al., 1992) which is within the range of Madeira archipelago natural seawater temperatures, 18–24 °C (Gouveia et al., 2003). The present results show that after four years in captivity, wild white trevally fed commercial diets commonly used for broodstock maintenance, supplemented with raw fish, were able to naturally spawn when water temperatures reached 19°. Spawning season was quite short (2 months) and stopped when the water temperature reached 22°, in agreement with what has been described in the wild for a Central North Atlantic population (Afonso et al., 2008).

Discrimination of "good" quality eggs by virtue of the eggs ability to float in seawater has long been used in many marine hatcheries (Carrillo et al., 1989; McEvoy, 1984). In the present study, the number of viable (buoyant) and unviable (sinking) eggs was variable throughout the spawning season and no correlation was detected with other egg quality parameters. The egg buoyancy has often been used as an indicator of egg quality in marine fish (Jia et al., 2014) and several

Table 5
Neutral lipids fatty acids profile (% detected) in the eggs of white trevally throughout spawning season. Data are expressed as mean ± SD (n = 2–4). Different letters within the same row represent statistical differences (P < 0.05).

	Weeks				
	1	3	5	7	8
Fatty acids (%)					
14:0	2,03 ± 0,15^{a}	1,88 ± 0,02^{ab}	1,73 ± 0,02^{b}	2,04 ± 0,03^{a}	1,99 ± 0,05^{ab}
16:0	12,02 ± 0,42^{bc}	11,51 ± 0,06^{bc}	10,42 ± 0,02^{c}	13,63 ± 0,16^{a}	12,85 ± 0,15^{a}
18:0	1,53 ± 0,21	0,81 ± 0,12	1,02 ± 0,15	0,61 ± 0,11	2,58 ± 1,63
Outros	0,48 ± 0,10	0,59 ± 0,03	0,59 ± 0,00	0,72 ± 0,09	0,54 ± 0,11
Total – SFA	16,06 ± 0,57^{abc}	14,78 ± 0,24bc	13,75 ± 0,19^{c}	17,01 ± 0,38^{ab}	17,96 ± 1,58^{a}
16:1	6,94 ± 0,69	6,32 ± 0,12	6,26 ± 0,02	7,07 ± 0,12	6,79 ± 0,14
18:1	26,89 ± 0,95^{a}	24,92 ± 0,14^{ab}	23,65 ± 0,17^{b}	27,22 ± 1,07^{a}	25,13 ± 0,88^{ab}
20:1	1,17 ± 0,52	1,57 ± 0,01	1,67 ± 0,00	1,61 ± 0,07	1,13 ± 0,52
Outros	11,69 ± 0,82^{b}	10,87 ± 0,08^{b}	13,98 ± 0,07^{a}	11,46 ± 0,24^{b}	10,63 ± 0,74^{b}
Total – MUFA	46,69 ± 1,53^{a}	43,67 ± 0,07^{b}	45,56 ± 0,07^{ab}	47,35 ± 0,64^{a}	43,68 ± 0,63^{b}
18:3w3	1,22 ± 0,42	1,85 ± 0,02	1,54 ± 0,01	1,58 ± 0,05	1,81 ± 0,07
18:4w3	4,61 ± 0,23^{a}	3,89 ± 0,02^{ab}	4,15 ± 0,02^{ab}	3,54 ± 0,23^{b}	3,89 ± 0,48^{ab}
20:4w3	0,40 ± 0,03^{b}	0,55 ± 0,03^{a}	0,30 ± 0,00^{bc}	0,59 ± 0,09^{a}	0,20 ± 0,05^{c}
20:5w3 – EPA	4,28 ± 1,14	4,26 ± 0,05	4,40 ± 0,01	3,23 ± 0,13	3,61 ± 0,14
22:5w3	1,52 ± 0,46	1,52 ± 0,07	1,67 ± 0,01	1,15 ± 0,05	1,21 ± 0,34
22:6w3 – DHA	12,29 ± 4,73	11,34 ± 0,26	13,52 ± 0,11	8,04 ± 0,08	8,74 ± 0,79
Outros	12,90 ± 4,88	18,14 ± 0,05	15,11 ± 0,01	17,52 ± 0,25	18,89 ± 0,11
Total – PUFA	37,25 ± 1,32^{c}	41,55 ± 0,31^{a}	40,69 ± 0,12^{ab}	35,65 ± 0,26^{c}	38,36 ± 0,97^{bc}
Σw3	25,52 ± 5,96	24,46 ± 0,22	27,16 ± 0,13	19,38 ± 0,12	20,68 ± 0,75
Σw6	0,11 ± 0,13	0,14 ± 0,01	0,25 ± 0,00	0,14 ± 0,02	0,07 ± 0,09

Limit of detection for all fatty acids: 0.1%; n = 20. SFA- saturated fatty acids; MUFA- monounsaturated fatty acids; PUFA- polyunsaturated fatty acids.

Table 6
Glycolipids fatty acids profile (% detected) in the eggs of white trevally throughout spawning season. Data are expressed as mean ± SD (n = 2–4). Different letters within the same row represent statistical differences (P < 0.05).

	Weeks				
	1	3	5	7	8
Fatty acids (%)					
14:0	4,81 ± 1,26	4,08 ± 0,14	4,89 ± 0,38	3,63 ± 0,07	3,12 ± 0,83
16:0	27,15 ± 2,83	28,17 ± 0,09	25,64 ± 1,14	26,82 ± 0,41	24,43 ± 0,66
18:0	5,29 ± 1,07	5,70 ± 0,07	4,33 ± 0,13	5,51 ± 0,09	5,41 ± 0,37
Outros	1,42 ± 0,05	1,63 ± 0,07	1,15 ± 0,01	1,24 ± 0,03	1,37 ± 0,38
Total – SFA	38,67 ± 3,00	39,59 ± 0,05	36,01 ± 1,40	37,20 ± 0,42	34,33 ± 1,49
16:1	7,10 ± 2,44	5,09 ± 0,01	7,99 ± 0,33	4,90 ± 0,09	4,68 ± 1,75
18:1	25,97 ± 3,67	21,73 ± 0,60	26,11 ± 0,01	21,20 ± 0,02	20,42 ± 3,51
20:1	1,52 ± 0,59	2,08 ± 0,18	0,95 ± 0,12	1,32 ± 0,11	1,87 ± 0,57
Outros	7,80 ± 7,51^{ab}	10,28 ± 0,08^{ab}	2,01 ± 0,04^{b}	12,01 ± 0,11^{ab}	16,95 ± 0,99^{a}
Total – MUFA	42,39 ± 2,23	39,17 ± 0,49	37,06 ± 0,25	39,44 ± 0,06	43,91 ± 4,84
18:3w3	0,00 ± 0,00^{b}	0,00 ± 0,00^{b}	0,49 ± 0,03^{a}	0,00 ± 0,00^{b}	0,00 ± 0,00b
18:4w3	3,14 ± 3,15^{ab}	5,77 ± 0,01^{ab}	1,06 ± 0,11^{b}	5,48 ± 0,00^{ab}	7,22 ± 0,79^{a}
20:4w3	1,40 ± 1,07	1,58 ± 0,08	0,60 ± 0,04	1,17 ± 0,13	1,22 ± 0,11
20:5w3 – EPA	3,48 ± 1,25	1,33 ± 0,01	2,79 ± 0,19	1,48 ± 0,02	2,79 ± 2,07
22:5w3	1,48 ± 0,49	3,42 ± 0,31	1,05 ± 0,13	2,87 ± 0,08	2,57 ± 2,97
22:6w3 – DHA	5,15 ± 3,78^{ab}	1,15 ± 0,11^{b}	10,24 ± 1,19^{a}	5,73 ± 0,18^{ab}	1,35 ± 0,49^{b}
Outros	5,29 ± 0,09^{c}	8,00 ± 0,03^{b}	10,70 ± 0,03^{a}	6,63 ± 0,01^{bc}	6,61 ± 1,04^{bc}
Total – PUFA	18,94 ± 1,28	21,24 ± 0,54	26,93 ± 1,65	23,37 ± 0,36	21,75 ± 6,30
Σw3	13,99 ± 1,63	13,24 ± 0,51	16,63 ± 1,61	16,73 ± 0,37	15,84 ± 4,48
Σw6	n.d	n.d.	n.d.	n.d.	n.d.

n.d.- not detected. Limit of detection for all fatty acids:0.1%; n = 20. SFA- saturated fatty acids; MUFA- monounsaturated fatty acids; PUFA- polyunsaturated fatty acids.

authors have reported that the ratio of buoyant eggs to total eggs spawned correlates positively with egg hatchability (Furuita et al., 2007; Unuma et al., 2005). In this study, no correlation was observed between hatching rate and egg buoyancy. Though the average number of produced eggs *per* female was comparable to the previously published literature (Table 1), the viability rates were lower. Hatching rate of white trevally decreased towards the end of the spawning season, in agreement to what has been described for many marine fish species in the wild (Chambers, 1977; Mihelakakis et al., 2001).

Both the hatching rate and egg size were negatively correlated with water temperature, decreasing towards the end of the spawning season. Explanations for these observed correlations include: a possible decline in sperm quality (Cabrita et al., 2011); differences between female's contribution in egg production during the spawning period (Fujita and

Table 7
Polar lipid fatty acids profile (% detected) in the eggs of white trevally throughout spawning season. Data are expressed as mean ± SD (n = 2–4). Different letters within the same row represent statistical differences (P < 0.05).

	Weeks				
	1	3	5	7	8
Fatty acids (%)					
14:0	0,87 ± 1,00^{b}	1,16 ± 0,07^{b}	4,89 ± 0,38^{a}	1,14 ± 0,12^{b}	1,16 ± 0,58^{b}
16:0	28,92 ± 1,59	30,90 ± 0,56	25,64 ± 1,14	29,39 ± 1,15	29,80 ± 5,01
18:0	12,88 ± 3,94^{a}	0,00 ± 0,00^{b}	4,33 ± 0,13^{b}	16,13 ± 0,10^{a}	19,33 ± 1,99^{a}
Outros	0,43 ± 0,50	0,94 ± 0,10	1,15 ± 0,01	0,87 ± 0,02	0,49 ± 0,58
Total – SFA	43,10 ± 1,73^{abc}	33,01 ± 0,39^{c}	36,01 ± 1,40^{bc}	47,54 ± 1,20^{ab}	50,79 ± 6,96^{a}
16:1	1,58 ± 1,83^{b}	2,40 ± 0,04^{b}	7,99 ± 0,33^{a}	2,84 ± 0,13^{b}	1,86 ± 0,56^{b}
18:1	13,99 ± 0,61^{b}	29,49 ± 0,06^{a}	26,11 ± 0,01^{a}	16,79 ± 0,06^{b}	16,60 ± 2,98^{b}
20:1	0,00 ± 0,00^{c}	0,61 ± 0,03^{b}	0,95 ± 0,12^{a}	0,00 ± 0,00^{c}	0,00 ± 0,00^{c}
Outros	2,29 ± 2,28	1,12 ± 0,13	2,01 ± 0,04	2,35 ± 0,12	2,55 ± 1,05
Total – MUFA	17,86 ± 1,07^{b}	33,63 ± 0,15^{a}	37,06 ± 0,25^{a}	21,98 ± 0,19^{b}	21,00 ± 4,56^{b}
18:3w3	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
18:4w3	1,68 ± 0,53	1,13 ± 0,18	1,06 ± 0,11	1,37 ± 0,25	0,75 ± 0,86
20:4w3	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00	0,00 ± 0,00
20:5w3 – EPA	15,13 ± 9,95	4,45 ± 0,10	2,79 ± 0,19	3,81 ± 0,32	3,08 ± 2,05
22:5w3	0,67 ± 0,79	0,88 ± 0,06	1,05 ± 0,13	0,90 ± 0,04	0,55 ± 0,64
22:6w3 – DHA	17,98 ± 12,43	19,03 ± 0,04	10,24 ± 1,19	16,25 ± 1,04	16,50 ± 7,31
Outros	3,58 ± 0,47c	7,88 ± 0,05b	10,70 ± 0,03a	8,15 ± 0,23b	7,34 ± 0,65b
Total – PUFA	39,04 ± 2,71	33,37 ± 0,24	26,93 ± 1,65	30,49 ± 1,38	28,21 ± 11,38
Σw3	35,47 ± 3,07	25,49 ± 0,29	16,63 ± 1,61	22,34 ± 1,15	20,87 ± 10,85
Σw6	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.- not detected. Limit of detection for all fatty acids:0.1%; n = 20. SFA- saturated fatty acids; MUFA- monounsaturated fatty acids; PUFA- polyunsaturated fatty acids.

Yogata, 1984); depletion of female energy reserves (Chambers, 1977); or a general reduction in egg quality as the spawning period continues (Brooks et al., 1997).

The biochemical composition of fish eggs is related to their quality, as egg composition must satisfy embryonic nutritional needs for development and growth (Lubzens et al., 2010; Tocher, 2003). Typically, total lipid content (TL) of marine fish eggs ranges from 15 to 35% DW (Dayal et al., 2003; Samaee et al., 2009; Sargent et al., 1995) and may increase, decrease or remain constant during the spawning season (Aegerter and Jalabert, 2004; Faulk and Holt, 2008; Fuiman and Ojanguren, 2011). In this study, though white trevally eggs TL content remained fairly constant throughout the spawning season (approx. 16% DW), it was lower than what was previously reported (Vassallo-Agius et al., 1998, 2001b, 2001c). In addition to being related with broodstock dietary lipids, eggs TL has also been suggested to be positively correlated with broodstock weight (Quiñones-Arreola et al., 2015). Since the broodstock individuals used in Vassallo-Agius et al. (1998, 2001b, 2001c) trials had lower mean bodyweight than the ones used in our study and the fact that diets used by those authors had higher lipid content (Table 1), the present results highlight the instrumental importance of dietary lipids as affecting egg lipid and fatty acid content (Sargent et al., 1995).

Moreover, similarly to what was observed in sole, sea bass, turbot (Devauchelle et al., 1982) and common dentex (Samaee et al., 2009), egg TL content was not correlated to egg size, oil droplet size or viability rate. On the contrary, TL was reported as being correlated with egg size in almaco jack (Quiñones-Arreola et al., 2015) and with viability in roach and bream (Wiegand, 1996). These contradictory results highlight the so far unclear relationship between egg total lipid content and egg size and viability in marine fish species, making it difficult to conclude whether these parameters directly affect egg quality of white trevally.

Within lipids composition, neutral lipids (NL) generally considered as a major energy reserve in marine fish eggs and larvae (Blaxter, 1988; Tocher, 2003), accounted for 50% of lipid classes. The high NL content found in this study reflects the relative increased size of the oil droplet as compared to egg size (approximately 30%), since oil droplet of marine pelagic fish eggs typically consists mostly of neutral lipids (Tocher, 2003; Wiegand, 1996). Moreover, glycolipids, which are important cellular membrane components for anchoring/sorting of membrane structures and signaling transduction (Simons and Ikonen, 1997), are also present as droplets in the yolk of teleost eggs (Sarasquete et al., 2002), contributing as well for the size of the oil droplet.

Fatty acids (FA) composition of white trevally eggs fitted the general marine fish FA profile (Sargent et al., 1999, 2002) and agreed with previous results for the same species (Vassallo-Agius et al., 1998, 2001b, 2001c). FA composition was fairly constant throughout the spawning season, without any relevant differences in the major fatty acid groups. Significant differences were found in palmitic acid (16:0) and oleic acid (18:1), which were the most represented fatty acids in the SFA and MUFA fractions, respectively. However, these FA contents were not correlated with any egg viability parameters.

Hatching rate was negatively correlated to both temperature and MUFA content. Accordingly, PUFA content, mostly represented by DHA (22:6n-3) and EPA (20:5n-3), was positively correlated with hatching rate, which agrees to what has been described for most marine fish species (Fernández-Palacios et al., 2011). The fact that hatching rate was not directly correlated with DHA content, the most abundant fatty acid in PUFAs fraction, highlights the importance of other essential unsaturated fatty acids in determining egg quality parameters. Still, DHA content was negatively correlated with water temperature, which is in agreement with Mejri et al. (2014) that reported a positive correlation between the degree of unsaturation of fatty acids and membrane fluidity. Mejri et al. (2014) suggested that a decrease in DHA content towards the end of the spawning season could be an adaptive mechanism to reduce membrane fluidity with the increase of temperature.

Arachidonic acid (ArA) content also correlated with egg quality in many other species (Bell et al., 1997; Mazorra et al., 2003; Salze et al., 2005; Tocher and Sargent, 1984), was always very low throughout the spawning season (Table 4) when compared to what has been described for most marine fish species eggs (Fernández-Palacios et al., 2011). Since egg lipid composition is directly affected by the parental diet (Bell

et al., 1997; Sargent et al., 1995), low detected levels of ArA in this study suggest that the proportion of this FA in the feed supplied to the brood stock could be unfitting for the quality of white trevally eggs.

As a consequence of low ArA levels and high EPA and DHA content, the n-3/n-6 HUFA ratio was higher than what is commonly found in most marine fish (2.9) (Henderson and Tocher, 1987). Despite these results, no significant relationship was detected between the sum of n-3 HUFA or n-3/n-6 ratio and number of buoyant viable eggs or any other egg quality measurements.

Within lipid fractions, the neutral lipids (NL) presented high amounts of MUFA followed by equally high contents of PUFA, which has been suggested to be a good indicator of offspring quality in fresh water species (Mejri et al., 2014). MUFA were also the most abundant FA in the glycolipid fraction (GL). However, in the GL fraction, SFA were more abundant than PUFA, mainly due to an increased amount of 16:0. In fact, GL displayed the lowest amounts of EPA and DHA. DHA was mainly found in the phospholipids (PL) fraction, confirming the important role of PUFA as structural and functional components in the cellular membrane (Tocher, 2003).

Despite no significant correlation was found between DHA percentage in all lipid classes and the viability parameters, the high relative abundance of DHA in all classes confirms the need for this FA in the developing embryos. DHA is particularly important for the membrane development in neural tissue, which comprises a relatively high proportion of tissues in rapidly developing embryos and larvae (Seaborn et al., 2009).

5. Conclusion

Egg quality control is crucial in species that have been “recently” introduced in the fish culturing systems, in order to characterize the husbandry practices that allow for the production of high quality larvae and juveniles, which is the key for the sustainability of a commercial hatchery.

In the present study, husbandry conditions differed from what has been previously published for this species. White trevallies were kept in smaller tanks at much higher densities, under natural photoperiod and natural water temperature fluctuations. Though spawning season was short, the number of spawned eggs per female was higher when compared with induced spawning of trevallies fed artificial diets. Correlations observed between the chemical composition of the eggs and viability parameters highlight the importance of broodstock nutrition and environmental parameters, such as water temperature on egg quality parameters. The present results suggest a combined and possibly synergistic effect of several parameters affecting egg quality, bringing up the need for a more appropriate experimental approach to investigate these biological interactions.

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