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Influence of the myotome zone and sex on the muscle cellularity and fillet texture of diploid and triploid turbots *Scophthalmus maximus* L.

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Abstract

The muscle and textural parameters were analyzed in four myotome zones (epaxial upper, hipoaxial upper, epaxial bottom, and hipoaxial bottom) in seven diploids (D) and seven triploids (T) turbot specimens. Diploid specimens showed the highest values of the size and number of white fibers in the epaxial zones, being such values higher in female than male specimens. In triploid specimens, the highest fibers sizes were found in the upper zones (epaxial and hipoaxial), whereas the lowest number and density of fibers were found in the epaxial upper zone. In this latter group (T), the lowest fibers sizes were found in female specimens, whereas the rest of the parameters were usually higher in female than male specimens. When comparing both groups, the hypertrophy was higher in T than D in all zones. In both ploidy groups, the highest textural values were usually observed in the upper epaxial fillet, being slightly higher in female than male specimens. The values of standard length, total weight, gonad weight, gonadosomatic index and gutted weight were higher in female than male specimens in both groups (D and T).

Introduction

The turbot (*Scophthalmus maximus*) is a species of flatfish from the Scophthalmidae family. It is a demersal fish found in the Mediterranean, the Baltic Sea, the Black Sea, and the North Atlantic. Turbot is highly prized as a food fish by its delicate flavor. Flatfish usually swim in anguilliform mode.[1] They swim, however, on their side, so that the undulations are vertical rather than horizontal. A very wide body span in flatfish is achieved both by a high compressed body and elongate dorsal and anal fins.[1] Turbot is a large left-eyed, has an asymmetrical disk-shaped body, and swims near the bottom. According to its fish anatomy as well as swimming behavior, the musculature axial of this species could differ depending on the side of the body (upper or bottom) and position concerning the body axis (epaxial or hipoaxial).

In fish farming, maturation essentially marks the end of the useful period of rearing and, if economic yields are to be maximized, fish must be sold before the deteriorative changes associated with maturation.[2] The ploidy influences on the growth and gonadal development of diploid (D) and triploid (T) fish.[2-4] Triploidy prevents gonadal maturation in fish, causing their sterility.[5] The effects of triploidy on growth are variable and probably depend on the induction method, husbandry practices, and the stage of life cycle being compared.[5] In salmon, *Salmo salar*, triploid specimens often show growth performance as good as or better than diploids when they are reared separately.[6,7] Other authors have determined the effect of triploidy in turbot, *S. maximus* L., from 6 to 48 months of age.[3] These authors have observed that the growth is similar for both ploidies during the first year of life, but after that, triploids grow more than diploids, with more marked differences after each spawning season. Their results have shown that the sterility of turbot allows better performance by avoiding the reduction in growth taking place during the spawning periods.[3]

Turbot is a marine teleost that has an important commercial value. Under culture conditions, the first

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maturation takes place at approximately 24 months of age. Nevertheless, the first maturity does not negatively affect growth, since, by that time, the gonads are still not big enough.[3] However, animals that are reared until they reach 4 kg undergo a second and third sexual maturity, with more marked effects on growth than in the first sexual maturity, due to their bigger gonads.[3] Other authors have recently studied the muscle cellularity and the flesh quality of two groups of turbot (diploid and triploid) reared under identical conditions until the age of ≈ three years and body weight greater than 2.00 kg.[8] Usually, this species is sold before reaching this weight to avoid growth losses because of the gonadal maturity. These authors have studied the muscle cellularity and the texture in the epaxial left zone of the myotome. However, according to the body morphology of this species, the characteristics of the myotome could differ among the different zones of the fish body and hence the muscle cellularity and texture could be different among them. [8]

Hence, in this paper, we have studied the same specimens as those studied by the authors cited above,[8] but we have analyzed the zones that were not studied by the cited authors to know if the zone of the myotome influences on the muscle cellularity and texture of the fillets. All the data were analyzed and compared with the results found by the cited authors. Furthermore, since the sex can also influence on the muscle characteristics,[9,10] the present work compares the results between female and male specimens in both diploid and triploid turbots.

Materials and Methods

Fish samples and rearing conditions. Fourteen turbots were studied including seven diploids (2N; four female specimens and three male specimens; 2,197 g and 45.10 cm) and seven triploids (3N; four female specimens and three male specimens; 2,240 g and 45.30 cm), 33 months old (≈ three years of age). These specimens were obtained from the Spanish Institute of Oceanography (Oceanographic Center of Vigo), Vigo, Spain in June 2009 from a broodstock adapted to captivity. These specimens are the same as those studied by the authors cited above.[8] Triploidy was induced by applying a heat shock shortly after fertilization of eggs,[11,12] as explained in the previous study.[8] The fish were reared under natural photoperiod and temperature conditions, as explained by the cited authors.[8] The specimens were euthanized by an overdose of the anesthetic MS-222 (500 mg L^{-1}; Sigma, Madrid, Spain). The degree of triploidy was verified using a molecular tool for triploid determination based on a set of highly polymorphic and centromere-distant microsatellites according to the methodology described by other authors.[13]

The biometric parameters of these specimens were obtained from the authors cited above [8] and then analyzed according to the sex influence (female *versus* male) in both groups (D and T) of turbot. After obtaining the body parameters, fish were filleted and so, four fillets were obtained from the four zones forming the entire myotome including epaxial upper (fillet or zone 1), hipoaxial upper (fillet or zone 2), epaxial bottom (fillet or zone 3), hipoaxial bottom (fillet or zone 4). The zone 1 was studied previously by the authors cited above,[8] whereas the three remaining zones of the myotome have been studied in the present work to compare all zones of the entire myotome. All fillets were packed in ice pellets for shipment to the Faculty of Veterinary Medicine of Murcia, Murcia, Spain 24 hr after slaughter.

Muscle sample processing for structural studies. All the fillets of the T and D specimens were cross-sectioned from the halfway point of the standard length to obtain the transverse section of the myotome (Fig. 1A). Muscle samples for structural studies with light microscopy were obtained by removal of 3-4 blocks of 5.00 × 5.00 × 5.00 mm from each transverse section of the myotome from each fillet. These blocks were frozen in 2-methyl butane (– 80.00 ˚C) snap frozen over liquid nitrogen and then stored in a – 65.00 ˚C freezer. Sections of 8.00 µm thickness were obtained at – 20.00 ˚C in a cryostat (CM 1850; Leica Biosystems Inc., Lincolnshire, USA) and then stained with Hematoxylin and Eosin (Figs. 1B-D). These sections were photographed using an image analyzer (version 5.0; SigmaScan Pro, San Jose, USA) connected to a light photomicroscope (Dialux 20; Leitz, Wetzlar, Germany). Later on, the sections were used to quantify the following muscle parameters: Total cross-sectional area of the red and white muscles, number of white muscle fibers, size (area and minor axis length) of white muscle fibers and muscle fiber density (number of fibers per μm^2). Around 800-900 fibers were measured in each fillet.

Textural parameters. Textural measurements were carried out in all the fillets (1-4). However, the textural values from the fillet 1 were previously analyzed by the authors cited above[8] and subsequently ceded by the cited authors to compare the texture values of all the fillets between themselves. Textural parameters were measured with a Texturometer (TA-XT texture analyzer; Stable Microsystems, Surrey, UK) equipped with a 25.00 kg load cell and a flat ended 20.00 mm diameter cylindrical probe. All measurements were done at room temperature (22.00 – 23.00 ˚C) and samples were tempered 30 min before the texture profiles analysis. Three measurements were made for each sample in the dorsal muscle perpendicular to the muscle fibers orientation. The distance, maximum force and maximum shear force values obtained from the texture profile curve of each sample were used to calculate the independent mechanical parameters (springiness, hardness, and cohesiveness) and three dependent parameters (chewiness, gumminess, and adhesiveness) following the methodology described by other authors.[14]

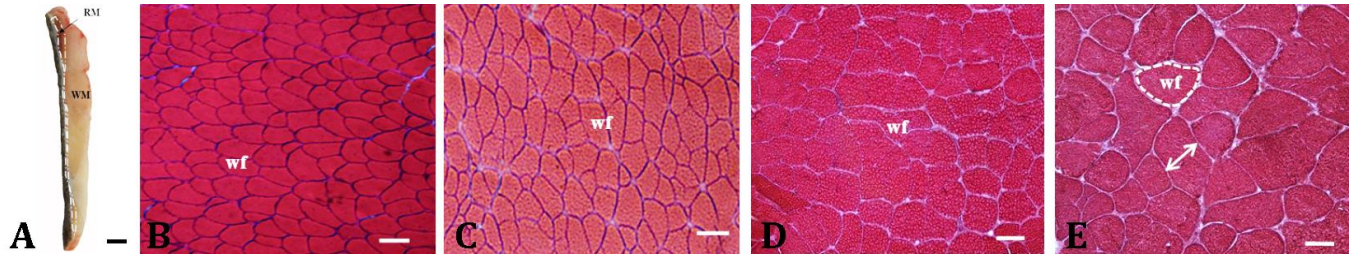

Fig. 1 A) Complete transverse section of the hypoaxial zone of the myotome of a diploid specimen (Scale bar = 1.00 cm). **B-D)** Transverse microscopic sections of the white muscle of diploid and **E)** triploid turbots obtained from different zones of the myotome: Bottom epaxial (B), bottom hypaxial (C), upper hypaxial (D and E) of male (B and D) and female specimens (C and E). WM: White muscle; RM: Red muscle; and wf: White muscle fibers. In A, the complete transverse section of the red muscle is indicated by a dashed line. In E, the transverse area of a white muscle fiber is indicated by a dashed line and the minor axis length of a white muscle fiber is indicated by a double-headed arrow, (H & E, Scale bars in B-E = 100 µm).

Statistical analysis. The statistical analysis was performed with Statistical Package SPSS (version 19.0; SPSS Inc., Chicago, USA). The mean and standard error from each group of data were calculated. Data distribution was analyzed in each group by the Shapiro-Wilk test for $p < 0.05$. About the size of the fibers, data did not show a normal distribution ($p < 0.05$) and Levene´s test did not show homogeneous variances ($p < 0.05$) either. Hence, non-parametric tests were used (Mann-Whitney and Kolmogorov-Smirnov tests) to evaluate the effect of the zone of the myotome (1-4) on the size of the fibers as well as the ploidy effect and sex influence on such zones for $p < 0.05$. For most of the other parameters, both tests (Shapiro-Wilk and Levene) showed values of $p > 0.05$, and hence, the analysis of variance (ANOVA) and Tukey´s test were used. A correlation analysis using Pearson´s correlation coefficient was conducted to measure the relationships between structural and textural parameters.

Results

Diploid group (D)

Influence of the myotome zone on the muscle parameters and fillets weight. When comparing all the fillets, we can observe a greater size (minor axis length) of the white muscle fibers in the epaxial (upper and bottom) than hipoaxial fillets ($p < 0.05$; Table 1). On the other hand, the fibers sizes were similar when comparing upper *versus* bottom epaxial fillets. Similarly, both hipoaxial fillets (upper and bottom) showed parallel values of this parameter. The transverse area of the white muscle showed a similar trend to that shown by the size of the fibers, such that the epaxial fillets (1 and 3) were bigger than the hipoaxial fillets (2 and 4), but the differences were only significant between fillets 1 and 4 (not shown). The red muscle cross-section showed similar results to those described for the white muscle. The number and the muscle fiber density did not show significant differences among the 4 fillets (Table 1). However, the muscle fiber density was higher in the hipoaxial fillets (2 and 4) than epaxial fillets, contrary to what described for the white muscle fibers size. Concerning the fillets weight**,** the weight of the epaxial fillets was higher than the weight of hipoaxial fillets in both females and males, but not significantly ($p > 0.05$; not shown). On the other hand, when comparing the weight of the upper fillets *versus* the bottom fillets, it was similar between them.

Influence of the myotome zone on the textural values. On the whole, the texture values were higher in fillet 1 than the rest of fillets, whereas the fillet 4 usually showed the lowest values. However, these results were usually not significant (Table 1). Significant differences were only observed for the following parameter: Adhesiveness, with values in the fillet 4 of –0.17 Newton-sec, significantly different from the values in the fillets 2 and 3 (–0.31 and –0.32 Ns, respectively). The springiness also showed significant differences between the fillets 4 and 1 (3.20 mm and 4.50 mm, respectively).

Sex influence on the muscle and textural parameters. Overall, all the muscle and textural parameters were higher in female than male specimens in all the fillets (1-4; Table 1), although some exceptions could be observed. To obtain an overall assessment of the influence of sex on the muscle and textural parameters and fillets weight, we have joined the values from all the fillets (1-4) from each specimen and then compared male versus female (Tables 1 and 2; Figs. 1A-D). The results showed that the transverse area of white muscle was greater in females than males ($p < 0.05$), parallel to a larger number and size of the fibers ($p > 0.05$; Table 1 and 3). The red muscle showed a similar trend ($p > 0.05$). Most textural parameters were also higher in females than males, but not always significantly (Tables 1 and 2). The weight of all the fillets (1-4) was higher in females than males (Table 3).

Sex influence on body parameters. Standard length, total weight, gonad weight, gonadosomatic index (GSI), using the following formula, and gutted weight were significantly higher in females than males (Table 4). Also, the percentage of eviscerated weight and the percentage of the edible part were lower in females than males.

$$GSI = gonad\ weight\ /total\ weight \times 100$$

Table 1. Mean values of the muscle parameters and hardness in each group in the zones 1-4 of the myotome: upper epaxial, upper hipoaxial, bottom epaxial and bottom hipoaxial, respectively, from seven diploids (D) specimens and seven triploids (T) specimens. Data from the fillet 1 were obtained in a previous study.[8]

Parameters	Group	Sex	Zone 1	Zone 2	Zone 3	Zone 4
Minor axis length of the white fibers (µm)	D	Female	92.52^{aA}	35.05^{aB}	94.03^{aA}	35.44^{aB}
		Male	87.50^{bA}	33.74^{bB}	87.73^{bA}	31.35^{bB}
	T	Female	131.68^{aA}	120.43^{aB}	108.63^{aC}	113.33^{aD}
		Male	132.09^{aA}	131.63^{bA}	127.43^{bB}	124.47^{bB}
Number of white fibers	D	Female	230736.57^{aA}	192382.15^{aA}	178776.85^{aA}	149865.21^{aA}
		Male	169914.55^{aA}	163116.47^{aA}	130083.61^{aA}	156677.92^{aA}
	T	Female	96735.19^{aA}	113921.64^{aA}	115329.59^{aA}	100079.27^{aA}
		Male	77407.37^{aA}	67791.47^{bA}	74000.81^{aA}	77803.25^{aA}
Density of white fibers (fibers per mm^2)	D	Female	122.10^{aA}	125.20^{aA}	108.70^{aA}	116.50^{aA}
		Male	125.20^{aA}	129.20^{aA}	105.80^{aA}	137.00^{aA}
	T	Female	53.90^{aA}	64.80^{aA}	66.40^{aA}	62.70^{aA}
		Male	53.60^{aA}	47.70^{aA}	54.80^{aA}	58.00^{aA}
Hardness (N)	D	Female	60.42^{aA}	36.74^{aA}	35.41^{aA}	30.87^{aA}
		Male	37.12^{aA}	28.40^{aA}	17.70^{aA}	38.38^{aA}
	T	Female	52.81^{aA}	38.79^{aA}	36.47^{aA}	40.93^{aA}
		Male	45.46^{aA}	30.87^{aA}	30.96^{aA}	29.18^{aA}

Different lowercase letters indicate significant differences between both sexes within each group (D or T) in each zone ($p < 0.05$), and different uppercase letters indicate significant differences among the four zones of the myotome within each group and each sex ($p < 0.05$).

Table 2. Mean textural values ± SEM from seven diploids (D) specimens and seven triploids (T) specimens. These data were obtained by joining the textural values of all the fillets/fish, being the data of the fillet 1 obtained in a previous study.[8]

Parameters	Groups	Female	Male
Cohesiveness (ratio)	D	0.40 ± 0.02 ^{aA}	0.50 ± 0.02 ^{aA}
	T	0.40 ± 0.02 ^{aA}	0.43 ± 0.03 ^{aA}
Chewiness (N mm^{-1})	D	78.60 ± 12.40 ^{aA}	47.40 ± 9.25 ^{aA}
	T	76.10 ± 8.90 ^{aA}	60.70 ± 10.62 ^{aA}
Springiness (mm)	D	4.00 ± 0.20 ^{aA}	3.25 ± 0.19 ^{aB}
	T	4.10 ± 0.11 ^{aA}	3.77 ± 0.17 ^{aA}
Hardness (N)	D	40.90 ± 4.70 ^{aA}	30.63 ± 4.46 ^{aA}
	T	42.25 ± 4.37 ^{aA}	34.18 ± 4.71 ^{aA}
Gumminess (N)	D	18.90 ± 2.00 ^{aA}	13.77± 1.91 ^{aA}
	T	18.10 ± 1.90 ^{aA}	15.96 ± 2.11 ^{aA}
Adhesiveness (N sec)	D	−0.40 ± 0.06 ^{aA}	−0.20 ± 0.03 ^{aB}
	T	−0.30 ± 0.03 ^{aA}	−0.37 ± 0.05 ^{bA}

Different lowercase letters indicate significant differences between both groups (diploid versus triploid) for each parameter ($p < 0.05$), and different uppercase letters indicate significant differences between females and males for each parameter in each group ($p < 0.05$).

Table 3. Mean values ± SEM of the muscle parameters and fillet weight from seven diploids (D) specimens and seven triploids (T) specimens. These data were obtained by joining the values from the four fillets/fish, being the data of the fillet 1 obtained in a previous study.[8]

Muscle parameters	Groups	Female	Male
Transverse area of the white muscle (mm^2)	D	1498.09 ± 65.86 ^{aA}	1207.99 ± 36.00 ^{aB}
	T	1707.59 ± 63.19 ^{bA}	1398.27 ± 45.04 ^{bB}
Transverse area of the red muscle (mm^2)	D	81.25 ± 16.06 ^{aA}	60.22 ± 13.78 ^{aA}
	T	68.60 ± 13.48 ^{aA}	78.96 ± 18.42 ^{aA}
White muscle fibers area (µm)	D	4833.20 ± 47.40 ^{aA}	4400.10 ± 47.70 ^{aB}
	T	15921.10 ± 87.60 ^{bA}	19454.00± 155.50 ^{bB}
Minor axis length of white fibers (µm)	D	59.50 ± 0.30 ^{aA}	56.70 ± 0.30 ^{aB}
	T	116.40 ± 0.40 ^{bA}	128.70 ± 0.50 ^{bB}
Number of white fibers	D	173674.70 ± 15011.60 ^{aA}	152443.80 ± 8714.50 ^{aA}
	T	108807.10 ± 4759.30 ^{bA}	73198.50 ± 7394.40 ^{bB}
Density of white fibers (fibers per mm^2)	D	117.00 ± 0.90 ^{aA}	126.00 ± 0.60 ^{aA}
	T	64.00 ± 0.30 ^{bA}	53.00 ± 0.60 ^{bB}
Fillet weight (g)	D	273.10 ± 18.10 ^{aA}	202.10 ± 10.20 ^{aB}
	T	282.80 ± 11.60 ^{aA}	226.70 ± 9.20 ^{aB}

Different lowercase letters indicate significant differences between both groups (diploid versus triploid) for each parameter ($p < 0.05$), and different uppercase letters indicate significant differences between females and males for each parameter in each turbot group ($p < 0.05$).

Table 4. Mean values ± SEM of body parameters obtained from seven diploids (D) specimens and seven triploids (T).

Parameters	Groups	Female	Male
Body length (cm)	**D**	48.10 ± 0.30 ^{aB}	41.10 ± 0.60 ^{aA}
	T	47.00 ± 0.40 ^{aB}	43.30 ± 0.20 ^{bA}
Total weight (g)	**D**	2560.00 ± 53.70 ^{aB}	1736.10 ± 111.70 ^{aA}
	T	2438.70 ± 37.90 ^{aB}	1975.40 ± 37.90 ^{bA}
Gonad weight (g)	**D**	135.90 ± 0.40 ^{aB}	7.60 ± 22.10 ^{aA}
	T	8.20 ± 0.58 ^{bB}	4.60 ± 1.20 ^{bA}
Gonadosomatic index	**D**	5.00 ± 0.00 ^{aB}	0.40 ± 0.70 ^{aA}
	T	0.30 ± 0.00 ^{bA}	0.23 ± 0.04 ^{bA}
Eviscerated weight (g)	**D**	2247.50 ± 49.40 ^{aB}	1590.00 ± 84.50 ^{aA}
	T	2263.70 ± 26. 30 ^{aB}	1828.20 ± 36.00 ^{bA}
Eviscerated weight (%)	**D**	88.10 ± 0.40 ^{aB}	91.60 ± 0.70 ^{aA}
	T	92.80 ± 0.50 ^{bA}	92.60 ± 0.10 ^{aA}
Edible part (%)	**D**	42.70 ± 0.40 ^{aB}	46.90 ± 0.20 ^{aA}
	T	46.40 ± 0.50 ^{bA}	46.00 ± 0.30 ^{aA}

Different lowercase letters indicate significant differences between both groups (diploid versus triploid) for each parameter ($p < 0.05$), and different uppercase letters indicate significant differences between females and males for each parameter in each group ($p < 0.05$).

Correlation between muscle and textural parameters. Following grouping the values from both sexes, we can appreciate significant and positive correlations between the parameters including chewiness, springiness, hardness, and gumminess with the number of fibers. By separating both sexes, female specimens showed a positive correlation of the parameters including chewiness and gumminess with the number of fibers ($p < 0.05$). The male specimens showed a positive correlation between the springiness and the number of fibers ($p < 0.05$).

Triploid group (T)

Influence of the myotome zone on the muscle parameters and fillets weight. The highest values of the white muscle fibers size were found in the upper epaxial fillet (fillet 1), followed by the upper hipoaxial (fillet 2; $p < 0.05$), whereas the bottom fillets (fillets 3 and 4) showed the lowest values of this parameter (Table 1; Fig. 1E). Similarly, the transverse area of the white muscle was bigger in the upper than bottom zones of the myotome (zones 1 > 2 > 3 > 4; $p > 0.05$; not shown). On the contrary, the muscle fibers density was higher in the bottom than upper zones ($p < 0.05$; Table 1). About the number of white fibers, the lowest values were found in the fillet 1 ($p > 0.05$; Table 1). The red muscle did not show significant differences among the fillets ($p > 0.05$). The weight of the epaxial fillets was higher than hipoaxial fillets in both females and males ($p < 0.05$; not shown). On the other hand, when comparing the values of the upper *versus* the bottom fillets, these were similar between them.

Influence of the myotome zone on the textural parameters. On the whole, the highest textural values were usually found in the fillet 1, whereas the lowest values were usually observed in the fillet 4, even though some exceptions could be found (Table 1). However, the differences were not very significant, such that these were only found in some fillets for the following parameters: Cohesiveness (fillet 2 was different from 4 and 1, with values of 0.50, 0.38 and 0.39, respectively); chewiness (fillet 1 was different from 4, with values of 97.68 and 50.30 N mm^{-1}, respectively) and springiness (fillet 1 was different from 4, with values of 4.36 and 3.57 mm, respectively).

Sex influence on the muscle and textural parameters. Most of the muscle and textural parameters were higher in female than in male specimens, with the only exception of the white muscle fibers size, which was higher in male than in female specimens in all the fillets (Table 1). Fillets weight was also significantly higher in females. Following joining all data from four fillets, the same results were found (Tables 2 and 3).

Sex influence on body parameters. Body length, total weight, gonad weight, GSI, eviscerated weight, and percentage of eviscerated weight were significantly higher in female than in male specimens (Table 4). The percentage of the edible part was also higher in females than males, but not significantly.

Correlations between the muscle and the textural parameters. Following grouping the values from both sexes, we did not find a significant correlation of the muscle cellularity (number and size of fibers) with the textural parameters. However, we found a positive correlation of the white muscle cross-sectional area, total weight, body length, and fillets weight with the texture parameters, although it was not always significant. By separating the sexes, the female specimens showed a significant and positive correlation between springiness and the size and density of the white muscle fibers. This correlation was not observed in the male specimens.

Ploidy influence: Diploid versus triploid specimens

Muscle parameters and fillets weight. Following comparing both groups (D *versus* T), we can observe that the white muscle fibers size was always greater in T than D specimens ($p = 0.000$) in all the fillets (Tables 1 and 3), in both female and male specimens. On the contrary, the

number and the white muscle fibers density were higher in D than T specimens in both sexes. About the transverse area of the white muscle, this was also greater in T than D (with the only exception of the fillet 1, which was similar between both groups, according to the authors cited above)[8] in both males and females ($p > 0.05$). The transverse area of the red muscle did no show significant differences between both groups. The weight of most fillets was also higher in T, although not significantly (Table 3).

Textural parameters. The textural data of all fillets (1-4) from each specimen were joined and then the results were compared between D and T, in both male and female specimens (Table 2). Significant differences were only found in springiness and adhesiveness.

Body parameters. The D females showed lower values of body length, total weight, and eviscerated weight than T females ($p < 0.05$), parallel to higher values of the gonad weight and GSI in D females (Table 4). In males, body length and total weight were similar between D and T, whereas the gonad weight and GSI were higher in D than T. The dressed weight was similar between both groups, but the percentage of gutted weight and the percentage of edible part were higher in T than D.

Correlation between the muscle and the textural parameters. After joining the results of both populations and applying the correlation analysis, it seems there is not a clear correlation between most of the muscle parameters and texture.

Discussion

In D specimens, the greatest size of white muscle fibers was found in the epaxial zones of myotome (fillets 1 and 3), whereas in T specimens, the biggest size of white fibers was found in the upper zones (fillets 1 and 2). These results show that the body asymmetry and the swimming behavior of this species influence the muscle cellularity of the myotome and it is also influenced by the ploidy. In other species, such as the trout (*Oncorhynchus mykiss*), other authors have found significant differences between the dorsal and ventral zones of the myotome.[15] Similarly, in salmon, *Salmo salar* L., differences in different points of the myotome were also observed.[16] However, other authors have studied different zones of the myotome of the sea bass, *Dicentrarchus labrax* L., and did not find muscle cellularity differences.[17]

Both populations usually showed the highest textural values in the upper epaxial zone, whereas the bottom hipoaxial zone showed the lowest values, although these results were not very significant. In D and T specimens, the textural parameters did not show a significant correlation with the size and density of the fibers, that agrees with the results found by the authors cited for the fillet 1.[8] These results differ from those found in other species where the muscle fibers size showed a negative correlation with the flesh firmness.[18-21]

Following comparing both sexes (female *versus* male) within each population, the muscle parameters and most of the textural parameters were higher in females than males in both populations (with the only exception of the white fibers size in T specimens). This population was previously studied in an earlier stage (at the beginning of the sexual maturity, with 22 months of age),[10] beings also observed higher values of white muscle cross-sectional in females than males for the D group, whereas the T group hardly showed differences in this parameter. Other authors have studied the sexual dimorphism of fast muscle fiber recruitment in halibut (*Hippoglossus hippoglossus* L.).[9] From the point of maturation, female specimens had higher values of body mass, total cross-sectional and number of fibers than male specimens. In the present study, the fillet weight was also higher in females in both diploid and triploid specimens of this study, as found by other authors.[10] Also, the body length, total weight, gonad weight, GSI and gutted weight were higher in females than males in both D and T specimens. Similarly, other studies in this species have found higher GSI values in females than males in diploid specimens, whereas the T group did not show differences in this index.[10] In turbot of 47 months of age (after the spawning period), it was also observed that the total and the eviscerated weight were higher in females than males in both D and T specimens.[3]

According to other authors, even though T males are functionally sterile, they produce near-normal levels of circulating androgens at spawning time, thus, causing the normal deteriorative changes associated with maturation.[2,22] On the contrary, T females are both functionally and hormonally sterile.[23] This would explain that the T females of this study showed higher values of muscle and body parameters than T males. Similarly, the male T rainbow trout are functionally sterile, but show considerable gonad development and develop secondary sexual characteristics, and so, the production of all-female T populations is most desirable to reduce any sexual-related disadvantages.[22,24] According to our results and those found in other species, it seems that it would be more profitable to produce all-female T, as suggested by other authors.[2]

The correlation analysis showed punctual correlations between muscle cellularity and texture. Thus, the number of white fibres showed correlation with chewiness and gumminess in D females, whereas the T group did no show this correlation. In T female, the springiness parameter was the only parameter that showed correlation with the size and white muscle density.

The transverse area of white muscle was higher in T than D specimens, in both males and females. Also, muscle cellularity was different between both populations, such that the muscle fibers size was greater in the T than D

group, whereas the number and muscle fibers density were higher in the D than T group. These results coincide with the data previously obtained for the fillet 1.[8] Previously, both groups of fish were studied at 22 months of age,[10] being observed a similar pattern to that observed in the present study in the size and number of muscle fibers. This shows that the ploidy effect in the muscle cellularity was already present from earlier stages and remained in advanced life stages. Other authors[4] have studied the effect of ploidy in trout (*O. mykiss*) and also observed that T trout had greater fibers size than D trout. Similarly, other authors[2] have studied the musculature in D and T female salmon (*S. salar*) and found a lower density of satellite cells and reduced rates of fibre recruitment, but a compensatory increase in muscle fibre hypertrophy in T compared to D fish.

Gonadal maturation in D produced higher gonad weight and higher GSI than T, in both males and females, similar to what was found in the previous stage of the age of this population.[10] The absence of gonadal maturity in T females of the present study was accompanied by increased growth in length, total weight, and gutted weight in this group, evidencing the highest growth efficiency compared to the rest of the groups. Concerning the male specimens of this study, these did not show differences in the values of total weight and body length between D and T, but the percentage of gutted weight and edible part was higher in T males, thus indicating the highest carcass yield because of the absence of gonadal maturity. Other authors[3] have also studied the effect of ploidy in turbot and observed similar results to those described in the present study, being the differences more marked among females than males. Similarly, other authors[4] have also observed higher body weight and higher fillets weight in T than D trouts. However, not all fish species have greater growth in the absence of gonadal development. Thus, shi drum (*Umbrina cirrosa,* L.) T specimens grew less than D specimens.[25]

Most of the textural parameters were similar between both D and T groups in male and female specimens. These data are similar to those found in the earlier stage of this population,[10,26] where no textural differences were noted between both groups of turbot. Also, similar results were obtained for the fillet 1.[8] However, it differs from results in other species, which showed a negative correlation between the fibrillar size and texture.[18-21] Other authors have observed that the texture in T shi drum was lower than D.[25] These authors did not measure the fibers, but suggested that the textural differences may be related to fibers size. In turbot, however, despite the significant differences in the fiber size between both populations (D and T), these did not influence on the texture. This can be beneficial for the aquaculture, because we can get T specimens with higher growth than D specimens of turbot, without compromising on its texture.

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Conflict of interest

The authors declare that there is no conflict of interest.

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