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Morphological, nutritional and safety traits of bluefin tuna (*Thunnus thynnus*) reared in floating cages

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ABSTRACT: To evaluate the influence of fattening on morphological, nutritional and safety characteristics, two lots of bluefin tuna were sampled before (November: 2 ♀, 4 ♂) and after 5 months of fattening (April: 5 ♀, 5 ♂). The specimens, after death, were refrigerated and analysed at different times over the period of a week for morphological and flesh physico-chemical parameters in six muscle sites.
Tuna sampled in April had greater body weight (44.04 *vs* 36.41kg), trunk length (52.21 *vs* 48.22cm) and minimum and maximum circumferences (13.74 *vs* 12.77 and 94.90 *vs* 89.10cm).
No differences in other linear measures or body components were found. Fattening did not influence flesh colour or total lipid content, producing small differences in its chemical composition: greater C18:0, C18:1n9 and PUFAn6 percentages; higher putrescine and histamine (0.489 *vs* 0.335 and 0.666 *vs* 0.370mg/kg) but lower spermine and spermidine (10.598 *vs* 17.387 and 2.420 *vs* 3.928mg/kg) levels. Large differences in physico-chemical parameters were found between muscle sites and a significant interaction between sampling date and muscle site indicated non homogeneous changes in chemical composition of dorsal, ventral and red muscle after fattening. Sex only influenced fat content in viscera (♀ 12.84 *vs* ♂ 9.84%).

Key words: Flesh colour, Fattening, Fatty acids, *Thunnus thynnus*.

INTRODUCTION – Tuna and tuna-like species fetch very high prices on the international market, where they are used raw (sashimi or sushi) and for canning. The high price of fresh and high quality bluefin tuna (BFT) on the Japanese market has led to severe exploitation of this species and imposition of quotas by international organisations (ICCAT), stimulating the development of rearing practices in the Mediterranean and other seas since the mid 1990s. Tuna farms can supply fresh tuna of any size at any time of year and their number is now growing.
BFT farming involves capture of generally lean wild specimens by trap fishing and transfer to sea cages for a few months, where they are fed to increase their fat content and hence commercial value, but other important quality characteristics, such as flesh texture and colour, may be influenced by fattening. Different rearing parameters and practices may also affect final quality and shelf life, as in the case of other species of reared fish. The effect of fattening on quality characteristics of BFT were limitedly investigated in the available literature and the importance to elucidate this aspect is justified by the quality characteristics of flesh demanded by the highly remunerative Japanese market, related to freshness, fat content, colour, absence of Yake. Aim of this study was to evaluate the influence of fattening on morphological, nutritional and safety characteristics of male and female specimens of BFT, studying in deep the quality aspects in different muscle locations within the same fillet.

MATERIAL AND METHODS – Specimens of wild bluefin tuna (*Thunnus thynnus*) were captured and transferred for rearing in sea cages of a tuna farm, near Vibo Marina (Vibo Valentia, Italy), in October 2005. During the fattening phase, the fish were fed a mixed diet consisting of small raw pelagic seafood species (anchovies, mackerel, sardines, herrings, cephalopods). Samplings were effected in November 2005 and April 2006.
The tuna sampled (6 in November: 2 ♀ and 4 ♂, 30.3 to 44.6kg b.w.; 10 in April: 5 ♀ and 5 ♂, 36.4 to 57.0kg) were killed one by one in sequence in each sampling with a diver's gun with hunting cartridge, routinely utilized in this tuna farm, and then refrigerated (1°C in ice). At different times after harvesting [4 (n=2), 5 (n=2) and 6 (n=2) days

after the November sampling; 2 (n=2), 5 (n=3), 6 (n=3) and 7 (n=2) days after the April sampling], the specimens were weighed, measured in length (total and to fork; of head, trunk, abdomen and tail) and circumference (maximum and minimum), then sectioned into the principal body components (head, viscera, liver, fillets, perivisceral fat). Colour of steaks from the left fillet was measured (by Minolta Chromameter) in 3 epaxial muscle sites (cranial, medial, caudal: D1, D2, D3), 2 hypaxial muscle sites (abdominal and caudal: V1, V2) and 1 red (R) muscle site (medial). Muscle samples from the same sites were analysed for chemical composition (moisture, crude protein, ash; total lipids; qualitative and quantitative composition of fatty acids by gas chromatography with C23:0 as internal standard). Biogenic amines (putrescine, cadaverine, histamine, spermine, spermidine; by HPLC) and mercury levels (only in D1 and V1 muscle samples) were also determined in tuna muscle. Data were analysed by SAS; morphological parameters by PROC GLM, taking sampling date, sex and related interactions as effects, and physico-chemical parameters by PROC MIXED, in a model having sampling date, sex, muscle site and hours from catching (only for colour parameters, biogenic amines and Hg) as fixed effects and the animal as random effect. Interaction of sampling date and muscle site was also tested.

RESULTS AND CONCLUSIONS – The tuna sampled in April had greater body weight (44.04 *vs* 36.41kg, +17%), trunk length (52.21 *vs* 48.22cm; $p<0.01$) and minimum and maximum circumferences (13.74 *vs* 12.77 and 94.90 *vs* 89.10cm, $p<0.01$ and $p<0.05$, respectively) but the other linear measurements (total length: 138.30 *vs* 131.87cm, length of head, abdomen and tail), condition index (body weight x 100/total length^3, 1.66 *vs* 1.59) and body components incidences were similar to those of tuna sampled in November. No significant changes were found in the percentage of fat in viscera (12.61 *vs* 10.08%; $p=0.06$), yield of fillets with skin (68.87 *vs* 69.79%) or dressed yield (~ 95%). Compared to males, females only had more fat percentage in viscera (12.84 *vs* 9.84%; $p<0.05$) and the interaction between sampling date and sex was not significant (data not shown). Sampling date and tuna sex did not influence colour parameters, which varied sharply in relation to muscle site (Table 1).
The three sections of dorsal muscle (D1, D2, D3) had similar values of colour parameters (L*, a*, b*), showing a whiteness intermediate between those of R and V1-V2 sites (the lowest and highest, respectively). The highest value of redness was recorded in R muscle and the lowest in V1. Ventral sites had similar yellowness which was higher than in dorsal and R sites.
Only whiteness changed significantly during the week of storage (coefficient of linear regression on hours after catching: $b=0.04$; $p<0.05$). After fattening, small differences in average chemical composition of tuna flesh only concerned certain fatty acid percentages (Table 1); the rearing period (effected prevalently in winter) and feeding with fish having high lipid content and cephalopods did not significantly increase the total lipid content of tuna flesh but was associated with higher percentages of C18, C18:1n9 and PUFAn6.
Very large differences between muscle sites emerged for proximate analysis and fatty acid compositions of lipids, V1 being richest in lipids (34.86 *vs* 18.24% for V2 *vs* 12.38% for R and 11.73% in average for D). The differences in fatty acid composition mainly concerned V1 and R, V1 showing the lowest percentages of saturated FA and HUFAn6, and the highest of C16:1 (with V2) and C20:5n3 percentages. R muscle had a lipid content similar to that of D sites, but fatty acid quality was quite different due to higher SFA (and C18:0) and C22:6n3 (~ +3%) and lower MUFA (and C16:1) and C20:5n3 (~ -2%) percentages. Overall, the chemical and fatty acid composition of D sites was similar, whereas some differences emerged between V sites (for proximate composition and SFA, C14:0, C18:0, C18:1n9, C20:5n3, PUFAn3, PUFAn6 percentages), V2 having a composition similar to that of dorsal sites.
The significant interaction between sampling date and muscle site highlighted a different distribution of chemical constituents between sites before and after the fattening period, probably due to different metabolic activity of dark red and white muscle, related to muscle exercise, physiological status and growth (Mourente *et al.,* 2002; Nakamura *et al*., 2006). In particular, lipids in V1 and R muscles showed a significantly opposite pattern in fish sampled in November and April (V1: 30.94 *vs* 38.77%; R: 16.94 *vs* 7.81%), which may explain the lack of significance of the effect of sampling date on total lipid content. Other important changes produced by the fattening specifically concerned the characteristics of R muscle (scarcely interesting for the consumer), as the sensibly diminished percentages of SFA and MUFA and the increased percentages of PUFAn6 and PUFAn3. Regarding the trend of decay indicators, changes in biogenic amine levels during the storage were not significant, whereas the flesh of tuna sampled in April had higher levels of putrescine (0.489 *vs* 0.335mg/kg; $p<0.05$) and histamine (0.666 *vs* 0.370mg/kg; $p<0.01$) but lower levels of spermine (10.598 *vs* 17.387mg/kg; $p<0.01$) and spermidine (2.420 *vs* 3.928mg/kg; $p<0.01$) (data not shown). Muscle sites only influenced putrescine content, which was highest in R muscle. Mercury content, higher in D1 than in V1 (0.598 *vs* 0.352mg/kg), was always below the safety threshold. The fattening period produced minimal changes in tuna morphological characteristics and in the colour and chemical composition of flesh. Very large differences in physico-chemical parameters emerged between muscle sites and the significant interaction between sampling date and muscle site indicated non homogeneous changes in chemical constituents between dorsal, ventral and dark red muscle, as a consequence of fattening. The rearing period did not produce any substantial changes in the quality

Table 1. Effect of sampling date, sex, muscle site, and interaction between sampling data and muscle site on colour parameters and proximate (%) and fatty acid composition (% of total FA).

	sampling date		sex		Site						RSD
	Nov.	*Apr.*	♀	♂	*D1*	*D2*	*D3*	*R*	*V1*	*V2*	
L*[1]	44.05	45.46	45.44	44.08	41.38^{cd}	41.88^{cd}	43.25^{c}	38.73^{d}	54.94^{a}	48.35^{b}	25.29
a*	15.48	14.51	15.19	14.8	15.09^{B}	14.43^{BC}	14.71^{B}	17.05^{A}	13.19^{C}	15.49^{B}	6.28
b*	5.72	5.98	5.95	5.76	5.44^{C}	4.98^{C}	5.02^{C}	5.73^{C}	7.37^{A}	6.59^{AB}	2.81
Moisture[1]	59.99	59.00	60.03	58.96	62.02B	62.73^{B}	62.36^{B}	65.19^{A}	45.71^{D}	58.96^{C}	7.27
Protein[1]	20.09	21.55	20.34	21.31	22.48^{A}	23.40^{A}	22.83^{A}	20.04^{B}	16.17^{C}	20.01^{B}	2.62
Ash	1.26	1.27	1.29	1.24	1.43^{A}	1.47^{A}	1.41^{A}	1.27A^{B}	0.86^{C}	1.14^{B}	0.10
Lipid[1]	16.36	17.19	17.23	16.33	12.73^{C}	11.62^{C}	10.84^{C}	12.38^{C}	34.86^{A}	18.24^{B}	12.83
C14:0	4.16	3.94	4.16	3.93	4.21^{AB}	4.15^{B}	4.06^{B}	3.39^{C}	4.35^{A}	4.13^{B}	0.04
C16:0[1]	17.98	17.56	17.69	17.85	17.87	17.81	17.74	17.82	17.72	17.65	0.05
C18:0[1]	5.84^{b}	6.31^{a}	6.08	6.07	5.91B^{C}	6.05^{B}	6.07^{B}	7.22^{A}	5.35^{D}	5.82^{C}	0.06
SFA[1]	29.37	29.30	29.37	29.30	29.40^{B}	29.48^{B}	29.36^{B}	29.98^{A}	28.78^{C}	29.01^{C}	0.10
C16:1n7	5.99	5.97	6.12	5.84	6.10^{B}	6.07^{B}	6.06^{B}	5.10^{C}	6.37^{A}	6.17^{AB}	0.07
C18:1n9[1]	19.76^{B}	20.97^{A}	20.48	20.25	20.35^{B}	20.39^{B}	20.45^{AB}	19.95^{D}	20.26^{CD}	20.78^{A}	0.22
MUFA[1]	32.36	32.31	32.46	32.21	32.28^{B}	32.28^{B}	32.45^{AB}	31.56^{C}	32.50^{AB}	32.95^{A}	0.56
C20:5n3	11.54	11.36	11.81	11.10	11.85^{AB}	11.75^{AB}	11.58^{BC}	9.65^{D}	12.14^{A}	11.73^{B}	0.31
C22:6n3	15.41	15.96	15.12	16.26	15.29^{B}	14.33^{C}	15.45^{B}	18.75^{A}	15.23^{BC}	15.07^{C}	1.58
PUFAn3[1]	33.50	33.27	33.12	33.65	33.36^{ab}	33.17^{b}	33.17^{b}	33.79^{a}	33.77^{a}	33.07^{bc}	0.49
PUFAn6[1]	2.86^{B}	3.25^{A}	3.03	3.08	2.98^{C}	3.10^{B}	3.10^{B}	3.27^{A}	2.86^{D}	3.01^{C}	0.01

Total fractions of FA include some minor components (<5%), not shown in table.

[1]Parameters for which interaction between sampling date and muscle site was statistically significant.

$^{a, b}$=P<0.05; $^{A, B}$=P<0.01.

decay trend, but was associated with increased levels of putrescine and histamine, the latter being below the EC safety level (10mg/100g). The storage period was probably insufficient to detect different patterns of deterioration.

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