A method to assess gaping in Sparidae species fillets

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A number of commercially important farmed fish species are marketed as fillets, primarily to satisfy consumer demands. Filleting, performed either mechanically or manually, is a processing stage that aims at adding value to the product, depending, of course, on the type of market (Borderías & Sánchez-Alonso, 2010).

Among fish fillet quality characteristics, texture integrity is considered crucial for consumer acceptance. Undesirable textural changes include softening and fillet gaping (Kristoffersen et al., 2006). Described for the first time in over forty years ago, gaping is a post-mortem phenomenon which is caused by rupture of the connective tissue resulting in gaps and tears at the myofiber-myocommata attachments and between myofibres (Mitchie, 2001; Ofstad, Olsen, Taylor & Hannesson, 2006). Kiessling, Espe, Ruohonen & Mørkøre (2004) reported gaping as the result of the interaction between the forces pulling the muscle apart, and the strength of the tissue. Factors that have proven to be strongly associated with the fish propensity to gap, include the species, the biological status, the catch or slaughter history, the temperature during storage (Lavety, Afolabi & Love, 1988; Sheehan, O'connor, Sheehy, Buckley & FitzGerald, 1996; Robb, Kestin & Warriss, 2000) and the processing procedure (Birkeland, RørA, Skåra & Bjerkeng, 2004).

Several methods have been described to evaluate the degree of gaping in fish fillets, measuring the quantity and size of slights in the fillet (Andersen, 1994; Espe et al., 2004) or evaluating the area covered by gaps (Kiessling et al., 2004). Automated and semi-automated methods have been also proposed for assessing fillet gaping, thus providing objective, accurate as well as re-analysable data (Ashton, Michie & Johnston, 2010; Balaban, Ünal Şengör, Soriano & Ruiz, 2011; Merkin, Stien, Pittman & Nortvedt, 2013).

The aforementioned methodologies have been proposed to describe gaping phenomenon in salmonids and specifically in Atlantic salmon (*Salmo salar*), which represents a species of principal importance in aquaculture industry. However, fish species of major importance in the Mediterranean mariculture, namely gilthead sea bream (*Sparus aurata*) and red sea bream (*Pagrus major*), also suffer from gaping and consequently economic losses burden their industry.

The extrapolation of methods developed for salmonids to other fish species might provide a less efficient description, since gaping and muscle textural characteristics are species-specific and, on the other hand, commercial fillet sizes largely differ. Thus, the aim of this study was to develop a semi-automated method, by using digital photography and computer image analysis, for measuring gaping in Sparidae species fillets. Furthermore, the data from applying this method were used to train assessors in order to speed up the measuring process and to make the scoring procedure accessible to all commercial gilthead sea bream and/or red sea bream processing plants.

Market-size (400-800 g) gilthead sea bream and red sea bream were harvested from sea cage farms during the summer period (July, 2020), slaughtered according to standard commercial procedures, packed with ice and shipped to Selonda Aquaculture SA processing facilities (Athens, Greece), where they were stored at 0-4 ^{o}C for two days. After mechanical scale removal by drum, fish were filleted, using a filleting-machine, weighted, ice-packed and transferred (within two hours) to the Hellenic Centre for Marine Research (HCMR, Anavyssos, Athens, Greece) to assess their gaping.

Fillets were placed skin side down on a polypropylene surface with a convex curvature of 165 degrees of a circle with 4.5 cm diameter. This allowed the gaps to remain open during image analysis without, however, causing additional damage of the fish flesh. A 12-megapixel camera (SP- 590UZ Olympus, Tokyo, Japan) was mounted on a retort stand and clamped 15.5 cm above the apex of the curved surface. Fillet images were taken individually and the records were digitally analysed, as described below. A scale bar (30 cm) was also included in each image. The fillets were placed in a way that allowed all gaps to be observed from a single image. Where this condition was not met, a second image was taken after the fillets were repositioned on the convex surface.

Fillet images were digitally analysed in order to evaluate fillet gaping severity by using ImagePro-Plus 4.5 software (Media Cybernetics, Silver Spring, USA). The software was used to manually highlight the total surface area of the fillet as well as the number, size and surface area of the gaps. Due to the curvature, a percentage of inaccuracy was found in the measurement located away from the focal point of the image, which determined to be less than 5%. Measurements of the gaps size were expressed in centimeters, while the gaping was also assessed as gap percentage of the total surface area of the fillet.

Three assessors were trained to recognize gaping phenomenon as well as to quantify gaping severity on Sparidae species fillets, based on gaping area percentage, according to the scale proposed herein (described in the results). To this end, the trainees were provided with the scale description and the photos of the two extremes for each scale point. Subsequently, they were randomly given coded fillets (N=50) of known gaping scores to assort in the scale. The procedure was repeated for three consecutive days and their performance was recorded. Training was considered successful when their performance was accurate more than 95%. After training completion, fillets (N=100) of unknown gaping scores were given to the assessors to assort in the scale. In all cases they could use the scale image photos when doubted on a sample. Their estimation was recorded and results were compared to those obtained from the digital image analysis method, in order to evaluate the method's objectivity and repeatability.

The degree of gaping in each fillet expressed as percentage of surface covered by gaps, has been computed against the number of gaps and against the maximum size of biggest gap in order to examine correlations. Regression analysis was used to examine how these measures are related.

For method validation a χ^2 method was adopted to examine a) if assessors rated in a uniform way with each other and b) to see if ratings deriving by image analysis (true) and those made by the assessors (observed) differed.

A two-tail Pearson correlation was conducted to evaluate how sample scaling results correlate with gaping area percentage.

Fillets of the two studied species, averaging 145.7 ±18 g, were assessed in order to digitally evaluate gaping characteristic and severity and thus to create the scale. The image analysis records (N=38) are presented in Table 1. Gaping of different intensity was identified in fillets of both species. In only two samples the flesh integrity remained intact, while six fillets were characterized as non-marketable.

According to Andersen et al. (1994), a scale from 0 to 5, evaluating the number and size of gaps, was proposed to assess the severity of gaping (score 0: no gaping; score 1: few small (< 2 cm) slit i.e., less than 5; score 2: some small slits i.e. less than 10; score 3: many slits i.e., more than 10 small or a few large (>2 cm); score 4: severe gaping i.e., many large slits; and score 5: extreme gaping, the fillets falls apart). However, as shown in Table 1, the mean number of gaps and the mean size of largest gap do not follow the same pattern as gaping severity expressed as percentage of gaping. This is furthermore confirmed from the low R^2 values in regression of gaping surface to gaps number and largest gap size ($R^2 = 0.503$ and $R^2 = 0.284$, respectively) observed herein. Adopting Andersen scale for Sparidae species tend to lead to overestimation of the gaping severity in low gaping categories' fillets, when compared to the area percentage method.

The total area covered by gaps, in small portion-size fillets, like the Sparidae ones, is what gives intuitively the severity impression. Thus we propose, a six point scale (from 0 to 5), based on the fillet gaping area (Table 2). In order to facilitate gaping classification by the assessors, an additional description, including the number and size of gaps coinciding with the gaping area-determined categorization, for each gaping point was also included (Table 2).

After deciding on the scale points (Table 2), images of the extremes were used as a graphic representation of the scale, in order to provide an extra tool for the assessors (Figure 1)

A total of N=100 unknown samples were rated by all assessors in order to indicate whether the proposed method was accurate and reliable. Specifically, the three trained assessors incorrectly classified only 3, 5 and 5 fillets out of 100, respectively. It appeared, however, that distinguishing between gaping score 2 (mild) and score 3 (moderate gaping) was the most problematic for the assessors, as the majority of the incorrectly sorted samples (11 fillets or 85% of the total false answers) were reported for these gaping points. Apparently, the computer image analysis is more accurate than the assessors, since it quantitatively measures the gaping area percentage. However, no differences have been observed between assessors frequencies ($p>0.05$). Most importantly, no difference was observed for either of the scale categories between the observed frequencies (assessors) and the expected ones (image analysis). The lack of quantitative sensitivity in gaping scoring methods has been previously reported (Merkin et al., 2013) and has been outlined as a masking effect in number of gaps differences between samples. The correlation coefficient between gaping surface percentage and received scores by the assessors was calculated to be 0.84, thus indicating a good estimation of gaping severity with the proposed scale.

Conclusively, the developed six-point method, based on the digital photography and computer image analysis, represents a sensitive approach for evaluating gaping in Sparidae species fillets. Assessors training is a rapid and effective process and despite the slight difficulties they encountered in assorting fillets with mild/ moderate gaps in the scale the accuracy of the method was found more than 95%. These indicate that the proposed method for evaluating gaping in Sparidae species is easy to apply in practice, allowing the scoring procedure to be accessible to all commercial gilthead sea bream and/or red sea bream farms.

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Table 1. Ranges of measured gaping area percentage, mean number of gaps and mean size of largest gap, and number of fillets harvested during the summer period

Area of gaping as % of the total fillet area	Mean number of gaps (min-max)	Mean size of largest gap in mm (min-max)	Number of fillets
0	0	0	2
0.68-1.95	5 (3-6)	2.7 (1.6-4.0)	12
2.23-3.71	6 (4-8)	4.2 (2.6-5.0)	9
4.09-5.98	10 (8-12)	5.9 (5.0-8.0)	6
6.20-7.41	10 (3-16)	5.6 (3.3-9.4)	3
8.19-14.67	10 (7-12)	5.9 (5.1-9.4)	6

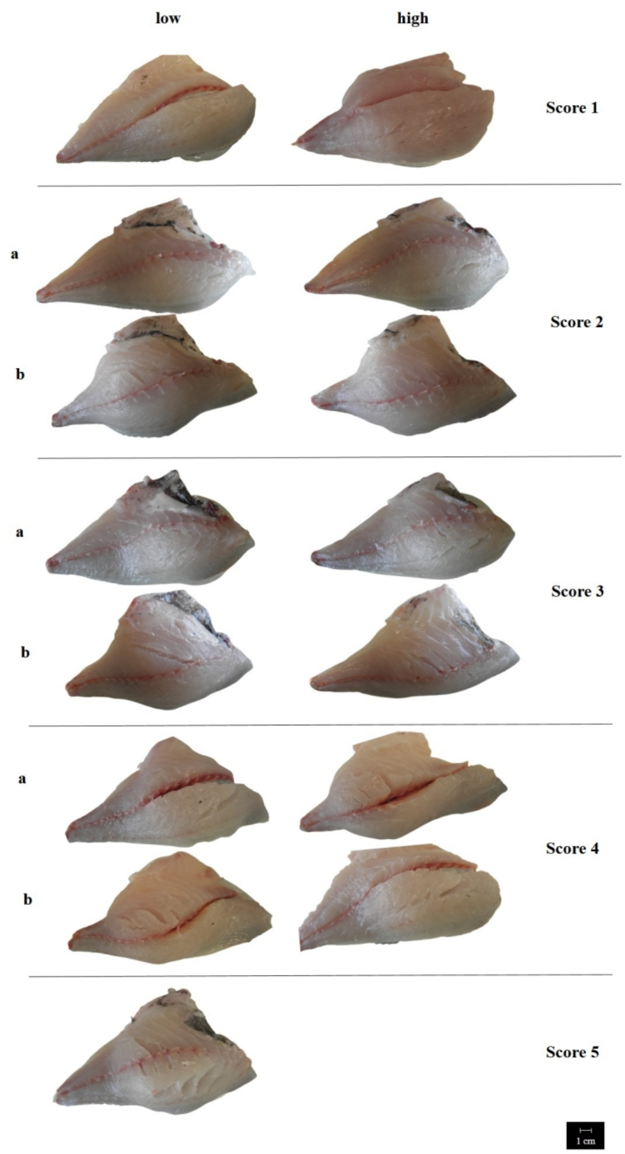
Table 2. Gaping score scale obtained by image analysis data of fillets (N=38) suitable for measuring gaping severity in Sparidae. Scale was based on the area of gaping expressed as % of the total fillet area. Additional description for each gaping score point is also included

Gaping score	Area (a) of gaping as % of the total fillet area	Gaping severity (additional description)
0	0	Absence/ No gaping
1	$0<\alpha<2$	Slight/Subtle gaping (up to 5 small[a] gaps)
2	$2<\alpha<4$	Mild gaping (up to 7 small gaps)
3	$4<\alpha<6$	Moderate gaping (up to 7 large[b] & few small gaps)
4	$6<\alpha<8$	Severe gaping (up to 7 large and/or many small gaps)
5	$8<\alpha$	Extreme gaping/ Non-marketable fillet (over 7 large gaps)

[a]: small gaps <5mm

[b]: large gaps >5 mm

Figure 1. Graphic representation of the scale: Images of the point extremes (low and high) for gaping score 1-5 (a, b: the two pictures of the same fillet after repositioning on the surface)



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181x347mm (150 x 150 DPI)