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A QIM-Based Evaluation of Sensory Quality of Frozen−Thawed Roundnose Grenadier (*Coryphaenoides rupestris*) and Its Applications

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ABSTRACT: The quality index method (QIM) is widely used for fish sensory assessment, but there are hardly any studies on quality changes in fish that have been previously frozen. A QIM scheme was developed for frozen Roundnose grenadier once thawed and stored at refrigerated temperatures (4 ± 1 °C). Next, this scheme was applied to determine the shelf life and evaluate the influence of frozen storage time on fish quality. The developed QIM scheme includes six descriptors. The quality index (QI) varies from 0 to 13 points. The maximum QI was reached 16 days after thawing. A strong linear correlation between QI and storage time was achieved (r = 0.9896), the least squares regression line being QI = 0.71 · (days after thawing) + 1.51. Using inverse prediction, the shelf life was estimated to be 5 days from the beginning of thawing. Statistical evidence of the negative effect of previous freezing time on the QI was found in a year-long study.

KEYWORDS: *quality index method, sensory quality, Roundnose grenadier, Coryphaenoides rupestris, shelf life, frozen−thawed*

1. INTRODUCTION

The Roundnose grenadier (*Coryphaenoides rupestris*) is one of the few commercially important species of the large Macrouridae family. It is distributed along the slopes of the temperate North Atlantic at depths of about 180 to 2200 m.[1] This valuable commercial fish is currently facing overexploitation. The flesh of the fish has excellent texture and taste,[2] is used for fishmeal or frozen, and can be consumed fried and baked.[3]

Different methods are used to maintain flesh quality. Freezing and frozen storage at −18 °C are considered to be the most important methods to keep fish flesh quality good for a longer time. Frozen storage has been widely employed to retain fish sensory and nutritional properties before the fish muscle is consumed or employed in other technological processes. However, deterioration in the quality of the fish muscle has frequently occurred during frozen storage because of the undesirable reactions that take place in lipid and proteins, and this leads to detrimental changes in nutritional and sensory properties.[4,5]

Sensory analysis is a first-choice procedure for assessing the quality of seafood products. The advantage of sensory evaluation is that it is simple and quick to carry out, and any tendency to subjectivity may be avoided by using an expert and extensively trained panel. As an alternative to general schemes for fish sensory assessment, a more specific method for each product can be developed by means of the quality index method (QIM).[6] This method is based on a scheme in which the sensory attributes associated with the freshness of each species and which change significantly over storage time are selected. A score from 0 to 1, from 0 to 2, or from 0 to 3 points is given depending on the degree of spoilage. The total sum of all points gives an overall sensory score, a so-called quality index (QI). A QI of 0 indicates a very fresh fish, and the score increases as the freshness characteristics deteriorate. A strong linear correlation between the sensory quality (expressed as the sum of the demerit scores) and the storage life on ice makes it possible to predict the time remaining until the end of shelf life.[7] This objective has resulted in various studies on the determination of the shelf life of fish based on the QIM; the most recent ones include Erikson et al.,[8] Khodanazary,[9] Kuvei et al.,[10] Tiyo et al.,[11] Silva et al.,[12] and Rocculi et al.[13]

The QIM scheme has been developed or adapted for many species and fishery products. Scientific literature on the QIM is abundant, and bibliographic reviews can be found in Ribeiro,[14] Bernardi et al.,[15] and Ndraha.[16] However, there are hardly any studies on the quality changes in frozen fish. Although Martinsdóttir et al.[17] already pointed out the need for the development of a QIM for frozen fish, to the best of our knowledge, only one study[18] has been carried out for frozen−thawed Atlantic mackerel. In a previous paper,[19] the investigators applied a QIM scheme developed for fresh fish to determine the rejection point in frozen hake once thawed and stored in ice. The QIM scheme has also been used on

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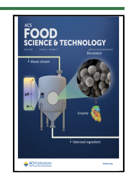

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frozen fish, specifically on cod[20] and on hake,[21,22] to assess whether the length of frozen storage time affects fish quality at the time of thawing.

The development of QIM schemes for new frozen fish species and the evaluation of their possible applications are therefore research topics of great interest that remain open. In this context, a complete study is presented to deal with gutted, headless, tailless and skinless, frozen−thawed Roundnose grenadier. First of all (Section 3.1), a QIM scheme was developed through a sensory analysis conducted with a sensory expert panel. Secondly (Section 3.2), validation of the developed QIM scheme was carried out, and its applicability to determinate the shelf life of this fish once thawed and stored at refrigeration temperatures was demonstrated. Finally (Section 3.3), QIM-based methods for assessing the influence of frozen storage time on the organoleptic quality of this fish based on a sensory study during which this fish was kept frozen up to a year were proposed. The sensorial analysis techniques as well as the statistical methods employed for each of these purposes are described next in Section 2.

2. MATERIALS AND METHODS

2.1. Samples. The analyzed fish came from freezer vessel catches belonging to the Hermanos Gandón S.A. company (Cangas, Spain). Samples were captured in March 2011 in fishing grounds in the Atlantic Ocean (NEAFC XII fishery, FAO area 27). The handling operations and the freezing (by contact) were performed on board. The fish were presented with an interfoliated distribution (i.e., with a plastic sheet between each layer) in 10 kg boxes measuring 470 × 253 × 86.5 mm. The fish weighed between 212−350 g and were 13−22 cm long.

All fish samples were taken from the same batch. Samples were stored by a frozen products' storage company, Frioriz S.A. (Guitiriz, Spain), at −25 °C until the start of the analysis. The cold chain was respected at all times.

For the treatment and preservation of the samples, the procedure described by López-García et al.[7] for Greenland Halibut was followed. For the thawing process, plastic food trays provided with grating for water drainage and covered with a thin polyethylene film were used. Thawed fish were stored in a refrigerator (4 ± 1 °C) with an appropriate quantity of flaked ice on top. During this time, every 24 h the thawing liquid was removed, the old trays were replaced with clean ones, the fish were turned to vary their position on the tray, and the melted ice was replaced.

2.2. Sensory and Statistical Analyses. The evaluation of the sensory quality of the fish was carried out with a panel of 10 judges (5 men and 5 women) with specific training and previous experience in related studies. The sensory analysis was carried out in the tasting room of the Food Technology Area of the USC Veterinary Faculty. Standard procedures[23−26] were followed in all the sensory analysis sessions. Informed consent was obtained for the 10 judges.

In each session, each judge received a fish sample of each of the degrees of deterioration (days in refrigeration) to evaluate in the session. A total of 120 gutted, headless, tailless and skinless Roundnose grenadiers were used in the development of the QIM scheme, 90 in the validation of the developed QIM scheme and its application in the study of shelf-life, and 200 in the year-long study of the effects of the prior freezing time.

2.2.1. Development of the QIM Scheme. The development of the QIM scheme was carried out in three phases (see Section 3.1): (I) a descriptive sensory analysis of the product to generate a first set of provisional descriptors, (II) a sensory analysis focused to select the descriptors of the QIM scheme using multivariate statistical methods, and (III) a final sensory analysis to establish the scales to evaluate the selected terms. In each of them, a sensory analysis session was carried out in which fish samples, placed under refrigeration for a previously determined number of days, were assessed.

2.2.2. QIM Scheme Validation and Shelf Life Estimation. The validation of the developed QIM scheme and the shelf life estimation required new sensory analysis sessions (see Section 3.2). These sensory analyses were carried out with samples that were thawed at refrigeration temperatures for different, previously selected lengths of time. In order to validate the QIM scheme, first a correlation analysis of the descriptors with the QI, to assess their relevance, was done. Secondly, the scope of the objective of the QIM scheme was verified by means of a regression analysis.

Shelf life determination was solved as a calibration problem in which its estimate and associated precision were obtained using inverse prediction methods[27] based on the linear fit obtained in the validation phase of the QIM scheme (see Section 3.2.2). According to López-García et al.,[7] shelf life was established by assigning a score of 1 to each one of the QIM scheme descriptors, with the exception of one descriptor, external mucus, for which the value of 0 (absence) was taken. Note that in the case of external mucus, only two values have been considered on the scale, 0 as absence and 1 as presence, and the appearance of the external mucus is a sign of deterioration.[28] In all other descriptors, a QI = 1 indicates that there are onset signs of deterioration but not rejection. A higher QI value indicates clear rejection (see QIM scheme).

2.2.3. Year-Long Study of Frozen Storage. A year-long study was carried out to assess the influence of frozen storage time on the organoleptic quality of this fish. The corresponding sensory analysis sessions took place in four phases (see Section 3.3). Phase 1 was carried out a few days after the fish landing. Phase 2 was four months later. Phase 3 occurred eight months after that, and Phase 4 was one year after the fish landing. In each phase, quality was evaluated using the previously developed QIM scheme. To this end, in the days before the evaluation, fish samples were selected for defrosting and storage at refrigeration temperatures following the protocol described in Section 2.1.

QIM data were used to compare the four phases by means of two statistical analyses. The first one was based on multiple linear regression and analysis-of-covariance models.[29] The objective was to compare the four regression lines, one for each phase, which describe the QI tendency with days under refrigeration. A second comparison of phases was carried out by analysis-of-variance models in which the interest focused on examining the mean QI of different combinations of phase-days under refrigeration.

3. RESULTS AND DISCUSSION

3.1. Development of the QIM Scheme. In a first phase, a descriptive sensory analysis of the product was carried out. A sensory analysis session was held in which judges were shown samples of Roundnose grenadier that had previously been stored covered with ice at refrigeration temperatures (4 °C) for 1, 4, 8, and 12 days. In this session, first the judges individually wrote down all the attributes they considered to have changed over time. Altogether, 31 descriptive terms were generated. Secondly, by means of panel consensus, as moderated by the director of the panel, a qualitative reduction of descriptors was made; in this way, the list of provisional descriptors was reduced to 26 terms.

In a second phase, a two-stage quantitative analysis of the preliminary descriptors was carried out in order to establish the definitive list of descriptors. A sensory evaluation session was held for this purpose. In it, panelists evaluated the perceived intensity of each descriptor on a scale from 0 to 5[23] for the Roundnose grenadier samples that had previously been stored covered with ice at refrigeration temperatures (4 °C) for 1, 4, 8, and 15 days. In the first stage of the analysis, based on the scores of the 10 judges, 15% of the descriptors were eliminated; they included the least relevant, that is, those with the lowest values for the geometric mean, $M = (F \times I)^{1/2}$. (For each descriptor,[23] F = number of descriptor's mentions divided by the total possible number of this descriptor's mentions, expressed as percentage, while *I* = sum of intensities given by the entire panel for descriptor divided by the maximum possible intensity of this descriptor, expressed as percentage). In the second stage, a reduction of descriptors was made to avoid redundant terms. A factorial analysis (*FA*) was performed using the principal component analysis (*PCA*) method for factor extraction with the scores of the remaining 22 descriptors. The 7 *PC* obtained (which explained 87.3% of the variance) were taken as a reference to select those terms that would allow for the best description of the product; in total, 11 terms were selected. Of these 11, it was decided that those not associated with freshness (the presence/absence of viscera, traces of skin or dirt on the surface) were to be included in an observation section. In the QIM scheme developed by Kent et al.[22] for frozen gutted hake, a descriptor related to the presence of gut remains was also included. During the rest of the study, there are no indications that these observations influenced the results, so they were not used in the end.

In the third and final phase for the development of the QIM scheme, how to evaluate the terms selected for this scheme was decided. A scale of 0 to 3, 0 to 2, or 0 to 1 demerit points, as well as the corresponding descriptions of the scales, were assigned to each one of the descriptors. To do this, a new sensory analysis session was held. At this time, and under the guidance of the panel moderator, judges were shown samples of Roundnose grenadier that had previously been covered with ice and stored at refrigeration temperatures (4° C) for 1, 6, 13, and 22 days. They were also provided with some typical definitions to be able to use as a guide.[25]

In this session, a consensus between judges and the panel director was made to dispense with two descriptors and to add a new observation called "others". The definitive QIM scheme was thus obtained (Table 1); in the end, it included the 6 selected descriptors, as well as 4 observations. According to the established scales, the QI varies from 0 to 13 points; a zero value corresponds to fresh fish and 13 to the maximum degradation.

Table 1. QIM Scheme for Thawed, Gutted, Headless, and Skinless Roundnose Grenadier

quality parameters	description	points
external color (D_1)	pinkish-white, translucent	0
	waxy, slightly yellow	1
	yellowish	2
	greenish yellow	3
External odor (D_2)	sea, sea-weedy	0
	neutral	1
	rancid, acid, sour	2
	rotten, fetid	3
external mucus (D_3)	absent	0
	present	1
flesh elasticity (D_4)	very firm, elastic (finger mark disappears rapidly)	0
	firm (finger leaves mark over 3 seconds)	1
	soft (finger print remains)	2
blood in bone (D_5)	bright red, pinkish, not present	0
	red brown	1
	brown	2
peritoneum (D_6)	very attached	0
	easily separable	1
	disintegrated	2
quality index (QI)		0−13
observations:		
• remains of guts	☐ yes	☐ no
• traces of skin	☐ yes	☐ no
• dirt on the surface	☐ yes	☐ no
• others:		

3.2. QIM Scheme Validation and Shelf Life Estimation. The developed sensory evaluation sheet was used to examine the relationship between the QI and fish storage time. Three new sensory analysis sessions were held. In each of them, the judges evaluated samples of gutted, headless, tailless, and skinless Roundnose grenadier that had been covered in ice and stored at refrigeration temperatures (4 °C) for 1, 2, 4, 6, 8, 10, 12, 14, and 16 days. In each session, the judges evaluated 2 (third session), 3 (first session), or 4 (second session) samples in order to minimize the phenomena of adaptation and the effects of mental and sensory fatigue.[26] With the obtained results, the average QI of each storage period under refrigeration was calculated.

The mean scores of all selected parameters are presented in Table 2. The correlation coefficient between the individual mean score of each descriptor and the storage time is generally high. For each attribute, Figure 1 shows how the corresponding score tended to increase to reach their maximum score with the number of days in storage in the established refrigerated conditions. In all the evaluated parameters, gradual changes were observed, with the exception of external mucus, for which the assessment scale is simpler. On the last day of the study, a total score of 13 points was reached, and this corresponded to the maximum QI of the QIM scheme developed for this species and presentation.

3.2.1. Relationship of the Quality Index with Days under Refrigeration. When examining Figure 2, the relationship of the QI with the time under refrigeration was observed to be linear. The equation of the least squares regression line, $Y = 0.7066X + 1.5069$, yielded a good description of the relationship between the mean quality index (Y) and frozen storage time (X). Besides, the degree of association of both variables was very high, $r^2 = 0.9794$, so that a 97.94% of the QI variability can be attributed to its linear relationship with time under refrigeration. Thus, for this species and presentation, the time under refrigeration prediction using the QIM scheme, which considers a sufficient number of attributes, will be simple and precise. According to Nunes et al.,[30] the QIM system does not emphasize any particular aspect, so the sample is not rejected on the basis of a single attribute. Small differences in the evaluation of a descriptor have no influence on the total score, which takes into account the ratings of all the attributes.

3.2.2. Shelf Life Estimation and Its Accuracy. Shelf life was estimated to be 5 days by inverse prediction, since for a QI = 5, days-under-refrigeration prediction is $\hat{x} = 4.94$ days. In other studies, in which shelf life of frozen−thawed fish was determined using QIM schemes, similar results were obtained. Therefore, for whole and ungutted fish, the shelf life was estimated to be between 4 and 6 days for Atlantic mackerel (*Scomber scombrus*),[18] 5 days for Greenland halibut (*Reinhardtius hippoglossoides*),[7] and 6−8 days for a whole and gutted hake (*Merluccius merluccius*).[19] In the case of skinless fish, the small differences in shelf life may be due to the fact that there is significantly higher fish flesh surface area exposed to

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Table 2. Mean Scores (Standard Errors) of the Descriptors of QIM Scheme and Their Correlation Coefficients with Days of Refrigeration Storage[a]

days under refrigeration	D_1	D_2	D_3	D_4	D_5	D_6	QI
1	0.00	0.75	0.00	0.25	0.00	0.88	1.88
	(0.00)	(0.16)	(0.00)	(0.16)	(0.00)	(0.13)	(0.30)
2	0.88	0.88	0.00	0.75	0.38	1.00	3.88
	(0.23)	(0.13)	(0.00)	(0.16)	(0.18)	(0.00)	(0.40)
4	1.13	1.38	0.25	0.88	0.00	1.00	4.63
	(0.13)	(0.18)	(0.16)	(0.13)	(0.00)	(0.00)	(0.26)
6	1.00	1.00	0.00	1.20	1.00	1.00	5.20
	(0.00)	(0.00)	(0.00)	(0.20)	(0.00)	(0.00)	(0.20)
8	1.60	1.60	0.00	1.20	1.00	1.00	6.40
	(0.24)	(0.24)	(0.00)	(0.20)	(0.00)	(0.00)	(0.40)
10	2.00	2.00	0.00	1.80	1.00	1.40	8.20
	(0.00)	(0.00)	(0.00)	(0.20)	(0.00)	(0.24)	(0.37)
12	2.40	2.40	1.00	2.00	1.20	1.40	10.40
	(0.24)	(0.24)	(0.00)	(0.00)	(0.37)	(0.24)	(0.60)
14	2.43	2.71	0.86	2.00	1.57	2.00	11.57
	(0.20)	(0.18)	(0.14)	(0.00)	(0.20)	(0.00)	(0.43)
16	3.00	3.00	1.00	2.00	2.00	2.00	13.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
correlation coefficient	0.97	0.97	0.80	0.96	0.94	0.91	0.99

[a] D_1: External color, D_2: External odor, D_3: External mucus, D_4: Flesh elasticity, D_5: Blood in bone, D_6: Peritoneum.

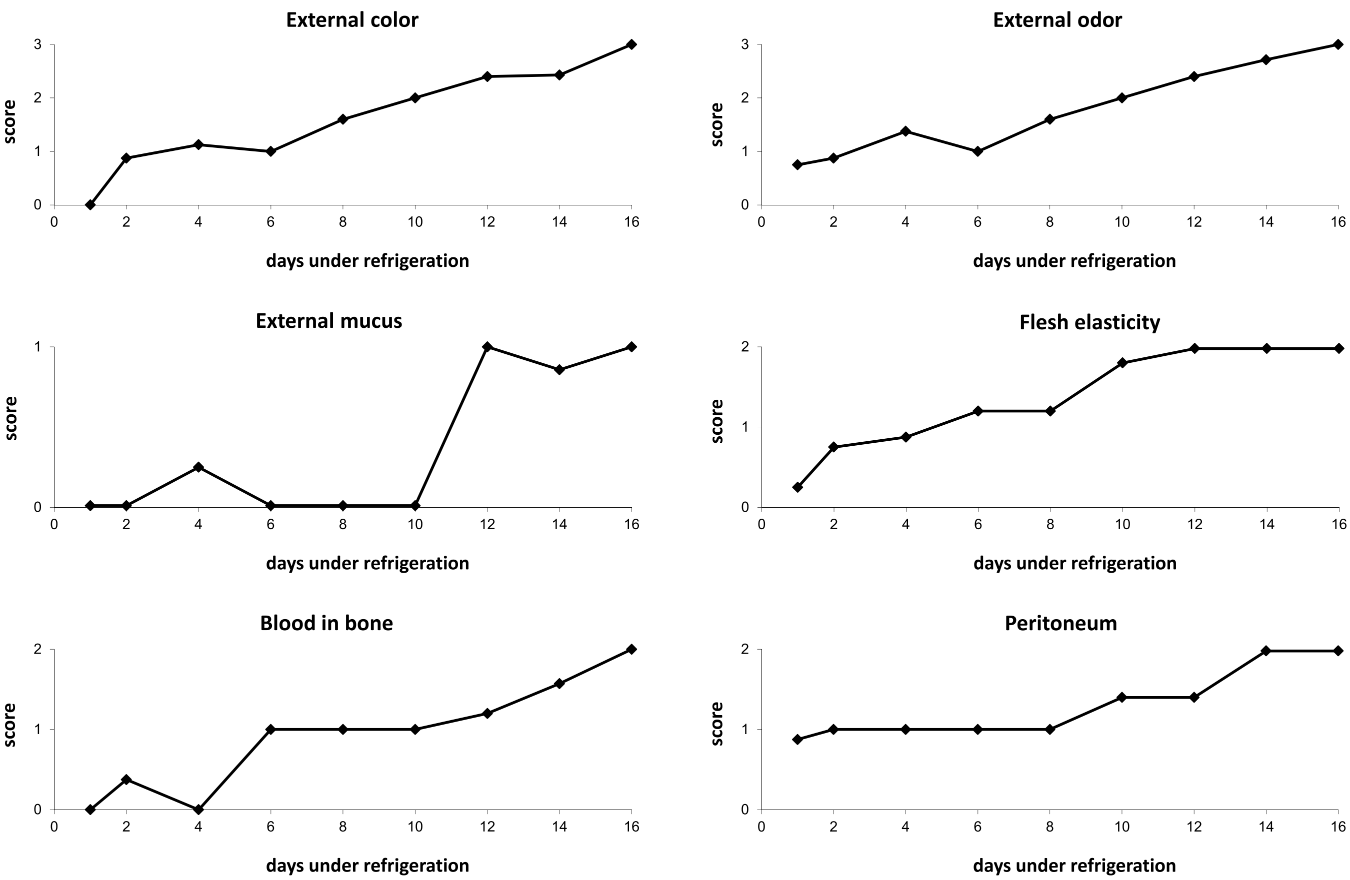

Figure 1. Mean scores of descriptors of QIM scheme

environmental microbial contamination versus other presentations like whole eviscerated fish,[31] while in the case of whole and ungutted fish, the microorganisms naturally present in the digestive system of fish contribute to their deterioration.[32]

As the estimate of shelf life was obtained by inverse prediction, the evaluation of its precision was made by means of a 95% confidence interval calculated by the inversion method: I_{inv} = (2.78, 7) days. The Wald method was also used to obtain an approximate 95% confidence interval, I_{Wald} = (4.94 ± 2.09) = (2.85, 7.03) days, and thus an approximate margin of error of $c = 2.09 \approx 2$ days.

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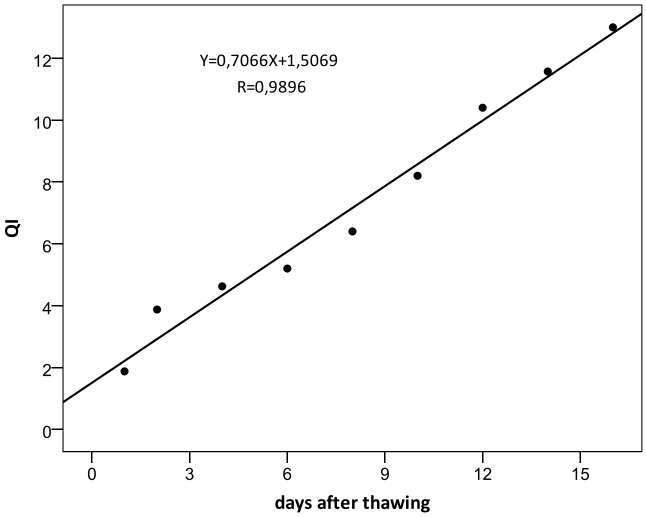

Figure 2. Mean QI as a function of storage time: least squares regression line and its associated determination coefficient.

3.3. Year-Long Study of Frozen Storage. For the study of how the length of time in frozen storage affects a product before defrosting, in each phase, certain predetermined days, that is, 1, 2, 3, 5 (the estimated shelf life) and 12 days before sensory analysis sessions, fish samples were selected for defrosting and refrigerated storage.

Figure 3 represents the data obtained in the sensory evaluation sessions of the four phases (described in Section 2.2).

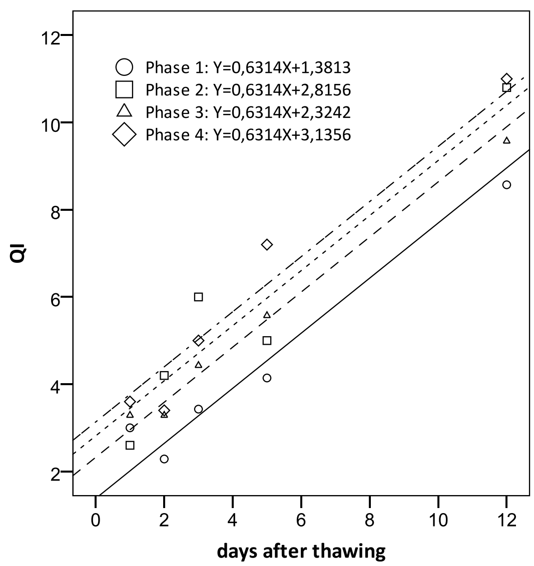

Figure 3. Evolution of QI at refrigeration temperatures after previous frozen storage periods of 0 months (Phase 1), 4 months (Phase 2), 8 months (Phase 3), and 12 months (Phase 4).

3.3.1. Comparison of Phases Using the Evolution of QI with Time under Refrigeration. The objective of the first statistical analysis was to compare the four lines, one for each phase, which described the evolution of the QI with the passage of time under refrigeration. The comparison was carried out by taking the multiple linear regression model as reference:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_1 X_2 + \beta_6 X_1 X_3 + \beta_7 X_1 X_4 + \varepsilon \quad \text{(MLR)}$$

where Y is the mean QI value, X_1 is the number of days of storage in refrigeration, X_2 is the binary variable that indicates if it corresponds to the Phase 2 ($X_2 = 1$), X_3 is the binary variable which identifies Phase 3 ($X_3 = 1$), and X_4 is the binary variable that indicates if it corresponds to Phase 4 ($X_4 = 1$). Phase 1 is characterized by $X_2 = X_3 = X_4 = 0$. The least squares adjustment of the MLR model was considered satisfactory ($R^2 = 0.956$) since a 95.6% of QI variability was explained by the fitted model.

First, one had to question whether it was admissible for the length of time in the freezer before thawing to not affect the QI; this situation was referred to as Case I. This was done by contrasting $H_0^{\mathrm{I}} = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = \beta_7 = 0$ against the opposite hypothesis (indicative of a phase effect). The result of the F test based on the extra sum of squares[29] was significant ($p = 0.039$) of a phase effect.

Secondly, one had to examine whether the effect of previous freezing time (the phase effect) did not change during the period the fish was under refrigeration; this situation was referred to as Case II. This was carried out by contrasting $H_0^{\mathrm{II}} = \beta_5 = \beta_6 = \beta_7 = 0$. According to the corresponding F test ($p = 0.542$), the QIM data were compatible with Case II. Under H_0^{II}, the QIM results of the four phases were described by a reduced linear regression model which is equivalent to the analysis-of-covariance model:

$$Y_{ij} = \mu + \underbrace{\alpha_j}_{\text{effect of the phase}\,j} + \underbrace{b}_{\text{common slope}} \cdot \underbrace{t_i}_{\text{days under refrigeration}} + \varepsilon_{ij} \quad \text{(AC)}$$

Figure 3 represents the parallel lines obtained by the least squares adjustment of the AC model. With this model as a reference, a by-pair phase comparison was carried out on the basis of the least significant difference (LSD) method. The results allowed us to establish two homogeneous subgroups: a first group formed by Phase 1 and a second group formed by Phases 2, 3, and 4. The differences between Phase 1 and Phase 2 were significant ($p = 0.005$), as were the differences between Phase 1 and Phase 3 ($p = 0.049$) and between Phase 1 and Phase 4 ($p = 0.001$). However, there were no significant differences between Phase 2 and Phase 3 ($p = 0.281$), nor did they appear between Phase 2 and 4 ($p = 0.477$) or between phases 3 and 4 ($p = 0.084$).

3.3.2. Comparison of Phase Means. A second statistical analysis for the comparison of phases was focused on the average QI value of different combinations (phase, days under refrigeration) and not on the tendency of the QI. First, the following ANOVA model was considered in order to carry out Tukey's test of non-interaction

$$Y_{ij} = \mu + \alpha_j + \beta_i + \gamma \alpha_j \beta_i + \varepsilon_{ij} \quad \text{(AOV)}$$

where α_j is the effect of the phase j, β_i is the effect of t_i days under refrigeration and the effect of interaction, phase × days under refrigeration, is of the type $(\alpha\beta)_{ij} = \gamma\alpha_j\beta_i$. Tukey's F-test for contrasting H_0: $\gamma = 0$ showed that the interaction effect phase × days under refrigeration was not significant ($p = 0.155$). However, the phase effect was significant ($p = 0.010$) based on the F test to contrast H_0^*: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$. Thus, the results indicated that the phase effect existed and

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that it did not depend on the length of time the fish was under refrigeration. These results were therefore compatible with Case II. Thus, conclusion based on the AOV model is that which had already been reached with the statistical analysis based on the MLR model. It should be noted that for the MLR model, the adjusted coefficient of determination was R^2_{adj} = 0.931, whereas for the previous ANOVA model (AOV), it was worth R^2_{adj} =0.939; so, both adjustments are equally satisfactory.

To finalize this second statistical analysis, a by-pair phase comparison was carried out based on the LSD method, taking as reference an ANOVA model without interaction, which results from assuming $\gamma = 0$ in the AOV model. The results are compatible with two homogeneous subgroups, the same as in the analysis based on the AC model. The differences between Phase 1 and Phase 2 were significant ($p = 0.007$), as were the differences between Phase 1 and Phase 4 ($p = 0.002$). The differences between Phase 1 and Phase 3 (for which $p = 0.055$) can also be considered significant if some flexibility is allowed with regard to the general criterion ($p \leq 0.05$). However, there were no significant differences between Phase 2 and Phase 3 ($p = 0.291$), nor did they appear between Phase 2 and 4 ($p = 0.485$) or between Phases 3 and 4 ($p = 0.093$).

3.3.3. Evolution of the QI in the Shelf Life Period. The statistical analyses above were also carried out by restricting the study to the shelf life period, the one of greatest interest. Since this period is shorter, fewer changes occurred at the sensory level, and the quality of the adjustments was also lower, R^2_{adj} = 0.653 for the regression model MLR and R^2_{adj} = 0.711 for the AOV model. By taking the AOV model as reference, in the shelf life period it was observed that there was no interaction effect phase × days under refrigeration, based on Tukey's additivity test ($p = 0.158$). The previous result was, therefore, consistent with that obtained in the full period of the QIM scheme. However, in the shelf life period, the phase effect was not significant ($p = 0.079$) based on the corresponding F test; there were only indications of this (since $p < 0.10$).

In summary, a specific QIM scheme for frozen, gutted, headless, tailless, and skinless Roundnose grenadier (*Coryphaenoides rupestris*) was developed and validated. It was observed that the relationship of the QI with storage time under refrigeration was linear, and the degree of association between both variables was very strong ($r = 0.99$). Therefore, using this index for the estimation of shelf life was proposed.

It was possible to determine with a satisfactory degree of precision the shelf life once fish was put under refrigeration: 5 days. The accuracy of the shelf life estimation was assessed by 95% confidence-level intervals obtained with the inverse method and the Wald method. The results obtained with both methods were concordant, which allowed us to derive an approximate margin-of-error of 2 days based on the Wald method.

In the year-long study carried out to observe the effects of frozen storage on the QIM scheme evaluation, the conclusions showed that there was evidence of previous frozen storage time having a negative effect on the QI. In the phases where the fish was frozen for longer than 4 months, the QI values were observed to follow a tendency that was always above that observed in Phase 1 (corresponding to 0 months), and higher QI means worse quality. However, when the analysis was restricted to the shelf life period, there was not enough evidence to consider differences to be significant.

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