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INFLUENCE OF EARLY PROCESSING (PRE-RIGOR) ON FISH QUALITY

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Abstract

The availability of high quality chilled, fresh fish products to the market, relies on early processing. Commercial processing of fillets is usually started after *rigor mortis* which often delays production for 2-4 days. Onset of *rigor mortis* has implications for processing because handling or filleting fish pre-rigor or in-rigor can change the product properties and quality. As intermediate storage of live fish and aquaculture is gaining more importance, aspects of early processing should be investigated.

Two methods for assessing the development of *rigor mortis* are discussed. Use of deflecting index and measurement of fillet length can give some information on the rigor state, but the fish to fish variation and the variation between the fillets of fish are high. Such measurements therefore can not be used as objective methods to assess the development of *rigor mortis*.

Results from experiments salt curing cod fillets showed great differences in yield (13 % in weight) in favour of post-rigor processing. Pre-rigor salting resulted in unfavourable changes in the texture and appearance of the products.

1. INTRODUCTION

Freshness is one of the most important parameters of quality in most markets. Fresh products often achieve a higher price based on a general attitude among consumers that "fresh is better". For the processor it is desirable to preserve freshness by starting production as early as possible after slaughter, in order to gain time for distribution.

It is reasonable to believe that the consumer is mainly interested in a positive experience when eating fish and usually not interested in information on quality level, freshness or preservation. In this context, the positive image of freshness is related to chilled or even "fresh frozen" products. Thus, "fresh" products can be broadly interpreted to include fresh, lightly salted, thawed, partly cooked or rehydrated from a stable, semi-processed raw material. We believe that the consumer prefers products that are percieved as fresh, are convenient, but most importantly, provide a good sensory experience.

Norwegian fish supplies are dominated by Atlantic cod (*Gadus morhua* L.) and Atlantic salmon (*Salmo salar*), (approx. 450,000 and 170,000 tonnes respectively in 1995) being available from wild fisheries, imports and aquaculture. Cod availability is seasonal, but small quantities are also kept alive in intermediate storage, to supply a fresh fish market. In aquaculture the fish can be harvested according to market demand and capacity in the factory, offering fresh, newly slaughtered fish at any time.

For the Norwegian fish industry, it is an objective to increase the production of processed products, based on demands from the market, in order to improve profitability. Chilled products are a priority area in this respect.

The interest in high quality fish products is increasing in many markets. These products can be fresh or lightly preserved, e.g. salted fillets, available from the chill cabinet and ready for easy preparation by poaching. The processor must be aware of the need for fresh raw material and how the process influences product quality, including yield. Our experiment shows that slightly different approaches in processing may result in large differences in the quality and yield of the finished product. By salting fish fillets for up to three hours in saturated brine, a lightly salted product (ca. 3% NaCl(w/w)) suitable for the kitchen can be produced.

1.2. Influence of *rigor mortis*

When packing fresh, whole salmon, it is important to work quickly to bleed, gut and ice the fish in boxes before *rigor mortis* starts. Processors have found that handling salmon in *rigor mortis* can result in bruising and gaping of the flesh. When fish is boxed and iced before the onset of rigor, the fish can be distributed to the market while rigor lasts, ensuring and demonstrating freshness to the customer.

It is of interest to extend the pre-rigor period or avoid the onset of rigor, and thus have more time for handling and packaging. *Rigor mortis* is dependent on the fish species, temperature and handling before slaughter, slaughtering stress, the biological status of the fish and temperature of pre-rigor storage, [1-7]. In this paper, we have focused on how temperature after slaughter influences the onset of *rigor mortis*. The effects of salting cod fillets, from very fresh fish have been examined.

In Norway, the processing of pre-rigor fish is well known to the industry, when filleting saithe (*Pollachius virens*). The factories often keep the fish alive in pens, being able to offer high freshness. The main products are iced, gutted fish for the fresh trade and frozen fillets in different sized blocks for frozen, breaded products.

When saithe is processed pre-rigor, the frozen blocks may give problems when used for fried products, as the batter and breading can blow off. This is because the fish when heated, goes into *rigor mortis* and changes shape, and partly because trapped pockets of water give rise to "explosions" when fried in oil. These problems are the result of the fish being too fresh when processed.

This paper presents data from experiments assessing onset of rigor; strength of rigor and how the state of rigor effects salt uptake, texture and sensory characteristics of lightly salted fish fillets.

2. MATERIALS AND METHODS

2.1. Atlantic salmon (*Salmo salar*)

45 Atlantic salmon were obtained from the aquaculture station in Kårvika near Tromsø (Nov., 1993). The fish had an average weight of approximately 2.5 kg. The salmon were killed by a blow to the head, bled for 20 minutes in a container with seawater, 8°C, before gutting and transport to the institute. Thirty fish were used to assess the development of *rigor mortis* in whole salmon, measured by deflecting index (DI). Fifteen salmon were filleted within two hours after slaughter. Three groups of ten fillets were placed on a smooth, plastic surface and covered with thin plastic sheet to avoid desiccation, before storage at the three temperatures, 0°C, 10°C and 20°C. Changes in length were measured regularly during storage for up to 96 hours.

2.2. Deflecting index

Onset of rigor in whole salmon was assessed by using a specially designed table as shown in Figure 1. According to Cutting [8] and revision by Bito [9] the rigor index is measured in relation to the deflection at the time of the first measurement. For newly slaughtered fish, we propose to only use the degree of deflection in relation to the length when the fish is placed exactly half way outside the table. The deflecting index is calculated as:

$$DI = 100*\text{deflection (cm)}/ 0.5 * \text{fish length} = 200 \times D/L$$

DI = Deflecting index, D = deflection in cm L = fish length in cm

DI values range from 100% for soft fish (either pre- or post-rigor) to 0% indicating high degree of *rigor mortis* as the fish is rigid.

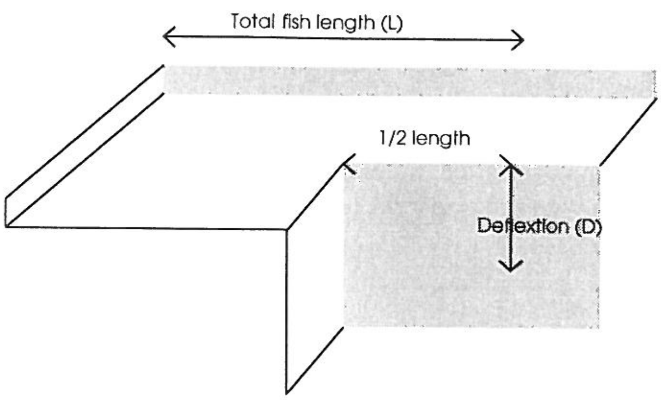

Figure 1. Table for measuring the deflecting index of fish.

2.3. Atlantic cod (*Gadus morhua* L.)

For the salting experiments, 45 Atlantic cod were obtained from the aquaculture station in Kårvika near Tromsø where the fish had been kept for five months in a net pen. The fish were caught in the wild by Danish seine. The fish were fed whole, thawed herring *ad libitum* for the last period (two months) before slaughter. They were killed by a blow to the head and bled for 20 minutes in a container with seawater, 8°C. The average round weight was 4 - 6 kilos.

Fillets from 15 cod were cut pre-rigor, 15 in-rigor and 15 post-rigor, to give a total of 90 fillets, skin on, divided into three groups. Each of the three groups of fillets were salted in saturated NaCl brine immediately after the respective times of filleting, i.e. 2 hours, 1 day and 4 days in ice after slaughter. All fillets were salted for 1, 2 or 3 hours at 0°C (in total 9 subgroups of 10 fillets each), to prepare a lightly salted product. Before and after brining, the fillets were weighed in batches of 10 fillets to calculate yield, packaged in vacuum pouches and stored in a chill room at 2-4°C until further analysis.

2.4. Salt content

The salt content was measured (w/w-basis) according to Volhard's method [10] in three separately homogenised fillets after each salting period.

2.5. Texture

Three fillets from each group were skinned and all pin-bones removed before cutting into 6 cm wide, 20 cm long pieces from the thickest section of muscle. Texture was measured using a 20 kg weigh cell in a KGS Materials Testing Machine, texture analyzer, developed at the institute. A 72 mm wide, 1 mm thick Warner Bratzler-type shear cell was used. Six parallel samples from each of the three fillets were measured. A cell speed of 4.88 mm/sec was used and maximum shear force at failure was registered. The results are given as the average for the three fillets with the standard deviation.

2.6. Sensory evaluation

The products were tested four days after slaughter. Fourteen different sensory characteristics were assessed in duplicate on cooked samples, by a trained panel of 10 persons. A non-linear scale from 1 to 10 was used. The samples were coded and cut into 3 cm wide slices and heated in hot, unsalted water for 5 minutes before serving. An ANOVA analysis of variance was run with Tukey's test to check significant differences.

3. RESULTS

3.1. Evaluation of rigor

Times for onset and strength of *rigor mortis* were measured by the deflecting index, DI, on 30 whole Atlantic salmon, 10 at each of the temperatures, 0°C, 10°C and 20°C. The results are given in Figure 2.

As the fish is not fully flexible, the deflecting index of a newly slaughtered pre-rigor salmon is close to 80%. Four to six hours after slaughter the development of *rigor mortis* can be measured as a reduction in DI. Onset of rigor was delayed a few hours for salmon stored at 0°C. These fish had a stronger rigor which lasted longer than for salmon stored at 10 or 20°C. After reaching maximum rigor, the resolution of rigor was more rapid at higher temperatures. We have not measured the fish stored at 20°C for longer than 30 hours as the fish then were spoiled. The individual variation between fish, the fish to fish variation, was marked, resulting in high standard deviations, because each fish had an individual development of *rigor mortis.* Measurements on a single fish showed a smoother development. The fish to fish variation resulted in measurements of DI from 0.9 to 27.8 after one day storage at 0°C. The big standard deviations were predominant at low values of DI, i.e. when some fishes were in full rigor while others had not reached that stage.

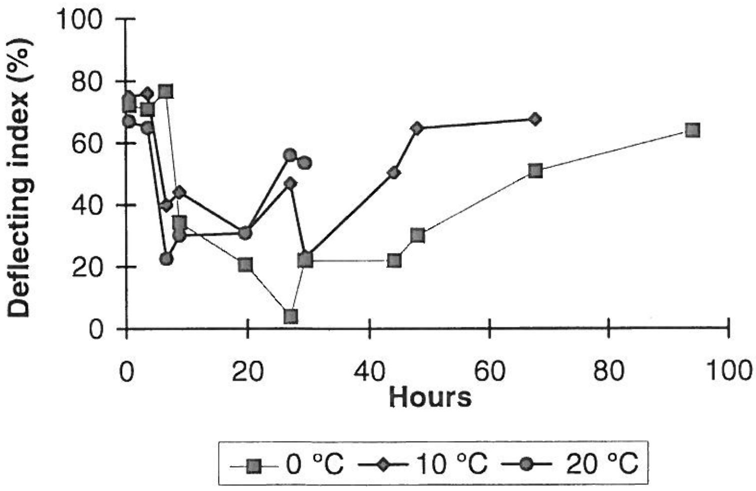

Figure 2. Deflecting index for whole Atlantic salmon during storage at different temperatures, 0°C in ice, 10°C and 20°C. Average of 10 fish at each temperature.

Maximum contraction of fillets was reached after 12 hours, first for the fillets stored at 20°C, while at the two other temperatures, a maximum was reached close to two days (40 hours) after slaughter (Figure 3). Contraction of fillets showed high individual variation with high standard deviations. After reaching maximum contraction, the fillets were handled in order to determine whether the fillet would return to its original length. This was not the case. Shortening is not affected by handling of the fillets after resolution of *rigor mortis*. The original fillet lengths were 45 ±5cm and 15% reduction in length is 7 cm. The deviation between samples were in the range of ± 2-3 cm, being approximately 30%.

The reduction in length of the fillets gave a product with different characteristics of appearance, being more dull, opaque (i.e less shiny), than the normal post-rigor filleted product. This is in accordance with previous results (unpublished), and was also confirmed by sensory analysis of cod fillets cut and salted pre-rigor, as described below.

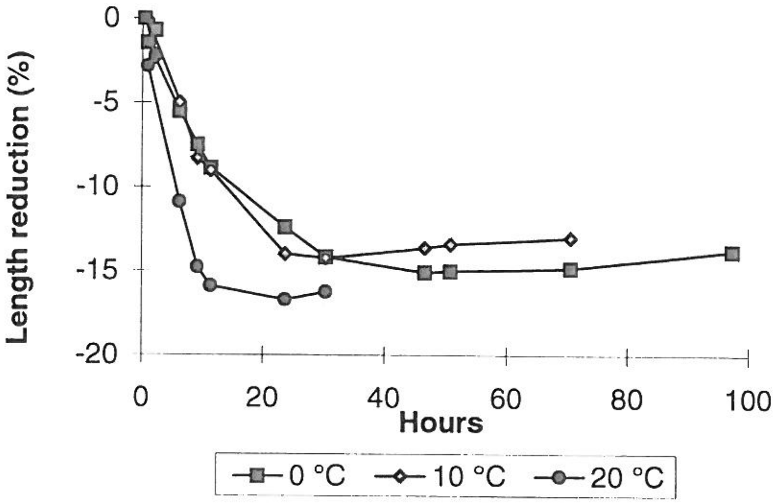

Figure 3. Reduction in length of single fillets of Atlantic salmon stored at different temperatures; 0°C, 10°C and 20°C, as a function of time. Measurements at each storage temperature represent an average of 10 fillets.

The texture, measured as maximum shear force at failure, on whole fillets, did not change much for the fillets cut respectively pre-rigor, in-rigor or post- rigor and stored in plastic bags in ice, Figure 4. The pre-rigor fillets were firmer and stayed firm during one week of storage.

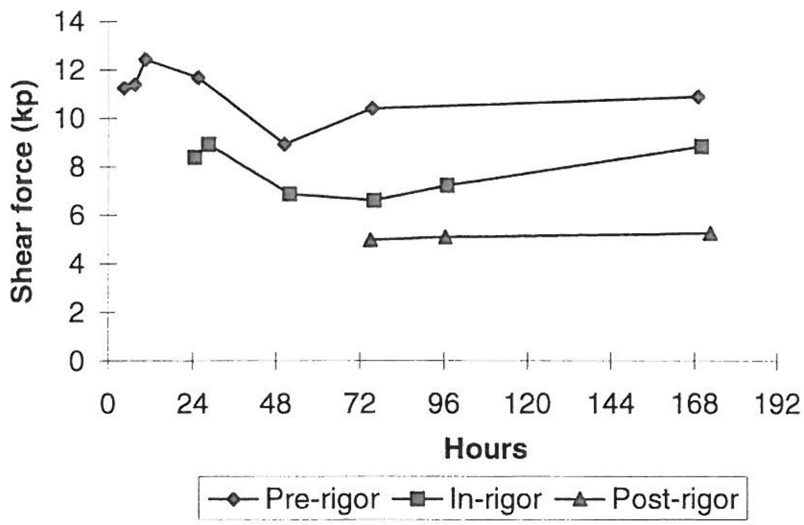

Figure 4. Texture measured as maximum shear force at failure. Results are presented as the mean of 10 fillets of Atlantic salmon, filleted respectively in the pre-rigor, in-rigor or post-rigor state. Total storage time in ice was 7 days.

In-rigor and post-rigor fillets were less firm and did not change much during one week. The standard deviations ranged from 13 to 30% for pre-rigor fillets; the first two measurements of in-rigor fillets had a standard deviation of 24 and 28% and the last measurements 11-15%. The three measurements of post rigor fillets had standard deviations of less than 10%. The deviations were highest in pre-rigor fillets and in fillets measured when in-rigor.

These results were confirmed when analysing cod fillets. Sensory analyses confirmed that the fillets were firmer and less juicy when filleted in the pre-rigor state.

3.2. Salting

Table 1 summarises measurements of weight, shear force, salt and protein content. The latter two measured in homogenised samples of three fillets in each group.

During salting for up to three hours the salt content increased in all fish fillets (Figure 5). It takes less than one hour to reach a salt level of 3% in post-rigor fillets and approximately three hours in pre-rigor fillets. The in-rigor fillets did not reach this level in three hours. A salt content of 3-3,5% in the fillet (w/w-basis) is regarded suitable for poaching.

Table 1
Total weight of 10 cod fillets from each group before and after salting for 1, 2 or 3 hours. Percentage change in weight is given together with average shear force, average salt content and average protein content of three fillets from each sample.

Rigor status	Salting (h)	Weight before salting (kg)	Weight after salting (kg)	Change in weight (%)	Average shear force ±Std.dev (Kp)	Average salt content (%)	Average protein content (%)
Pre-rigor	1	7.26	7.04	-3.0	9.56±2.17	1.87±0.03	16.69±0.81
Pre-rigor	2	8.70	8.27	-4.9	10.59±0.73	2.44±0.03	17.26±0.15
Pre-rigor	3	6.61	6.15	-7.0	9.74±2.21	3.25±0.02	17.42±0.37
In-rigor	1	8.14	8.40	3.2	6.56±1.98	2.15±0.01	16.65±0.24
In-rigor	2	5.61	5.79	3.2	5.25±2.40	1.86±0.07	16.10±0.52
In-rigor	3	5.35	5.35	3.4	12.32±3.45	2.47±0.13	14.90±0.28
Post-rigor	1	4.45	4.74	6.5	5.81±1.61	3.52±0.11	14.53±0.08
Post-rigor	2	4.90	5.18	5.7	6.83±1.07	4.10±0.14	15.17±0.26
Post-rigor	3	6.47	6.76	4.5	8.52±2.66	4.79±0.12	14.42±0.06

The pre-rigor salted fillets did enter rigor during the salting process and the appearance of the fillets changed from being smooth and shiny to having a rough and dry surface.

The pre-rigor fillets lost weight from the start of the salting process; 7% weight was lost after 3 hours. The cod fillets cut while in-rigor and post-rigor, increased in weight during the three hour salting period, by 3.4 and 4.5% respectively (Figure 6).

3.3. Texture

The maximum shear force at failure was stable in the pre-rigor samples during the salting period and at a higher level than the samples measured when salting in-rigor and post-rigor fillets (Table 1). The ANOVA analysis of variance showed significant differences between the product groups at α=0.0001 level.

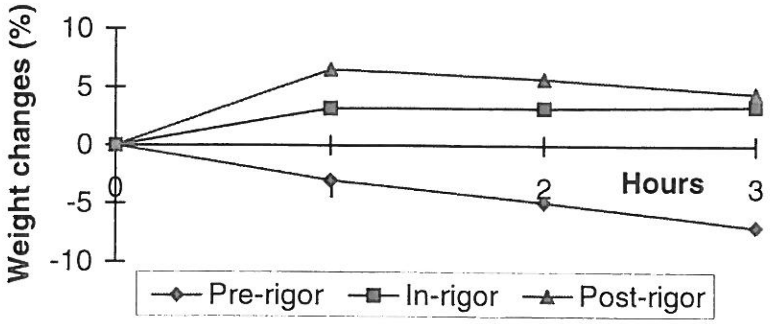

Figure 5. Average salt content in pre-rigor, in-rigor and post-rigor cod fillets after 1, 2 or 3 hours salting in saturated brine

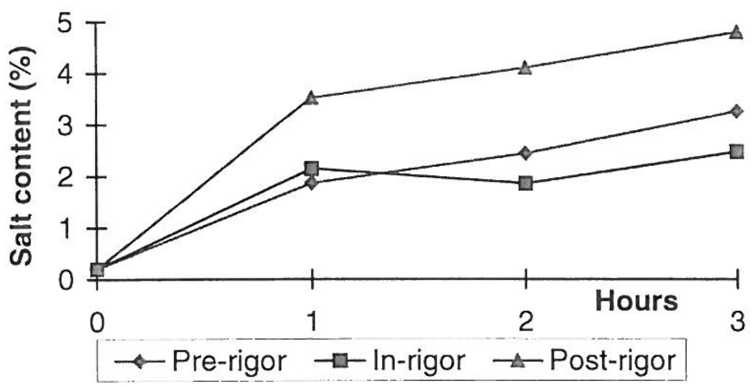

Figure 6. Average weight changes during salting for 1, 2 or 3 hours of pre-rigor, in-rigor and post-rigor cod fillets.

3.4. Sensory evaluation

Table 2 gives the results from the sensory analysis of 14 parameters. Whiteness, glossiness and yellowness of the fillets are significantly different between the groups, describing differences in appearance. The texture related parameters, juiciness and firmness are different at p=0.01-0.001 level, chewiness at p=0.05-0.01 level, while gaping and cohesiveness show no significant correlation between the groups of salted fillets.

Table 2
Results from a sensory analysis of 14 parameters in cod fillets. The fillets were cut pre-rigor, in-rigor and post-rigor assessed after salting for 1, 2 and 3 hrs in saturated brine.

Sensory properties	Pre-rigor 1- 2- 3 hrs	In-rigor 1- 2- 3 hrs	Post-rigor 1- 2- 3 hrs	Significance level (p<)	*, **, ***, n.s)
Whiteness	5.1-5.3-4.6	6.4-5.8-5.5	6.3-6.4-7.4	0.0003	***
Juiciness	2.1-3.9-4.7	5.3-6.0-4.4	7.0-5.6-5.9	0.0028	**
Saltiness	4.4-4.6-5.1	4.7-5.4-6.0	6.0-6.4-7.4	0.0047	**
Firmness	4.7-4.4-2.9	4.3-3.7-4.3	3.7-4.3-6.2	0.0063	**
Glossiness	0.8-2.6-2.5	4.0-2.7-3.3	4.1-4.1-5.0	0.0066	**
Yellowness	1.3-2.3-1.9	1.0-1.2-1.4	0.8-1.5-0.5	0.0118	*
Off taste	2.0-2.6-2.0	1.7-1.0-1.6	0.1-0.4-0.3	0.0126	*
Off odour	3.9-3.2-3.6	2.8-2.3-3.1	0.3-1.9-0.1	0.0159	*
Chewiness	6.4-5.0-3.4	4.0-3.2-5.5	3.2-5.2-5.0	0.0166	*
Smell, dry fish	1.0-1.2-1.0	0.9-1.0-0.7	0.7-0.7-0.4	>0.05	n.s.
Taste, dry fish	1.5-1.3-1.0	0.8-1.0-1.4	0.8-0.4-0.6	>0.05	n.s.
Gaping	4.9-4.5-4.1	5.1-5.0-6.6	6.2-5.6-5.9	>0.05	n.s.
Wateriness	1.3-2.6-4.7	2.1-3.1-3.5	3.3-2.9-2.9	>0.05	n.s.
Cohesiveness	4.7-4.0-2.7	3.6-3.8-4.2	4.0-4.1-4.7	>0.05	n.s.

Significance level p=0.05-0.01 is shown by *, p=0.01-0.001 by ** and p<0.001 by ***.
n.s. = no significant difference between products at $\alpha = 0.05$.

4. DISCUSSION

Commercial processing of fish must take the development of *rigor mortis* into consideration since it affects yield and fish flesh quality. Whole, gutted and iced fish from aquaculture should be boxed before onset of *rigor mortis* to avoid possibilities of flesh damage. Information is needed to advise the processor on which conditions can delay onset of rigor. Temperature is one parameter that can be manipulated and we have assessed the relation between temperature after slaughter and onset of *rigor mortis* in Atlantic salmon. In preliminary experiments we have also found that chilling live salmon will influence both onset and length of the *rigor mortis* period.

To assess *rigor mortis,* the method of Bito *et al.*[9] is often referred to. It depends on several measurements of the same fish and the time that the first measurement is recorded. By using a deflecting index we have a measure that is independent of time. Still, the measurement is very dependent on individual fish. In addition, each measurement involves handling of the fish, which in itself can alter rigor development. An objective measurement should involve very large numbers of fish and the measurement should be performed only once on each fish in order not to be biased by handling the fish. This is an approach that we have not been able to follow due to cost of fish. The deflecting index method thus gives very useful information on the development, strength and duration of *rigor mortis*.

Assessing contraction of fillets could be regarded as more objective since the fillets are left untouched while rigor lasts, but assessment must be made on a smooth surface, and the fillets must be protected from surface drying. The two methods indicate that onset of rigor is more rapid in fish stored at 20°C and it resolves more rapidly. Since the fillets were approximately 50 cm in length, 2% change involves one cm fillet contraction, so that definite conclusions are difficult to make.

When whole fish or fillets go into rigor, the appearance changes and different levels of shear force can be measured. The standard deviations were high especially in the first period of the texture analysis, up to 30% in single measurements. At day two the standard deviations were reduced to around 10% which we regard as acceptable. The levels of shear force for the salmon were quite comparable to the results on cod fillets (Table 1) but, as salting influences the water content of the fillet, we can not compare the results directly.

In the salting experiments with cod fillets, we had large cod that were heavily fed until slaughter. This should not have influenced the results, since all fish had the same treatment, coming from the same net pen.

The large differences between pre-rigor and post-rigor salting of the fillets are important findings for the processors when preparing salt cured products that are popular in the market. The importance of freshness in relation to yield must be discussed. The same results have been reported for full-salting of cod onboard vessels. A lower yield is obtained than for the salting ashore of fish that have been iced for 5-7 days (Icelandic report). Also, other attributes of quality such as colour, discoloration and gaping must be considered.

It is known from practical experience and our previous unpublished experiments, that pre-rigor and in-rigor fish absorb salt more slowly than post-rigor fish. A common explanation of the salting process is that salt is absorbed in the first stage and, at pH above the isoelectric point, the Cl-ions will neutralise positive ions, resulting in repulsion of the proteins. Water is absorbed and the weight increases, due to swelling of the muscle [11-12].

The pre-rigor fish fillets in this experiment did not swell and they lost weight. This can be explained by water loss due to contractions squeezing water out when *rigor mortis* is triggered by salting in brine [13]. As the fish is very fresh the cells are more intact and liquid is not easily absorbed into the cells by swelling. The practical result is that it is far more economical to salt a post-rigor fillet than a pre-rigor one, if a lightly salted fillet is the desired product. In this respect it is correct to say that optimal quality is more important than highest degree of freshness.

5. CONCLUSION

It is important to be aware of the onset of *rigor mortis* when packaging and processing very fresh fish, either from intermediate storage, onboard factory ships or from aquaculture. Knowledge of both onset and duration of *rigor mortis* is important. Objective methods for assessing the development of rigor can not be proposed based on this experiment as the standard deviations are high both for the deflecting index method and contraction of fillets.

The quality of a fillet that has been prepared pre-rigor, is different from a traditional post-rigor fillet, especially in appearance, colour, shape, texture and technological properties such as salt uptake. The yield is very different: post-rigor fillets increases 6% in weight to reach 3% salt (w/w-basis), while pre-rigor fillets lose 7% weight in 3 hours to reach 3% salt in the fillet. A difference of 13% in yield is of great importance to the processor.

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