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Quality aspects of fillet, loin and tail products made from live-stored feed-deprived Atlantic cod (*Gadus morhua* L.) at different times *post mortem*.

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Abstract

During last decade, the amount of live-caught Atlantic cod stored in sea cages has increased. However, the issues of feeding regime during live-storage and time of processing after slaughter are central to provide high quality products. The goal of this study was to investigate how the quality of fresh fillet, loin and tail products can be affected by the length of feed-deprivation and the processing time *post mortem*. Feed-deprived cod were slaughtered after 2, 26, 54 or 82 d. On the last three sampling days, the three products were made 4, 6, 10, 14, 24 and 48 h *post mortem.* All products were then stored in ice until day 7 *post mortem* before analysing product quality. The results demonstrated that prolonged feed deprivation and time of filleting affected both the biochemical and the sensory properties of the muscle. Feed deprivation resulted in fillets having higher water content, gelatinous texture, atypical white colour and less fresh sea odour. These changes in product quality occurred mainly after 54 d of feed deprivation. The tail products were more prone to the contraction and had higher drip loss than loins and whole fillets independently of the period of feed deprivation and time of filleting.

1. Introduction

For the last decade, live-storage of wild Atlantic cod (*Gadus morhua* L.) has been developed in Norway as a method to extend the marketing season of fresh cod throughout the year (Dreyer, Nøstvold, Midling, & Hermansen, 2008). Although the concept is growing, it is still marginal, reaching a supply of only 5.800 tonnes fresh cod in Norway in 2016 (The Norwegian Fishermen's Sales Organization, 2016). There are several advantages when keeping wild cod alive near fish processing plants; such as continuous access to fresh raw materials, the possibility of long-term planning of production, *pre rigor* processing of cod and better marketing prospects (Dreyer et al., 2008). The Norwegian regulation states that wild cod can be held in sea cages for up to 12 wk after capture. The first four weeks of live-storage can be done in the absence of feeding (FOR-2004-12-22-1878, 2004). The extension of the live-storage period without feeding is preferable since wild cod do not easily accept formulated feed. However, the welfare and the quality of the fish must not be compromised (Sæther et al., 2016). The quality of the raw material has a strong effect on the processed products (Akse, 2005; Kiessling et al., 2007), and thus, it is important to explore the factors that can affect the biological status of live-stored cod.

It is known that prolonged feed deprivation and time of processing are factors that can strongly affect the muscle quality of fish. Long-term starvation of Atlantic cod makes the fish metabolise muscle nutrients, leading to decreased protein concentration, increased water content and softening of fillet texture (Beardall & Johnston, 1983; Black & Love, 1986; Love, 1988). The fillet texture is also influenced by the time of processing since *pre rigor* produced fillets get firmer texture than fillets made *post rigor* (Jørpeland, Imsland, Stien, Bleie, & Roth, 2015; Kristoffersen et al., 2006; Kristoffersen, Vang, Larsen, & Olsen, 2007). The texture is a critical quality parameter of fish both for the processors and for the consumers. In fact, it has been reported that soft texture can cause a downgrading of farmed salmon, resulting in as

much as 40% loss in value (Michie, 2001). The water content of fish muscle is another quality aspect that is of importance. Specifically, loss of water is economically equivalent to a loss of meat by weight, and the liquid accumulated in the product package can be unattractive to consumers as well as containing nutrients from the muscle (Foegeding, Lanier, & Hultin, 1996; Kristoffersen et al., 2007).

To our knowledge, most reports on changes in fish quality are based on data obtained from whole fillets. Today however, fish processers commonly produce different fillet products like loins and tails. There is limited knowledge on how feed deprivation prior to slaughter and time of processing *post mortem* affect properties of such different fillet sections. The goal of this trial was to study the quality of fresh products (fillet, loin and tail) made from feed-deprived cod at different times *post mortem*. Quality aspects investigated were product contraction, drip loss, muscle hardness, water content and sensory aspects like texture, colour and odour.

2. Materials and methods

2.1 Fish and samplings

The work was carried out in a compliance with Norwegian veterinary authorities (Code number: 7327). Atlantic cod caught by demersal seine were kept alive in sea cage and transported to onshore facilities 8 d after catch. Feed-deprived fish were slaughtered 2, 26, 54 or 82 d after capture. The biological data of the Atlantic cod, procedures of capture, transport, tagging, live-storage condition and slaughter procedures are described by Ageeva, Jobling, Olsen, and Esaiassen (2017).

2.2 Experimental design and sample preparation

On the first sampling day (2 d post-harvest), 10 fish were filleted and skinned by hand 24 h *post mortem.* On the remaining sampling days (26, 54 and 82 d post-harvest), 10 fish were filleted and skinned 4, 6, 10, 14, 24 or 48 h *post mortem*. The fillet obtained from the right side of each fish was studied as a whole fillet, while the left side fillet was cut into a loin (the upper dorsal back area of the fillet, length: 28 cm) and a tail (length: 20 cm). The initial length and weight were measured on each product, and the individual products were put into numbered plastic bags (350x650 mm). Then, the products were placed as a single layer in plastic boxes, covered with ice, and stored in a cold room (0 ^{o}C) until day 7 *post mortem*. On this day, the measurements of the length and weight of the fillets, loins and tails were repeated. The changes in length (contraction) and weight (drip loss) during ice storage were expressed as percent of the initial values determined at the time of filleting.

2.3 Physicochemical analysis

At day 7 *post mortem* muscle hardness, pH and water content of the fillets were measured. Muscle hardness was assessed by performing the compression test as described by (Ageeva, Olsen, Joensen, & Esaiassen, 2018). The compression force (CF [N]) was analysed on skin side, about 7 - 8 cm from the anterior edge of each fillet and 1 cm above the lateral line. For

each measurement, the recording was repeated four times, and the average value was calculated.

Muscle pH was determined immediately after muscle hardness measurements by inserting a Hamilton double pore glass electrode (Hamilton Bonaduz AG, Bonaduz, Switzerland) of WTW 330/set-1pH-meter (Wissenschaftliche-Technische Werkstätten GmbH, Weilheim, Germany) 1 cm into the muscle in the loin part on the cut side of the fillet.

Analysis of water content was carried out on five muscle samples (200 ± 20 g) cut from the loin part of the whole fillets, and the samples from each experimental group were chopped together in a precooled Stephan mixer (Type UM 12, Germany) for 3 x 5 sec. Then three replicas (10 g) of the mince were dried at 103 ± 2 ^{o}C for 16 – 18 h.

2.4 Sensory analysis

The whole fillets (right side) were evaluated by an expert panel of three persons by using the fillet index method (Esaiassen, Dahl, Eilertsen, Gundersen, & Sivertsvik, 2008) with minor modifications. The attributes given demerit scores were odour (0: sea fresh, 1: neutral, 2: fishy, 3: ammonia/sour), gaping (0: none - 5: disjointed fillet), fillet surface (0: dry and shiny - 2: dispersed), colour (0: homogeneous white, 1: milky-white/non-transparent, 2: grey/yellow/reddish) and texture (0: naturally - 3: severe soft). The sum of all scores was used as fillet index to evaluate the quality changes occurring due to different filleting time. However, it has been shown that starved cod may develop a gelatinous (sloppy) texture and an atypical white colour (Love, 1988; Sæther et al., 2016). These properties are not covered by the fillet index method. Thus, the intensity of these attributes was evaluated in this experiment: atypical colour (0: naturally, 1: atypical white), gelatinous texture (0: none, 1: partly gelatinous and 2: severe gelatinous).

2.5 Statistical analysis

The data were analysed using The Unscrambler version 10.3 (CAMO Process AS, Oslo, Norway). Prior to the analyses, the variables were weighted by 1/STDEV in order to standardise the data to the same scale. Principal Component Analysis (PCA) was used to identify the differentiation amongst samples on the basis of biological, physicochemical, sensory and instrumental data. Partial Least Square Regression (PLS) with Martens Uncertainty Test were applied to identify the significant effect of feed deprivation, time of filleting and size of fish on contraction, drip loss, muscle hardness and sensory attributes of the products.

Analysis of variance was carried out to determine the significant differences between treatment groups filleted at different time points at each sampling and the differences between groups filleted at the same time point *post mortem* obtained on different sampling days. A two-sample *t*-test was used to explore the differences between loins and tails made at the same filleting time within the same sampling. A two-sample *t*-test was also used to examine the differences in muscle hardness (N) and water content (%) in fillets made at the same time point *post mortem* obtained on different sampling days.

3. Results and discussion

In order to identify any differentiation in data due to time of feed deprivation as well as time of filleting, a weighted principal component analysis (PCA) was performed on a matrix with 190 objects (fish) and 11 variables. The variables used in the analysis were time of feed deprivation, time of filleting, length and gutted weight of cod, muscle pH, muscle hardness, contraction, drip loss, fillet index, gelatinous texture and atypical colour of the fillets. The score and correlation loading plots showed that the two principal components (PC-1 and PC-2) explained 54 % of total variation in the data (Fig. 1). In the score plot, the cod subjected to feed deprivation for 82 d after capture were distinct from the other fish groups. This distinction pattern follows mainly PC-1, and according to the correlation loadings plot the most feed-deprived cod (82 d) is associated with gelatinous texture and atypical colour, as well as higher fillet index and higher muscle pH. On the other hand, the fillets cut from cod exposed to shorter periods of feed deprivation had a higher fillet contraction and muscle hardness. Further, the changes in drip loss, contraction and muscle hardness are also explained by PC-2, which is related to the time of filleting (not shown in the figure). It appears that fillets made early *post mortem* got higher contraction degree and muscle hardness.

In order to get an overview on how feed deprivation, time of filleting and size of fish (length and gutted weight) influenced the quality parameters of the fillet, a partial least squares (PLS) analyses were run. The results of the analyses are summarized in Table 1. The size of fish (length and gutted weight) significantly affected muscle pH, muscle hardness, drip loss and fillet index, all being higher for smaller fish. Higher pH in smaller cod has been previously reported by Love, Robertson, Smith, and Whittle (1974). It is also shown that gaping was significantly influenced by size, giving lower score for gaping in smaller fish. In addition, smaller fish, as measured by gutted weight, were more prone to develop gelatinous

texture and atypical colour. Feed deprivation significantly decreased muscle hardness and odour, increased water content and fillet index, as well as occurrence of gelatinous texture and atypical white colour. Time of filleting also significantly influenced the quality parameters. Early filleting provided higher muscle hardness, more contraction and drip loss, lower water content, lower fillet index, less gaping and less occurrence of gelatinous texture and atypical white colour. In the following, attributes that were significantly affected by the feed deprivation and time of filleting are presented in more details.

3.1 Contraction and drip loss of loin and tail products

Regarding contraction and drip loss, no noticeable differences were found between whole fillets and loins (results not shown). However, differences were found between loin and tail products, and the results obtained on sampling days 26, 54 and 82 after catch are presented in Fig. 2.

As expected, *pre rigor* loins and tails (4, 6, 10 and 14 h after slaughter) contracted more than loins and tails produced after the establishment of *rigor mortis* (24 and 48 h *post mortem*), independent of the duration of feed deprivation (Fig. 2 A and B, Appendix A, Table A.2). The changes in fillet length due to *rigor* contraction are well known, and have been reported in several studies (Jørpeland et al., 2015; Kristoffersen et al., 2007; Misimi, Erikson, Digre, Skavhaug, & Mathiassen, 2008; Mørkøre, Tahirovic, & Einen, 2008).

Further, tails seem to contract slightly more than loins during the development of *rigor mortis*. On sampling 26 d after capture, tails (Fig. 2 B) made 4, 6, or 10 h *post mortem* contracted significantly more than loins (Fig. 2 A) made at the same time (Appendix A, Tables A.1 and 2). Prolonged feed deprivation resulted in gradually reduction in tail contraction (Fig. 2 B, Appendix A, Table A.2). On the other hand, there was no reduction in contraction of loins during the feed deprivation for up to 54 d, but the contraction of loins was significantly reduced after 82 d of feed deprivation (Fig. 2 A, Appendix A, Table A.2).

Specifically, the loins made after the onset of *rigor* (14, 24 and 48 h post mortem) contracted significantly less than that detected during the previous two sampling days.

The different pattern in reduction of contraction in loins and tails towards the end of feed deprivation may be due to the tails having higher ratio of dark and white muscle and the tails differing in geometric shape, i.e. thin with a high surface to volume ratio. The dark muscle is located near the lateral line of the fillet, and the proportion of dark to white muscle increases toward the tail region (Foegeding et al., 1996). In addition, in this experiment the pin bones were cut from the loins, resulting in even less amounts of dark muscle in these products. It is known that the dark muscle are richer in mitochondria, lipid and glycogen content than white muscle (Buttkus, 1963; Cappeln & Jessen, 2002; Foegeding et al., 1996), and thus, it can have a different *rigor* development. For instance, Stien, Suontama, and Kiessling (2006) reported a slightly faster initial *rigor* contraction in the posterior part of the fillet than in the anterior area in rainbow trout. It has also been shown that the contraction in length can be three times higher in red than in white muscles in lingcod (*Ophiodon elongatus*) (Buttkus, 1963). Further, it is also known that long-term feed deprivation leads to the cod utilizing muscle nutrients, depleting glycogen and ATP reserves, which in turn limit *post mortem* glycolysis (Black & Love, 1986; Foegeding et al., 1996; Love, 1988). Thus, it is most likely, that energy reserves in red muscle in both products decreased with prolonged feed deprivation. Since the proportion of red to white muscle is higher in tails than in loins, and tails are thinner with higher surface to volume ratio, it is possibly that tails were more prone to changes in length due to both rigor contraction and feed deprivation.

In addition to the reduction in length, changes in product weights were observed due to drip loss during storage (Fig. 2 C and D, Appendix A, Tables A.1 and 3). However, the changes in drip loss both in tails and in loins were not significantly dependent on the time of filleting. This is in agreement with Akse, Kristiansen, Tobiassen, Dahl, and Eilertsen (2008)

who reported almost equal drip loss in *pre* and *post rigor* loins made from Atlantic cod feed-deprived for four weeks. On the other hand, it is well known, that drip loss during storage can be strongly influenced by *rigor* contraction, resulting in increased drip loss in *pre rigor* made fillets (Jørpeland et al., 2015; Kristoffersen et al., 2006; Kristoffersen et al., 2007).

There were, however, clear differences in drip loss between loin and tail products, where all tails lost more weight than loins independent of the duration of feed deprivation and the time of filleting. (Fig. 2 C and D, Appendix A, Tables A.1 and 3). The greater surface to volume ratio in the tails will probably result in the loss of more muscle liquid. The fact that tails were more prone to contraction than loins may also contribute (Fig. 2 A and B, Appendix A, Tables A.1). Muscle shrinkage, occurring during *rigor* contraction, forces the mobile water from intramyofibrillar spaces into the extramyofibrillar areas in the muscle cells where it is more easily lost as drip during storage (Bertram, Purslow, & Andersen, 2002; Huff-Lonergan & Lonergan, 2005; Offer & Trinick, 1983).

Further, it is of interest that the differences in drip loss between tail and loin products appeared to be reduced towards the termination of the experiment. This occurred due to reduction in drip loss in tails and not in loins. The differences between the products remained significant for up to 54 d of feed deprivation while after 82 d of feed deprivation, they were less distinct (Fig. 2 C and D, Appendix A, Table A.1). It is difficult to explain this reduced drip loss in tails after prolonged feed deprivation. A reduced liquid loss of whole fillet after feed deprivation has been reported earlier for salmon (*Salmo salar* L) and Atlantic cod (Akse et al., 2008; Mørkøre et al., 2008; Olsson, Gundersen, & Esaiassen, 2006).

3.2 Muscle hardness and water content

The measurements of muscle hardness and water content were carried out in the loin area of the whole filet. As found by the PLS-analyses (Table 1), feed deprivation and time of filleting significantly influenced both variables, however, muscle hardness were also affected by the

size of fish (length and gutted weight). Furthermore, previous research have demonstrated a correlation between body length and texture in fillet. Love (1988) observed a positive correlation between body length and texture of heated fish; the larger fish had firmer texture. Bjørnevik et al. (2016) analysed texture in raw cod and reported that the fish with higher growth rate had softer muscle texture. In order to study the direct impact on texture of feed deprivation and time of processing in the present study, the length was used as a covariate in the statistical evaluation of muscle hardness. The results showed that fillets from the most feed-deprived cod had softer texture than fish feed-deprived for 54 d (Fig. 3). However, only the fillets made after the onset of *rigor* development (14, 24 and 48 h *post mortem*) differed significantly (Appendix A, Table A.4). In addition, not surprisingly, the fillets from cod starved for 82 d had higher water content independent of time of filleting (Fig. 3). This could contribute to the softening of muscle during feed deprivation, as discussed by Love (1988). The higher proteolytic activity because of increased protein catabolism in muscle of fish feed-deprived for a prolonged period may also contribute to the reduced muscle hardness (soft texture). Our results are contradictory to the results reported by Hagen and Solberg (2010) who showed that feed deprivation of Atlantic cod for 11 wk greatly improved fillet texture. However, the texture was measured as shear force and the results were suggested to be linked to the strengthening of connective tissue due to feed deprivation.

It appeared that the fillets made early after slaughter were firmer and had slightly less water in the muscle (Fig. 3, Appendix A, Table A.4). This is probably due to unrestricted *rigor* contraction (Fig. 2 A and B) and slightly higher drip loss (Fig. 2 C and D) in *pre rigor* than *post rigor* made products. Other scientists have also shown that the time of filleting can significantly affect the content of water in fillet, resulting in *pre rigor* produced fillets having lower water content (Jørpeland et al., 2015; Kristoffersen et al., 2006). The differences in muscle hardness between the fillets made early and late *post mortem* became clearer in fish

255 feed-deprived for 82 d (Fig. 3). This could be explained by the higher water content and
256 higher proteolytic activity in the muscle of such fish as mentioned earlier.

257 *3.3 Sensory evaluation*

258 The changes in fillet index due to feed deprivation and time of filleting are presented in Table
259 1. The sensory panel also stated that fillets produced from the most feed-deprived cod had
260 more neutral odour, brighter colour and softer texture independently of time of filleting.
261 Similar results have also been reported for feed-deprived salmon where the group starved for
262 86 d had fillets of less acidulous flavour and brighter colour compared to the groups starved
263 for shorter periods (Einen & Thomassen, 1998). Furthermore, all fillets produced before the
264 onset of *rigor mortis* (during the first 10 h *post mortem*) in our study, had less gaping and
265 firmer texture than the remainder groups. This is in accordance with previously reported
266 results for cod (Kristoffersen et al., 2006; Kristoffersen et al., 2007). The number of fillets
267 having gelatinous texture and atypical white colour increased towards the end of the feed
268 deprivation (Table 1). It appeared that those two defects could occur either simultaneously on
269 the same fillet or separately. After 26 d of feed deprivation, only 1 of 60 fillets was described
270 to have gelatinous texture and atypical white colour. After 54 d of feed deprivation, 7 of 60
271 fillets were evaluated to be strongly affected by feed deprivation; however, only 3 of these
272 had both defects simultaneously. On the last sampling, 34 of 60 fillets were assessed affected
273 with 21 fillets having both gelatinous texture and atypical white colour.

274 It may be questioned whether the gelatinous texture and atypical white colour is solely
275 due to feed deprivation or also due to spawning, since the fish in the experiment were
276 spawning during the first 54 d of live-storage (Ageeva et al., 2017). However, other scientists
277 experienced that long-term feed-deprived Atlantic cod can have fillets with characteristic
278 gelatinous or “sloppy” texture and atypical white colour (Love, 1988; Sæther et al., 2016).
279 Sæther et al. (2016) studied quality changes during live-storage of immature cod caught

during an intensive feeding season. They also observed increasing number of the fish with gelatinous texture and atypical white colour as the period of feed deprivation increased.

4. Conclusion

The results demonstrated that prolonged feed deprivation and time of filleting of mature live-stored Atlantic cod affect both biochemical and sensory aspects of the muscle. Feed deprivation resulted in fillets having higher water content, unpleasantly soft texture, atypical white colour and less fresh sea odour. These changes in product quality occurred mainly after 54 d of feed deprivation. The tail products were more prone to contraction and had higher drip loss than loins and whole fillets independently of the period of feed deprivation and time of filleting.

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389 **Figure legends**

390 **Fig. 1.** Score plot and correlation loading plot of the PCA-model of quality differences
391 between the fish exposed to feed deprivation for 2, 26, 54 or 82 d. PCA-1 and PC-2 explained
392 33% and 21% of total variation in the data, respectively. The outer and inner ellipses indicate
393 100% and 50% of explained variance, respectively. Gel texture, gelatinous texture, Atypical
394 colour, atypical white colour are close to each other in the loadings plot.

395 **Fig. 2.** Average contraction (% of initial product length) and drip loss (% of initial product
396 weight) in loins (●) and tails (□) made 4, 6, 10, 14, 24 and 48 h after slaughter of Atlantic cod
397 exposed to feed deprivation for 26 d (solid line), 54 d (dashed line) and 82 d (dotted line) after
398 catch. All products were stored at 0 ^{o}C until day 7 *post mortem*. Lower case letters indicate
399 differences ($p < 0.05$) between time of filleting for either loins or tails, and asterisks (* = $p <$
400 0.05) show significant differences from the other two sampling days. In addition, the
401 contraction of tails (B) produced 4 h *post mortem* from cod feed deprived for 26 d was
402 significantly higher those produced after 82 d but not after 54 d of feed deprivation (not
403 shown in Fig.).

404 **Fig. 3.** Muscle hardness (N) and water content (%) measured 7 d *post mortem* on whole cod
405 fillets made 4, 6, 10, 14, 24 and 48 h *post mortem*. The fish were starved for 54 (dashed line,
406 muscle hardness: ▲, Water: ●) and 82 (dotted line, muscle hardness: Δ, Water: ○) d after
407 capture. Lower case letters show significant differences ($p < 0.05$) between time of filleting
408 (h) at each sampling day, and asterisk (* = $p < 0.05$) indicate the significant differences at
409 same time of filleting for fillets produced on day 54 and day 82.

Table A.1

Statistical characteristics for contraction and drip loss measured on day 7 *post mortem* in loins and tails obtained from cod feed-deprived for 26, 54 or 82 d after capture. The products were made on time spans 4, 6, 10, 14, 24 or 48 h *post mortem*. The statistical differences ($p < 0.05$) between loins and tails within same sampling day and time for filleting (h) are given as *t*-statistic and p-value under "Between loins and tails". The differences between times of filleting (h) within same sampling day for each product are specified using F- and p – values for "Between times of filleting (h) within same sampling day".

	Between loins and tails					
Time of filleting (h)	**Contraction**			**Drip loss**		
	26 d	**54 d**	**82 d**	**26 d**	**54 d**	**82 d**
4	*t*(18) = -4.256, p = 0.001	*t*(18) = -0.698, p = 0.494	*t*(18) = -0.826, p = 0.419	*t*(18) = -2.870, p = 0.012	*t*(18) = -4.890, p = 0.000	*t*(18) = -0.912, p = 0.374
6	*t*(18) = -3.638, p = 0.002	*t*(18) = -0.814, p = 0.426	*t*(18) = -2.248, p = 0.037	*t*(18) = -3.849, p = 0.001	*t*(18) = -3.258, p = 0.004	*t*(18) = -3.467, p = 0.003
10	*t*(17) = -6.480, p = 0.000	*t*(18) = -0.410, p = 0.687	*t*(18) = -0.030, p = 0.977	*t*(17) = -5.414, p = 0.000	*t*(18) = -1.833, p = 0.084	*t*(18) = -1.042, p = 0.311
14	*t*(18) = -0.841, p = 0.411	*t*(18) = 2.811, p = 0.012	*t*(18) = 0.140, p = 0.890	*t*(18) = -3.206, p = 0.005	*t*(18) = -2.368, p = 0.034	*t*(18) = -0.660, p = 0.518
24	*t*(18) = 0.501, p = 0.622	*t*(18) = 2.288, p = 0.034	*t*(17) = 0.354, p = 0.728	*t*(18) = -2.613, p = 0.018	*t*(18) = -1.026, p = 0.319	*t*(17) = -0.510, p = 0.617
48	*t*(18) = -2.646, p = 0.016	*t*(18) = -0.821, p = 0.422	*t*(17) = -3.075, p = 0.007	*t*(18) = -3.652, p = 0.002	*t*(18) = -2.204, p = 0.041	*t*(17) = -3.143, p = 0.006
	Between times of filleting (h) within same sampling day					
Loins	F(5,54) = 39.926; p = 0.000	F(5,54) = 29.609; p = 0.000	F(5,52) = 92.016; p = 0.000	F(5,52) = 6.087; p = 0.000	F(5,53) = 1.344; p = 0.260	F(5,52) = 1.741; p = 0.142
Tails	F(5,53) = 42.805; p = 0.000	F(5,53) = 44.246; p = 0.000	F(5,54) = 37.050; p = 0.000	F(5,53) = 1.433; p = 0.228	F(5,53) = 42.805; p = 0.045	F(5,54) = 3.357; p = 0.010

Table A.2

Contraction (Range, %) detected on day 7 *post* slaughter in loin and tails produced at the same time (h) but on different samplings, 26, 54 or 82 d after capture. The statistical differences ($p < 0.05$) are given as F-statistic and p-value.

Between samplings 26 d, 54 d and 82 d after capture								
	Contraction							
Time of filleting (h)	Loins				Tails			
	26 d Range (%)	54 d Range (%)	82 d Range (%)	Statistical differences	26 d Range (%)	54 d Range (%)	82 d Range (%)	Statistical differences
4	18.2-22.5	16.8-28.9	18.2-25.7	F (27) = 0.163, p = 0.850	20.5-29.5	19.5-29.5	18.0-26.0	F (27) = 3.485, p = 0.045
6	14.3-22.5	16.8-25.0	17.1-22.1	F (27) = 0.439, p = 0.649	19.8-28.5	19.0-30.0	16.5-36.0	F (27) = 1.067, p = 0.358
10	12.9-20.7	14.3-24.3	17.5-21.8	F (27) = 2.578, p = 0.095	21.5-31.0	15.0-25.0	11.5-27.0	F (26) = 7.470, p = 0.003
14	10.7-23.9	16.1-25.0	7.8-18.2	F (27) = 8.918, p = 0.001	9.5-25.0	11.0-22.0	0.0-23.0	F (27) = 2.875, p = 0.074
24	1.9-18.2	4.6-20.4	-1.8-13.9	F (26) = 6.681, p = 0.005	7.0-21.0	4.5-15.0	4.0-9.4	F (26) = 9.371, p = 0.001
48	1.1-7.1	0.7-11.1	0.4-1.8	F (26) = 6.940, p = 0.004	3.9-10.5	2.5-9.0	-0.5-11.5	F (27) = 9.371, p = 0.305

Table A.3

Drip loss (Range, %) detected on day 7 *post* slaughter in loin and tails produced at the same time (h) but on different samplings, 26, 54 or 82 d after capture. The statistical differences ($p < 0.05$) are given as F-statistic and p-value.

Time of filleting (h)	Between samplings							
	Drip loss							
	Loins				Tails			
	26 d Range (%)	54 d Range (%)	82 d Range (%)	Statistical differences	26 d Range (%)	54 d Range (%)	82 d Range (%)	Statistical differences
4	1.4-4.1	1.6-3.4	1.5-9.2	F (27) = 0.062, p = 0.940	2.4-7.5	2.9-8.3	1.7-6.1	F (27) = 2.690, p = 0.086
6	0.8-3.0	0.0-2.7	1.6-3.4	F (27) = 1.542, p = 0.233	2.7-7.6	1.6-9.3	1.8-6.8	F (27) = 0.155, p = 0.858
10	0.8-2.7	1.0-5.7	0.7-5.3	F (27) = 2.283, p = 0.121	2.3-4.1	1.4-6.7	0.3-4.0	F (27) = 3.486, p = 0.046
14	1.5-3.2	0.6-2.8	1.0-4.4	F (27) = 0.877, p = 0.427	1.4-6.5	1.4-5.9	1.0-5.7	F (27) = 1.843, p = 0.178
24	0.9-3.4	0.7-5.1	1.0-5.0	F (26) = 0.058, p = 0.943	1.6-8.3	1.1-4.8	0.0-6.3	F (27) = 1.868, p = 0.174
48	0.4-2.1	0.4-3.9	0.0-2.1	F (26) = 0.058, p = 0.186	1.5-4.9	1.3-7.0	1.1-2.8	F (27) = 3.593, p = 0.041

Table A.4

Statistical characteristics for muscle hardness (N) and water content (%) measured on day 7 *post mortem* in fillets made 4, 6, 10, 14, 24 or 48 h *post* slaughter of Atlantic cod exposed to feed deprivation for 54 or 82 d after capture. The statistical differences ($p < 0.05$) between sampling days but within the same time of filleting (h) are given as *t*-statistic and p-value, and between times of filleting (h) within the same sampling day are given as F-statistic and p – value.

Between sampling days 54 and 82 after capture		
Filleting (h)	**Muscle hardness (N)**	**Water content (%)**
4	$t(18.000) = 2.402$, $p = 0.027$	$t(10.000) = -5.014$, $p = 0.001$
6	$t(18.000) = 1.173$, $p = 0.256$	$t(10.000) = -3.603$, $p = 0.005$
10	$t(18.000) = -0.218$, $p = 0.830$	$t(10.000) = -4.263$, $p = 0.002$
14	$t(17.000) = 2.590$, $p = 0.019$	$t(10.000) = -4.121$, $p = 0.002$
24	$t(18.000) = 2.116$, $p = 0.049$	$t(10.000) = -10.785$, $p = 0.000$
48	$t(18.000) = 2.540$, $p = 0.021$	$t(10.000) = -3.727$, $p = 0.004$

Between filleting hours within same sampling day		
54 d	F(5,53) = 1.324; p = 0.268	F(5,30) = 3.177; p = 0.020
82 d	F(5,53) = 5.712; p = 0.000	F(5,30) = 4.312; p = 0.004

Table 1.

Variables with significant impact on quality attributes. The effect is shown based on weighted regression coefficient (Rw). Significance is identified by Martens uncertainty test ($p < 0.05$). PLS analysis, Y, muscle pH, MH (muscle hardness), contraction, drip loss, water content, fillet index (odour, gaping, colour, texture), gelatinous texture and aberrant colour, X-matrix, length, gutted weight, starvation and time for fileting.

Quality attributes	Variables with significant effect on quality attributes of fillet	Rw
Muscle pH	Length	-0.0671
	Gutted weight	-0.1274
MH	Length	-0.1280
	Gutted weight	-0.0773
	Feed deprivation	-0.3558
	Time for filleting	-0.2574
Contraction	Time for filleting	-0.8947
Drip loss	Length	-0.1126
	Gutted weight	-0.1216
	Time for filleting	-0.2250
Water content	Feed deprivation	0.6970
	Time for filleting	0.2378
Filet index	Length	-0.0549
	Gutted weight	-0.1552
	Feed deprivation	0.2779
	Time for filleting	0.2157
Odour	Feed deprivation	-0.2694
Surface	None	
Gaping	Length	0.1144
	Gutted weight	0.1055
	Time for filleting	0.2380
Colour	Gutted weight	-0.1156
	Feed deprivation	0.3501
Texture	Feed deprivation	0.3853
	Time for filleting	0.2247
Gelatinous texture	Gutted weight	-0.1591
	Feed deprivation	0.3914
	Time for filleting	0.1382
Atypical white colour	Gutted weight	-0.1388
	Feed deprivation	0.3989
	Time for filleting	0.1769

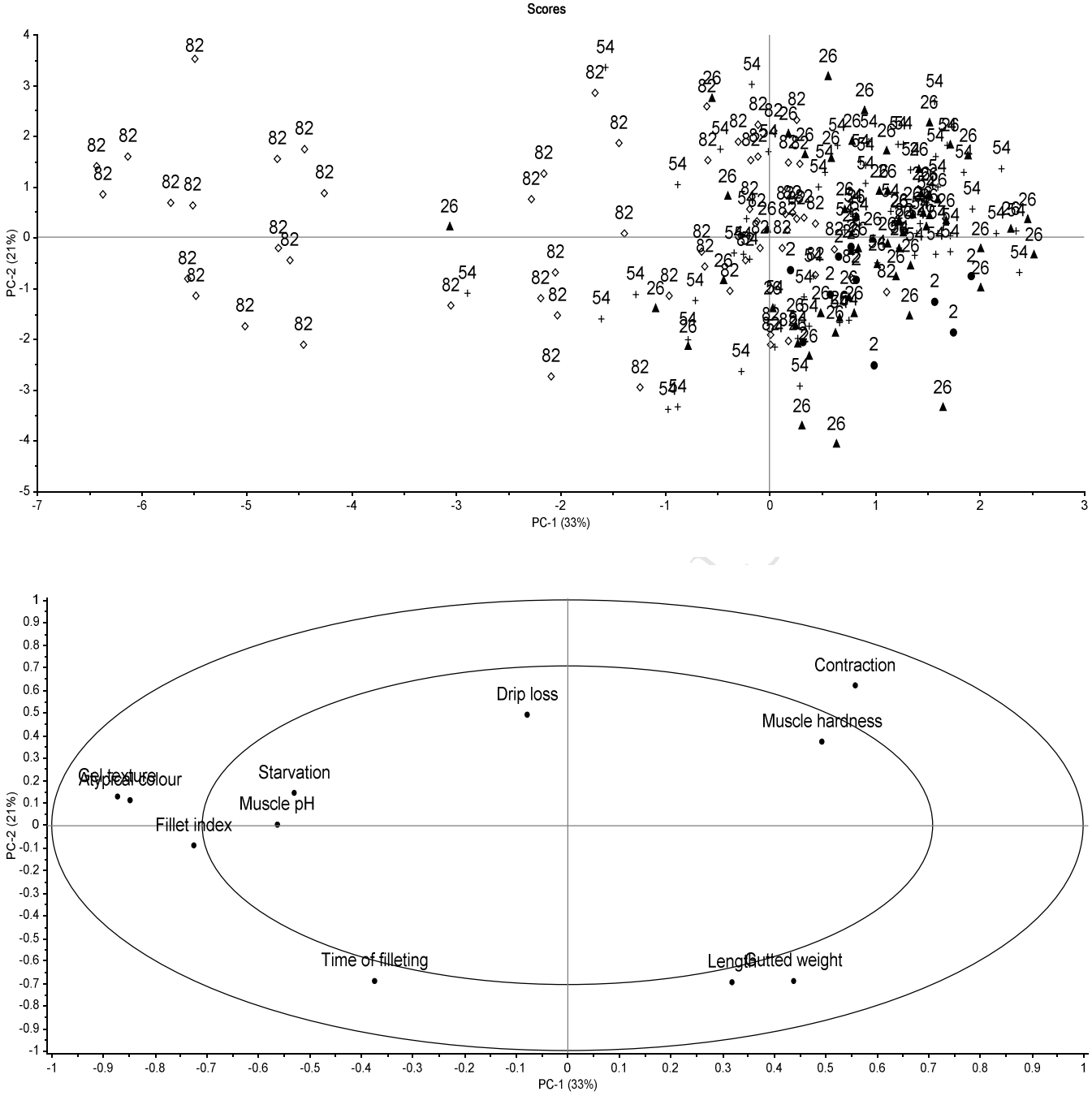

Fig. 1.

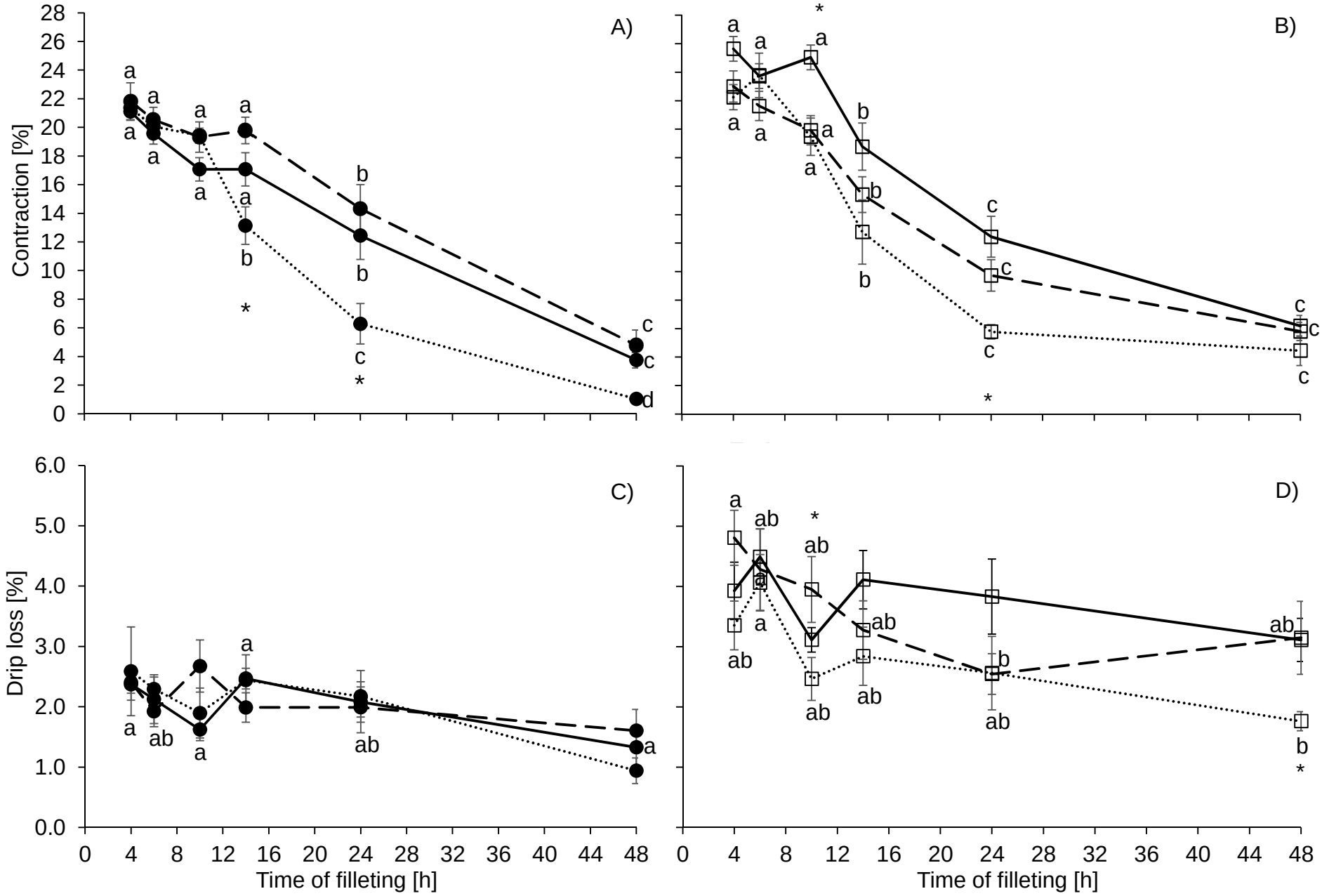
A)
B)
C)
D)
Contraction [%]
Drip loss [%]
Time of filleting [h]
Time of filleting [h]

Fig. 2.

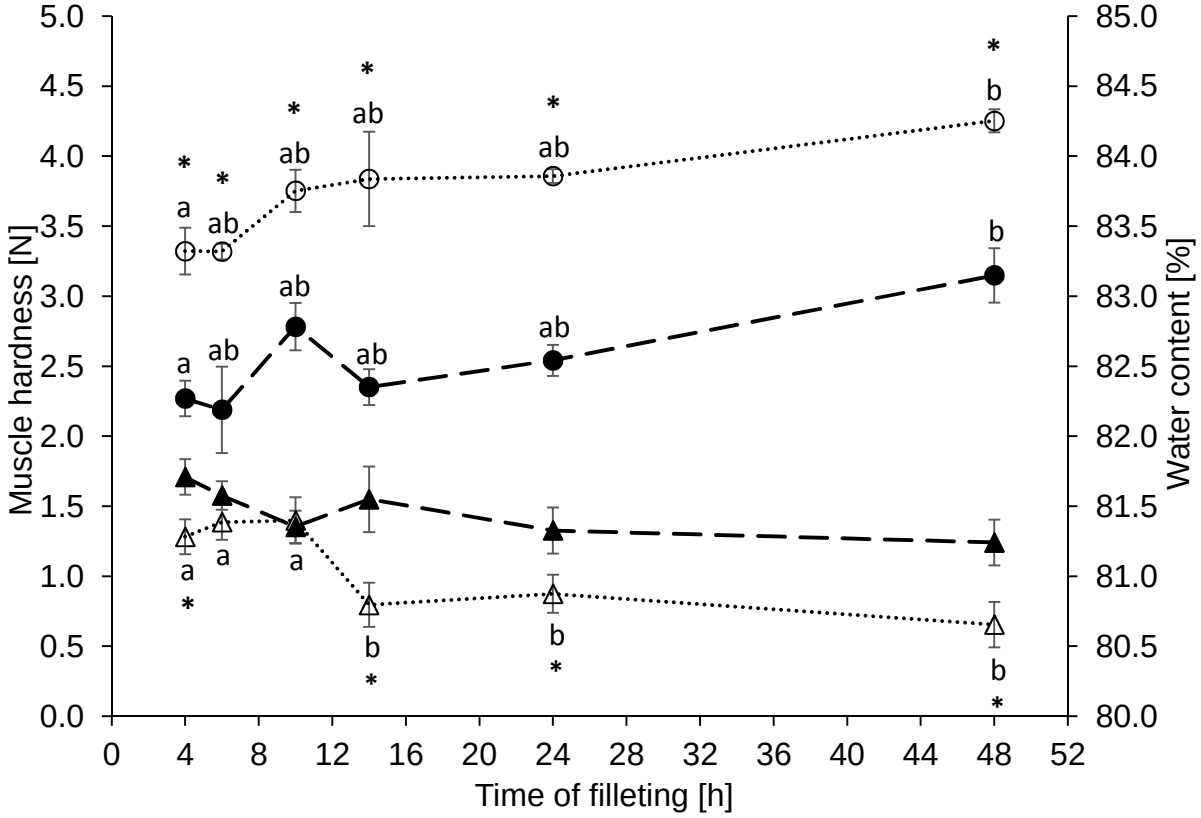

Fig. 3.

Highlights:

- Prolonged feed deprivation reduced biochemical and sensory quality of the final cod products.
- After 82 days of feed deprivation, 60% of fillets had gelatinous texture and atypical white colour.
- The main changes in quality of fillets occurred after 54 days' feed deprivation prior slaughter.
- Tail products were more prone to contraction and had higher drip loss than loins and whole fillets.