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Capture induced stress and live storage of Atlantic cod (*Gadus morhua*) caught by trawl: Consequences for the flesh quality

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ABSTRACT

Stress associated with commercial trawling of Atlantic cod was evaluated together with the effects of live storage (0, 3 and 6 h) on the blood pH, glucose, lactate, muscle pH, and mortality. Additionally, the commercial method of direct gutting, used to process fish on-board, was compared to live storage fish that was percussively killed, bled by throat cutting and exsanguinated for 30 min prior to gutting. Visual quality defects related to capture, such as discoloration, net marks and blood spots were evaluated both on whole fish and fillets. The haul duration influenced the survival rate (mean ± SD: 73.2 ± 19.6%), elevated the lactate levels (mean ± SD: 5.22 ± 2.54 mmol L^{-1}) and declined the blood pH (mean ± SD: 7.05 ± 0.16) and muscle pH (6.97 ± 0.16). The hauls with the highest mortality, the lowest initial blood pH (mean ± SD: 7.05 ± 0.16; $P < 0.05$) and the ones that showed an elevated blood lactate (mean ± SD: 5.22 ± 2.54 mmol L^{-1}; $P < 0.05$), were the longest hauls in duration (>5 h) and had the highest catch (>10 tonnes). The fish recovered during live storage, but the haul size and duration influenced the blood and muscle pH significantly even after 6 h. After slaughter, it was observed that 52% of examined fish had catch related damages; red discoloration, net markings and skin scratches. The commercial processing method resulted in a significant ($P < 0.05$) increased in muscle discoloration, compared to fish that was bled immediately. The 3 h live storage increased the muscle discoloration significantly ($P < 0.05$). However, after 6 h live storage, most of the red discoloration was removed and the fillets were considerable lighter. This clearly shows that fish are able to redistribute blood from the white muscle during recovery and that the haul duration influenced the mortality, muscle and blood chemistry. Thus, the time from capture to bleeding and recovery are important factors in order to improve flesh colour of trawl caught cod.

1. Introduction

Atlantic cod (*Gadus morhua*) is one of the most important commercial fish species in the North Atlantic. The total landings of North East Arctic cod in ICES Subareas I and II were 610,000 tonnes in 2010. Approximately 70% of the Atlantic cod was caught by demersal trawls and 30% was caught by other gear types (ICES, 2011). The total catch of Atlantic cod landed in Norway in 2011 was 362,410 tonnes. In Norway, there are 2 main types of raw material for the production of cod products; first, there is the fresh raw material caught by small coastal fishing vessels. These vessels mainly use gill nets, Danish seines, lines and hand lines to capture fish. Secondly, there is the on-board frozen raw material delivered from the ocean trawlers and long liners. In a typical year about 30% of the Norwegian cod quota is taken by demersal trawl (Anon., 2012).

The most significant challenge currently facing the cod fisheries is that the management structure (structured multispecies vessels with a portfolio of quotas) and availability (short catch seasons) have led to a situation in which efficiency is more profitable than the quality optimization (Hermansen and Dreyer, 2010). However, focus on environmentally sustainable fishing, predictable high-quality products and aquatic animal welfare is increasing (Thrane et al., 2009; Catchpole and Gray, 2010; Svanes et al., 2011). To produce new predictable high-quality products, it is essential to thoroughly implement various mechanisms that govern quality. Especially on board in trawlers, where most of the northeast Arctic cod is harvested. The choice of fishing gear regarding cod is determined by several complex parameters, e.g. historical aspects, fuel prices, politically decided fishing quotas and price of frozen vs. fresh raw material. However, different fishing gears affect the environment, the life cycle assessment and the fish muscle quality

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in different ways. These topics are also synonymous with the consumer's decision as far as fish products and pricing in the market is concerned (Margeirsson et al., 2006; Thrane et al., 2009; Catchpole and Gray, 2010; Svanes et al., 2011).

Fishing gears have multiple impacts on fish quality and can result in quality degradation of the final products (Botta et al., 1987; Esaiassen et al., 2004; Margeirsson et al., 2006; Digre et al., 2010). Typical quality defects for cod caught by bottom trawl and Danish seine are bruises and muscle discoloration due to insufficient exsanguination. The bruises can be linked to pressure in the trawl and tough handling of the fish before it is bled (Digre et al., 2010; Rotabakk et al., 2011). Regarding Danish seiners and trawlers, it has been suspected that weather conditions, duration and size of the haul also may affect the quality of the catch (Margeirsson et al., 2007). However, the sensory quality of the final product depends on many factors; such as seasonal variations (feeding and spawning), capture method and -process, as well as processing procedures and transport. These factors may vary significantly from batch to batch, both for fish captured in the wild as well as farmed fish. In the initial stages (harvesting and slaughter), fish experience various types and degrees of physiological stress (Poli et al., 2005; Veiseth et al., 2006; Erikson, 2008; Gatica et al., 2010). This may lead to low muscle pH, a shortening of the pre-rigour period, increased gaping, and potentially reduced bleeding. Altogether, this has a significant impact on the product yield, quality, shelf-life and profitability (Margeirsson et al., 2007; Bjornevik and Solbakken, 2010; Digre et al., 2010, 2011; Borderias and Sanchez-Alonso, 2011).

Generally, on-board fishing vessels, bleeding and gutting fish are difficult tasks with large hauls. It is not unusual that large hauls of fish, taken by bottom trawl or Danish seine, can be kept in storage bins for hours before bleeding and gutting. The last fish in the storage bin are often dead before bleeding, and this leads to bruises and muscle discoloration due to insufficient exsanguination and pressure on the fish. When fish is exposed to increased physical activity, the blood volume to the muscle rises (Farrell et al., 2001). Live storage and restitution before bleeding can therefore improve exsanguination and flesh colour.

The aim of this study was to determine under commercial conditions the effect of stress associated with commercial trawling of Atlantic cod and survival during live storage; and secondly to compare changes in logistics (short time live storage) before slaughter, with normal commercial procedures, to document any effects on the flesh quality (damages, residual blood, haemorrhages and colour).

2. Materials and methods

Atlantic cod was caught by a typical North Atlantic commercial trawler (M/T J. Bergvoll, length 57 m, BT 1499, HP 3900) at Thor Iversen-Banken (N 73.00, E 033.00) from the 22th to 28th of October 2011. Operating conditions and catch from each haul are shown in Table 1. The cod was caught using an Alfredo No. 5 twin trawl (REFA, Tromsø, Norway) and a RFG-Hunter 610 single trawl (RFG, Tromsø, Norway). A single trawl was used on rough bottom and in high wind (>12–15 m s^{-1}.) to keep the trawl speed at ~4 knots and hold the symmetry of the trawl during towing. The catch sensors (SuperCatch, Scanmar AS, Norway) on the trawl bag were set to give an alarm at 10 tonnes.

2.1. Commercial processing

After trawling, the net with the fish was hauled up on deck along a slipway and the net (codend) was emptied in a holding bin without water. All fish was directly gutted mechanically on the processing line and then cleaned and sorted (species and size) within 4–6 h (h) after capture. Next, all fish was frozen pre-rigour in blocks (25–50 kg) in plate freezers and finally stored (<−20 °C). For each haul (n = 10) Atlantic cod (2.5–5 kg gutted and headed fish; n = 15) was randomly collected from the processing line. The cod was frozen in blocks prior to thawing, processing and a sensory quality comparison was done against live storage cod caught in March 2012.

2.2. Live storage, recovering and processing

Immediately after each haul (n = 10), Atlantic cod (n = 70–80) was randomly collected from the codend while it was still on deck. Cod was brought into 2 stk. 800 L containers, filled with sea water to allow the cod to recover for 3–6 h. During recovery, fresh seawater was pumped into the tank with a water flow at approximately 50 L per min. Live cod (n = 15) was randomly collected and killed with a blow to the head immediately after capture. Next cod was killed both 3 h (n = 15) and 6 h (n = 15) after capture. After killing the cod, the blood-pH, blood lactate, blood glucose, fish size (total length and weight) and muscle-pH was measured. Then the throat was cut manually and the cod was exsanguinated into clean seawater for 30 min prior to beheading, gutting and cleaning. All cod was tagged and frozen pre-rigour in blocks and stored until thawing in March 2012. The quality of the thawed fish was then compared against the commercially slaughtered cod. The mortality in the tank was estimated after 6 h live storage and the remaining live fish was slaughtered and brought into the trawler's processing line. No further experiments were performed on this fish.

2.3. Blood glucose and lactate

Immediately after killing the fish with a blow to the head, the pericardium was opened with a scalpel and blood was collected from the heart. Then the blood glucose was measured with a FreeStyle Lite® blood glucose monitoring system (Abbott Laboratories, Abbott Park, IL, USA). Approximately, 1 μL of full blood was placed on the test strip and the measurement was completed after 5–10 s. The blood lactate was measured with a Lactate Pro portable analyser (ARKRAY Inc., Kyoto, Japan). Full blood (5 μL) was placed on the test strip and the measurement was completed within 60 s.

2.4. Blood and muscle-pH

The blood-pH was measured in the pericardium within 2 min after killing. Then the muscle pH was measured in white muscle of the loin part, above the lateral line. The pH was measured with a hand-held WTW330/set-1 pH-metre (Wissenscaftliche-Technische Werkstätten, Weilheim, Germany) equipped with a Hamilton double pore glass electrode (Hamilton Bonaduz AG, Bonaduz, Switzerland). The instrument was frequently calibrated using pH 4.01 and pH 7.00 buffers, and the electrode was also cleaned to obtain consistent results.

2.5. Thawing, filleting and salting

To distinguish between small and large hauls, the frozen fish (n = 178) from 4 hauls (2 hauls; >20 tonnes and >6 h duration, 2 hauls; <10 tonnes and <5 h duration) were thawed in 600 L bins using a 2 step process; 14 h in water with initial temperature of 4 °C, followed by separating the blocks to single fish and subsequent storage in ice chilled water until filleting and a visually assessment of quality. The cod muscle was held at 0 °C when it was filled, cleaned, washed and pickle salted in layers with 1 kg salt per kg fish (Sea salt N° 4F5 Fishery Quality; GC Rieber Salt AS, Norway) in 100 L containers at 2–4 °C for 1 week. The cod fillets were taken out of the container and dry salted on pallets for 2 weeks to allow