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Effect of pre- and post-mortem temperature on rigor in Atlantic salmon muscle as measured by four different techniques

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Abstract

The effects of ante- and post-mortem temperature regimes on the timing and strength of the rigor process in muscle of Atlantic salmon (*Salmo salar*) were measured by four frequently used methods for assessment of rigor. The methods were isometric tension (IT, Newton) in excised muscle strips measured by a Rigotech® meat analyzer, whole fillet contraction (WFC, percentage shrinkage) by automatic image analysis, changes in muscle hardness (*H*, Newton) by compression with a spherical probe and stiffness (*S*, percentage of full bend) measured by tail bending (also known as "Rigor index"). The fish were moved into experimental temperature tanks 10 days prior to slaughter. The temperature was either kept constant at 4 or 12 °C, or changed from 12 to 4 °C 2 h before slaughter. Storage (post-mortem) temperature was set to 4, 12 or 20 °C. Maximum IT, *H* and *S* decreased in response to higher storage temperature ($p<0.0001$), while WFC increased ($p<0.0001$). The occurrence in time of maximum value differed between methods, with chronological succession; IT→WFC→*S*→*H*. The rigor process was always delayed when storage temperature was reduced ($p<0.0001$). The effect of ante-mortem temperature was more complex. At the same storage temperature (4 °C), fish that had been moved from 12 to 4 °C 2 h before slaughter had a significantly more rapid rigor process than fish that were kept at a constant temperature before slaughter ($p<0.0001$), possibly indicating an effect of stress when changing water temperature. General agreement between treatments and relative response was observed among the four methods. Even so, significant differences were seen, especially in the resolution power of treatment effects, with IT>WFC>H>S.

Keywords: Salmon; Pre-rigor filleting; Storage temperature; Rigor measurements

1. Introduction

Temperature is one of the main factors affecting the quality and shelf life of fish (Sikorski, 1989; Wheaton and Lawson, 1985) via its effects on both enzymatic and microbial activity post-mortem. Fish are unique among farmed animals, being poikilotherms, i.e. the body temperature of the live animal can be manipulated by altering the surrounding water temperature.

Death stiffening (*rigor mortis*) is a process that takes place post-mortem and is responsible for transforming muscle into meat. The rigor process consists of an initial contractile phase (Tornberg et al., 2000), during which

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the muscle fibres contract, and a second stiff phase that is traditionally considered to be signified by a permanent binding of the contractile proteins myosin and actin. This process is modulated by pre-slaughter stress and post-mortem temperature (see Judge et al., 1989). In wild-caught fish, in which stress and temperature are difficult to control, rigor is reported to take place within an hour of catching (Love, 1980). In farmed fish, stress and temperature can be controlled by technical measures. The Norwegian salmon farming industry has adopted live chilling as an effective means of reducing pre-slaughter body temperature. Typically, fish are cooled in seawater at a temperature of 1 °C for 30–60 min to a core temperature below 4 °C before being slaughtered (Skjervold et al., 1996, 1999, 2001a). This chilling procedure, together with reduced stress, prolongs the rigor process in farmed Atlantic salmon by up to 5–6 days (Skjervold et al., 1999). This is advantageous when supplying fresh fish on ice, as shelf life is prolonged for the same length of time as rigor (Erikson et al., 1997; Lowe et al., 1993; Nakayama et al., 1992), but it creates a delay if the fish are to be filleted or frozen. However, like the delay in resolution of *rigor mortis*, pre-slaughter chilling combined with reduction of stress also delays the onset of *rigor mortis*, creating a time window long enough to allow pre-rigor filleting and processing to take place, thus avoiding the problem that during the rigor process the fish becomes stiff and mechanical handling is liable to cause muscle rupture (Skjervold et al., 2001a).

By default, a pre-rigor fillet will contract during rigor, as it is detached from the bone structure that normally obstructs such shrinkage. Several investigators report permanent differences compared to post-rigor fillets in technical quality, including fillet shortening (Sørensensen et al., 1995; 14% in Atlantic salmon and about 25% in cod at 9–11 °C), increase in fillet height (Skjervold et al., 2001a, Atlantic salmon), more difficult pin bone removal and lower salt diffusion and uptake if the salt is added pre-rigor (Rørå et al., 2004; Wang et al., 2000). Even though it is widely accepted that temperature affects the timing and results of rigor, very little is known about quantitative effects on rigor strength and how pre-cooling temperatures interact with the rigor process. The increased possibility of manipulating this process in farmed fish has triggered a need for better understanding of the process and its interaction with factors such as pre- and post-mortem temperatures.

In order to study the rigor process, measurement methods were introduced as early as the 1930s by Cutting (1939); these were later modified by Bito et al. (1983a,b), who introduced a method for whole fish rigor measurement by tail bending. This method has also been used by Korhonen et al. (1990). In later studies, Sørensen and Brataas (1994) used changes in muscle texture hardness (measured as resistance to pressure) during rigor to register not only the time curve but also the strength of the rigor process. The RigoTech® meat analyser, developed by Tornberg et al. (2000), permits detailed monitoring of isometric and isotonic tension changes during the rigor process in an isolated muscle sample. Time-lapse digital imaging of the whole fillet enables temporal measurements of muscle contraction in fillet to be made. Although all these different techniques are believed to measure the rigor process, it is not known if they reflect different aspects of the process, signifying specific biological events or simply are different methods describing the same events. Furthermore, it is not known if these methods will yield the same response to the same treatment or if a treatment × method interaction exists.

The aims of this study were, in the first place, to investigate the rigor process in Atlantic salmon (*Salmo salar*) subjected to different pre- and post-slaughter temperature profiles, and secondly, to determine whether the different rigor measuring techniques used yield different or overlapping information. Our third aim was to illuminate possible interaction effects between treatment and measuring method. Finally, based on the characteristics of the rigor process, with an initial active phase of muscle contraction, followed by a stiff phase, we tested the null hypothesis that the measures of muscle contraction and hardness would not attain maximum values simultaneously.

2. Materials and methods

2.1. Experimental conditions and design

The Atlantic salmon were reared in covered 0.6 m^3 round indoor tanks supplied with pumped aerated filtered full-strength seawater at the Institute of Marine Research-Matre Aquaculture Research Station (61°N, western Norway). The fish were exposed to a simulated natural photoperiod and fed continuously in surplus with a commercial standard feed (BioMar 6 mm, Norway) during light hours for the 6 months prior to the experiment. The gross chemical composition of the feed was 38% protein, 35% fat and <10% water. Feeding was terminated 10 days before slaughter. From this time, the fish were moved to experimental temperature tanks and subjected to different temperature treatments: groups of fish were first moved to a water temperature of either 4 or 12 °C. After this 10-day