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Quantification of dry matter % and liquid leakage in Atlantic cod (*Gadus morhua*) using computerised X-ray tomography (CT)

Kari Kolstad *, Turid Mørkøre, Magny S. Thomassen

AKVAFORSK, Institute of Aquaculture Research and Norwegian University of Life Sciences, Department of Animal and Aquacultural Sciences, NO – 1432 Ås, Norway

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Abstract

Farmed Atlantic cod (*Gadus morhua* L) were subjected to computerised X-ray tomography (CT) to evaluate CT as a non-destructive and rapid method for analysing muscle dry matter percentage (DM%) and liquid leakage in cod fillets. The study consisted of a total of 317 Atlantic cod (three batches) with gutted weights varying from 0.7 to 2.7 kg. The fish were scanned at four anatomical defined positions in the longitudinal direction. DM% in whole fillets correlated positively with average CT values over all scan positions, demonstrating that CT can be used as a non-destructive method to predict dry matter percentage in cod (r=0.6 to 0.9; SEP=0.3 to 0.7 DM%). The scan position anterior to the hind back fin gave highest prediction accuracy (r=0.63 to 0.93), and DM% in whole fillets provided better information than DM% analysed in specific anatomic positions. CT value and DM% increased from head to tail in all three batches (P<0.001), demonstrating that the CT-method can provide information also about the variation of DM% within fillets. Classification of liquid leakage during storage into low (<6%), medium (6–10%) and high (>10%) amounts also corresponded significantly with distinct CT (HU) intervals, demonstrating the potential for studying and improving liquid holding capacity in cod fillets using CT. Significant differences were detected in CT and DM% between sexes and between families (P<0.001) indicating genetic variation in these traits and a potential for improvement by selective breeding.

Keywords: Farmed cod; Computerised tomography; Quality; Dry matter; Liquid leakage; Family differences

1. Introduction

Fast, easy and non-destructive methods for analysing traits of importance for fish quality are becoming increasingly more important, both in the industry and as research tools (Sigurgisladottir et al., 1997; Jørgensen and Thomassen, 2000). Computer tomography (CT) methods were developed and used during the eighties and nineties to analyse fat percentage in rainbow trout (Gjerde, 1987) and salmon (Rye, 1991; Bæverfjord and Rye, 1994; Mørkøre et al., 2001), and now recently also in common carp and halibut (Hancz et al., 2003a,b; Kolstad et al., 2004). This non-destructive method for analysing body components is based on the fact that different body tissues are different with respect to X-ray attenuation. During data collection (scanning) an X-ray source is rotated 360° around the object (fish) at defined anatomic positions along the body. For every degree of rotation an X-ray pulse goes through the body. On the opposite side of the X-ray beam, a detector is placed to measure the amount of X-ray, which has passed through the body for every degree movement of the X-ray beam. These recordings provide information about the relative density of a great number of small units in the cross sectional CT image, and have shown to be very well correlated to body composition (Rye, 1991; Jopson et al., 1995; Kolstad et al., 2004). The method can be used in a time efficient way. Several hundred fish can be analysed per day.

Atlantic cod is considered as a lean fish specie with less than 2% fat in the fillet (Haard, 1992; Mørkøre et al., 2007). Large

* Corresponding author. AKVAFORSK, Institute of Aquaculture Research, P.O. Box 5010, NO-1432 Ås, Norway. Tel.: +47 926 52 977; fax: +47 64949502.
E-mail address: kari.kolstad@akvaforsk.no (K. Kolstad).

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Table 1
Average, minimum and maximum gutted weight (g) in the three batches of Atlantic cod

	N	Gutted weight (g)	Min	Max
Batch 1	25	1983	1210	2731
Batch 2	69	2009	1145	2590
Batch 3	223	1538	710	2525

variation is, however, found in protein and water content in both captured and farmed cod. For example, Love (1980) reported variation in water content from 80 to almost 90% in captured cod, and these variations in DM% correlate significantly to variations in quality related characteristics, such as texture and liquid holding capacity.

Most of the existing knowledge related to variations in dry matter percentage and other raw material characteristics were obtained in studies of wild cod. An increasing research activity is, however, directed towards studies of farmed cod under controlled feeding. Farmed cod frequently develop tough texture and high liquid leakage, particularly after freezing. These unfavourable quality characteristics coincide with lower DM% and pH (Lonsnegard et al., 1986; Mohr, 1986; Rustad, 1992; Hemre et al., 1993; Førde-Skjærvik et al., 2006).

The main objective of the present study was to investigate computer tomography as a non-destructive, rapid and efficient method for measuring dry matter percentage and liquid holding capacity in farmed Atlantic cod.

2. Material and methods

2.1. Fish material

Three batches of Atlantic cod (*Gadus morhua*, L) were used in this study: the pilot study (batch 1; $n=25$, average gutted weight 2.0±0.5 kg), batch 2 ($n=69$, average gutted weight 2.01±0.3 kg) and batch 3 ($n=223$, average gutted weight 1.5±0.4 kg). The cod were fed extruded commercial cod feed in experimental cages (125 m^3) at the sea water research station of AKVAFORSK at Averøy at the west coast of Norway. The cod within batch 1 and batch 2 had similar genetic background, but slaughtered at different times of the year. The cod within batch 3 originated from half- and full-sib families from MarineBreed's breeding population. The number of individuals from each family varied from 5 to 15.

Slaughtering was performed according to standard procedures for all three batches (anaesthetisation using CO_2 and gill-cutting) in March 2002, December 2003 and May 2005, respectively. Gutted weight was recorded in all fish (Table 1). In addition, gender and gonad weight was recorded in batch 3. After gutting and bleeding, the fish were iced in styrofoam boxes and shipped to the Norwegian University of Life Sciences at Ås for computer X-ray tomography (CT) analyses. In all three batches CT was followed by dry matter analyses. In batch 3 the fish were also subjected to analysis of liquid leakage.

2.2. CT-scanning and image analysis

A SIEMENS Somatom AR HP computer X-ray tomography (CT) (Siemens, Germany) was used for non-invasive examination of whole body samples in all batches. Parallel cross sectional images were taken on four positions along the cod carcass. Total scanning time was less than 1 min per image. These scan positions were: right in front of the first, mid and hind back fin, and at the gut opening (Fig. 1). The instrumental settings used in all three batches were: voltage 130 kV, slice thickness (i.e. scanning width) 3 mm, zoom factor 2, exposure time 3 s and dosage 300 mAs. The X-ray beam goes 360° around the object, where a detector on the opposite side measures X-ray attenuation expressed by CT value in Hounsfield units (HU). From this CT images were created, with matrices of 512×512 elements (pixels) with defined areas. The CT values of the pixels calculated by the scanner were the weighted mean of the attenuation of X-ray for the tissues found in the volume of the pixel, and are linearly related to tissue density. A frequency distribution over CT values in a CT image of one of the experimental fish is presented in Fig. 2. The CT values from each pixel was converted into grey scale values and then displayed as an image on a monitor (Fig. 2). Variation in grey scale values thus reflected variation in X-ray attenuation. Soft tissues are expected to take CT values in the range of −200 to +200 HU, while bone tissue and air takes CT values far outside above and below this range.

The CT images were analysed further by the medical imaging software OSIRIS (Ligier et al., 1994a,b) to find the range of CT values for edible soft tissue excluding skin, fins and bone, respectively. This included tissues coloured red in Fig. 2. The image analysis software Autocat (Jopson et al., 1995) was then used to calculate mean CT value for the pixels within the defined range for soft tissue in each image. As the Atlantic cod contained no visible fat, no distinctions were made between fat and lean.

After scanning, the cod were stored at −20 °C until further processing and analyses.

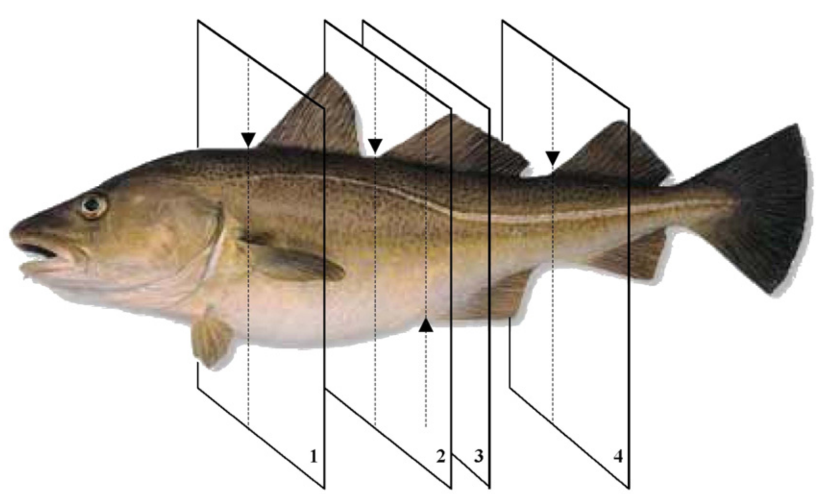

Fig. 1. Locations of the four cross sectional scan positions. Scan positions 1, 2 and 4 were right in front of the first, mid and hind back fin, respectively, while scan position 3 was at the gut opening.