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Seasonal and geographical variation in chemical composition and lipid stability of Atlantic mackerel (*Scomber scombrus*) caught in Icelandic waters

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ABSTRACT

Atlantic mackerel (*Scomber scombrus*) appears in Icelandic waters during its heavy feeding period, resulting in variation in product quality. Fish caught at different times during the summers of 2012 and 2013 (July, August, September) and at different sites of the Icelandic fishing area (East, Northeast, South and Southeast) were analysed. Measurements of lipid and water content, fatty acid composition, lipid hydroperoxide (PV), thiobarbituric reactive substances (TBARS) and free fatty acids (FFA) were studied with the aim of investigating whether this raw material was suitable for the production of high quality products for human consumption. In general, samples collected during the summer of 2012 showed a better condition than fish from 2013. The results indicated seasonal variation in lipid content and rancidity development. The lowest rancidity values were observed in the middle of the Icelandic catching season, indicating that this raw material was best suited for production of high quality products. Moreover, geographical variation of the mackerel catches had an impact on the saturation of the fatty acids, and appeared as follows: East > Northeast.

1. Introduction

Atlantic mackerel (*Scomber scombrus*) is an excellent source of ω-3 polyunsaturated fatty acids (PUFAs) which makes it a valuable species (Orban et al., 2011; Delgado-Lista et al., 2012; Perica and Delas, 2011). It is a novel species for the Icelandic fish industry. It was discovered in great quantities in 2007 within the Icelandic fishing area and has gained great commercial importance since then. This pelagic fish, well known from its long distance migration, appears in Icelandic waters during the summer period (June–September), in order to find larger and richer feeding areas to rebuild its muscle lipids and to restore energy sources after spawning and travelling (Astthorsson et al., 2012; Overholtz et al., 2011; Valdimarsson et al., 2012). The feeding migration of Atlantic mackerel has changed in the last decade and it has been observed that its presence within the Icelandic fishing area is highly related to ocean warming (Hannesson, 2013). Mackerel was initially only discovered in the South and Southeast of Iceland, where the ocean temperature reached 10–12 °C. In recent years, mackerel has been observed migrating further to the East of Iceland (ocean temperature around 7–9 °C), where it has been found in large quantities ever since. In addition, recently it has been spotted in relatively small amounts in the Northeast (5–7 °C) of Iceland (Nøttestad et al., 2015, 2012, 2013).

Mackerel migrations patterns are very unstable and are influenced by oceanographic conditions (Iversen, 2002). Variability of external factors, such as size of the stock, ocean temperature, feed conditions, feed availability and competition for feed with other species, such as herring, may negatively affect the biological condition of the mackerel, and hence affect the quality and stability of the initial raw material intended for further processing. Moreover, the heavy feeding period and the variation in muscle lipid content, as well as variation in biological conditions may lead to great fluctuations in the quality of mackerel. There is limited information on how the seasonal and geographical variation may affect the lipid characteristics and fatty acid distribution in Atlantic

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mackerel. Little is known about the physicochemical properties and processability of Atlantic mackerel caught during the summer months and if this raw material is suitable for the production of high quality products for human consumption. Thus in-depth analyses are required.

The main emphasis of the present study was to investigate the impact of different catching grounds (East, Northeast, South, and Southeast of Iceland) and times (middle and end of July, beginning, middle and end of August, and beginning of September) on the composition and lipid stability of Atlantic mackerel caught in Icelandic waters. The variation in the quality of mackerel between different years of catch (2012, 2013) was also studied.

2. Materials & methods

2.1. Raw material and sampling

Atlantic mackerel (*S. scombrus*) was caught during the summer (July–September) in the years 2012 and 2013. Collection of the samples was carried out approximately every 10 days. Correspondingly, samples collected between the 1st and the 10th day of the month are referred to as fish from the *beginning of each particular month* (e.g., beginning August, beginning September); fish sampled during the 11th to the 20th day of the month are referred to as fish caught in the *middle of the month* (e.g., middle July, middle August); and fish caught during the 21st and the 31st day are referred to as fish caught at the end of the month (e.g., end July, end August). Additionally, samples were collected at different sites in the Icelandic waters (Northeast Atlantic Ocean—FAO no 27) to give an indication of geographical differences on the condition of the mackerel.

Samples collected at the end of July 2012 were from the East and the Northeast fishing areas around Iceland. Fish caught in the beginning and end of August 2012 were only from the East, while samples collected in the beginning of September 2012 were only from the Northeast. Correspondingly, samples collected in 2013 during the middle of July and beginning of August were both from the East and Northeast of Iceland, while samples from the middle of August 2013 were only from the Southeast. Samples from the end of August 2013 were then only from the South. Information of year, season and area of catch is displayed in all figures and tables. The sampling pattern was driven by the availability of mackerel from different seasons at certain geographical locations within Icelandic waters (Table 1).

The mackerel was caught by trawlers where temperature on board was kept at −1 °C. Fish (300–500 g) were frozen whole on land, using an air-box freezing method and stored at −25 °C prior to analysis. Commercially available frozen blocks of mackerel (16 kg) were used in this study. Analyses of the samples were performed within one week from the time of catch. All samples were thawed at room temperature for approximately 17 h prior to further processing. Three individual fishes ($n = 3$) from each group were analysed independently. Fishes were filleted by hand, minced with skin and used for all chemical analysis. Any deviations from this protocol are included in the methods description.

Table 1
Overview of the samples collected.

		East	Northeast	Southeast	South
2012	end July	x	x		
	beginning August	x			
	end August	x			
	beginning September		x		
2013	middle July	x	x		
	beginning August	x	x		
	middle August			x	
	end August				x
	beginning September		x		

All chemicals used during analyses were of analytical grade, and were purchased from Fluka (Buchs, Switzerland) or Sigma-Aldrich (Steinheim, Germany/St. Louis, MO).

2.2. Water and total lipid content

The water content of the ground mackerel samples was determined by the weight difference during drying of 5 g minced fillet at 104 ± 1 °C for 4 h to constant weight (ISO, 1999). Results were calculated as g water/100 g sample.

Total lipids (TL) of the fish samples were extracted according to the method of Bligh and Dyer (1959). The lipid content was determined gravimetrically and the results were expressed as g lipid/100 g of the sample.

2.3. Fatty acid profile

The fatty acid profile of the samples was determined on the TL extracts by gas chromatography (Varian 3900 GC, Varian, Inc., Walnut Creek, CA) of fatty acid methyl esters (FAMEs), according to the AOCS method (AOCS, 1998). The Varian 3900 GC was equipped with a fused silica capillary column (HP-88, 100 m × 0.25 μm film), a split injector, and flame ionization detector fitted with a Galaxie Chromatography Data System, (Version 1.9.3.2 software, Varian Inc.). The setting of the oven was as follows: 100 °C for 4 min, then increased to 240 °C at a rate of 3 °C/min for 15 min. The injector and detector temperatures were 225 °C and 285 °C, respectively. Helium was used as a carrier gas at a column flow of 0.8 mL/min, and a split ratio 200:1. The program was based on the AOAC , 2001 method.

The polyene index (*PI*) was calculated according to the fatty acids contents ratio as follows (Rodríguez et al., 2007): $PI = (C22:6 + C20:5)/C16:0$, where C22:6 represents docosahexaenoic acid, C20:5 eicosapentaenoic acid and C16.0 palmitic acid.

Analyses were not performed on samples from the middle of July 2013 (East/Northeast of Iceland), nor at the beginning of August 2013 (East of Iceland) due to lack of availability of samples at these otherwise potential sampling occasions.

2.4. Lipid oxidation products

2.4.1. Lipid hydroperoxide values

A modified ferric thiocyanate method was used to determine lipid hydroperoxides (Shantha and Decker, 1994). Five grams of samples were mixed with 10 mL of ice-cold chloroform:methanol (1:1) solution (with addition of 500 ppm butylated hydroxytoluene (BHT), which was used to prevent peroxidation during measurements) and 5 mL of sodium chloride (0.5 M) were added to the mixture, which was homogenized at 2400 rpm for 10–20 s. (Ultra-Turrax T25 basic; IKA Labortechnik, Staufen, Germany). Phase separation was facilitated by centrifugation at 5100 rpm for 5 min at 4 °C (TJ-25Centrifuge, Rotor TS-5.1-500, Beckman Coulter, Fullerton, CA). The lower chloroform layer containing the lipids was collected (100 μL) and mixed with 900 μL of a chloroform: methanol (1:1) solution. Finally, a 5 μL mixture (1:1) of ammonium thiocyanate (4 M) and ferrous chloride (80 mM) was added, before vortexing. After 10 min of incubation at room temperature, the absorbance was measured at 500 nm (Tecan Sunrise, Männedorf, Switzerland) in a polypropylene microplate (Eppendorf, microplate 96/F-PP). The concentration of lipid hydroperoxide was determined using a standard curve prepared from cumene