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A comparative study of organic- versus conventional Atlantic salmon. II. Fillet color, carotenoid- and fatty acid composition as affected by dry salting, cold smoking and storage

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ABSTRACT

The aim of the present study was to investigate the effect of dry salting, cold smoking and 14 days refrigerated storage at 4 °C on the stability of carotenoids, color and fatty acids in commercially reared organic Atlantic salmon (*Salmo salar* L.). As reference, conventionally reared Atlantic salmon was used. Pigment sources in feeds for the organic and conventional salmon were Panaferd-AX® (PAN) and Carophyll Pink® (CP), respectively. The dry salting process was found to be the main cause for losses of carotenoids throughout salting, smoking and storage, whereas no differences were found in stability of the different flesh carotenoids. The diverse composition of flesh carotenoids in organic salmon seems however to have minor influence on the color of the cold smoked product. Colorimetric characteristics of the fillet surface and liquid loss during storage of cold smoke fillets were found to be mostly affected by the fatty acid composition of the flesh which differed between the organic and conventional raw material. Moreover, dry salting and cold smoking were found to alter colorimetric differences between raw organically and conventionally reared salmon, resulting in an equal colorimetric perception of cold smoked organic and conventional salmon fillets after 14 days refrigerated vacuum storage.

Statement of relevance:

- This paper investigates the stability of carotenoids, color and fatty acids throughout processing and storage of cold smoked organic farmed Atlantic salmon.
- This paper focuses on the diversity of carotenoids presented in organic salmon fed a feed containing Panaferd-AX and how these carotenoids affect the color of the smoked product.
- This paper investigates the suitability of the presented organic salmon as raw material for the smoking industry.

1. Introduction

Consumers' perception is a key attribute for the smoking industry when it comes to product quality (Cardinal et al., 2004; Gormley, 1992; Rørå et al., 2004). For producers of organic Atlantic salmon (regulated by European Council Regulation (EC) No. 834/2007, 889/2008, 710/2009 and 1358/2014) it is important that the quality of the raw material is acceptable for the smoking industry. The reddish color of salmon flesh is caused by carotenoids (Foss et al., 1984; Skrede and Wold, 2008), and the exceptional color contributes much to the elite image of salmon products (Gormley, 1992). Visual appearance of cold-smoked salmon is one of the most important consumer purchase criterion (Gormley, 1992; Rørå et al., 2004), where the consumers prefer the stronger red-colored salmon products (Bjerkeng, 2000). The flesh color of farmed salmonids is influenced by several factors including dietary lipid level (Bjerkeng et al., 1997; Nickell and Bromage, 1998; Regost et al., 2001), dietary oil source (Regost et al., 2004), fillet fat content (Mørkøre et al., 2001; Nickell and Bromage, 1998), season of harvest (Mørkøre and Rørvik, 2001), dietary carotenoid concentration (Bjerkeng, 2000; Hatlen et al., 1998) and dietary pigment type (Buttle

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et al., 2001; EFSA, 2007; Lerfall et al., 2016; Skrede and Storebakken, 1986; Storebakken et al., 1987). One criterion for production of organic Atlantic salmon is to use a natural pigment source. The most commonly used available natural pigment today is Panaferd-AX® (Nippon oil, Japan). Panaferd-AX® consists of dried sterilized cells of a red carotenoid-rich soil bacterium (*Paracoccus carotinifaciens*) containing around 4% red carotenoids, predominantly astaxanthin (2.2%), adonirubin (1.3%) and canthaxanthin (0.4%) besides some more yellowish carotenoids like β,β-carotene and echinenone (EFSA, 2007). In conventional production of Atlantic salmon, synthetically produced nature identical astaxanthin is normally used. One common trademark is Carophyll Pink, produced by DSM Switzerland, which consists of approximately 6–8% astaxanthin. In a study by Lerfall et al. (2016), from the same sampling as the present study, the fish diet was found to have significant effects on the fillet composition. Compared to conventional salmon, the investigated organic salmon were found to have; similar total content of muscle carotenoids, lower content of astaxanthin, more diverse composition of muscle carotenoids, higher contents of SFAs and PUFAs, lower contents of MUFAs and significantly darker appearance. The product quality of cold smoked Atlantic salmon is known to be affected by both the raw material characteristics (Bencze Rørå et al., 1998; Birkeland et al., 2004a; Birkeland et al., 2007; Cardinal et al., 2001; Larsson et al., 2012; Lerfall and Rotabakk, 2015) and processing conditions (Birkeland et al., 2004a; Birkeland et al., 2007; Cardinal et al., 2001; Espe et al., 2002; Lerfall et al., 2011; Sigurgisladottir et al., 2000). During primary (i.e. slaughtering and filleting) and secondary (i.e. salting and smoking) processing, both decomposition and/or extraction of carotenoids and discoloration of the fillet surface may occur (Birkeland et al., 2004b; Lerfall et al., 2011). Depigmentation of cold smoked salmon fillets is immediately apparent to the consumer and negatively affects the visual perception of color in the product. Due to their chemical structure, different carotenoids differ in extractability and stability (Lerfall et al., 2011). Introduction of "new" carotenoids (other than astaxanthin and canthaxanthin) into the salmon muscle may raise questions about carotenoid stability during processing and how these carotenoids affect the quality of the cold smoked product. Thus, the presented study was undertaken to elucidate the effect of dry salting, cold smoking and 14 days refrigerated storage on the stability of carotenoids, color and fatty acids in commercially reared organic Atlantic salmon fed commercial feed adapted to organic salmon farming. As a reference, conventionally reared Atlantic salmon fed conventional feed was used.

2. Material and methods

2.1. Raw material and experimental design

Atlantic salmon (*Salmo salar* L.) were reared in Romsdalsfjorden at the Norwegian West Coast under standard rearing conditions. Organically produced smolts of Rauma strain were transferred to sea in September 2012 at 80 g where they were kept until live weight of 1 kg in November. The livestock were then split into two nearby (distance; 2.5 km) rearing sites in Romsdalsfjorden: fish at location Gjermundnes (62° 64′ 58″ N; 7° 10′ 04″ E) were produced as conventional Atlantic salmon from ca. 1 kg until harvest, while fish at location Furneset (62° 63′ 39″ N; 7° 13′ 93″ E) were produced in compliance with EU rules for organic production until harvest. Both fish groups were kept in large circular net pens (circumference; 157 m, net depth 30 m) at ambient light and temperature, and were fed either organically or conventionally salmon extruded feeds delivered by feed manufacturers EWOS UK, Grangemounth, and Skretting N, Averøy, respectively. The organic feed contained a high proportion of marine ingredients (>65% over the life cycle), predominantly derived from herring trimmings, organically certified legumes and oil seed meals compared to conventional feeds. The latter contained a higher proportion of conventional vegetable protein and oil at the expense of marine protein and oil ingredients. The organic feed was added approximately 60 mg × kg^{-1} of natural pigment source Panaferd-AX® (Nippon oil, Japan), stabilized with natural antioxidants, whereas synthetic astaxanthin (Carophyll Pink, DSM, Switzerland) was added to the conventional feed at approximately 50 mg × kg^{-1} dose.

On May 23 (2014), the fish were starved according to commercial procedures before they were transported by a well-boat from the rearing cage to the sea cages at the processing plant. There they were acclimated for 2 days before commercial slaughtering (live chilling at 0 °C for 30 min and percussive stunning).

After slaughtering, fifteen gutted Atlantic salmon of each group (organic: gutted weight 5.1–5.8 kg, condition factor (Cf): 0.91–1.21, and conventional: gutted weight 5.1–5.7 kg, Cf: 0.99–1.25), in total thirty salmon were filleted and filet weight was measured before the right side fillets were transported on wet ice in polystyrene boxes to Sør-Trøndelag University College (HiST, Trondheim, Norway). Right side fillets were thereafter divided into two different groups. The first group (both organic and conventional fillets) was used to study raw fillet quality (Lerfall et al., 2016) whereas the second group (both organic and conventional fillets) was used in a cold smoking trial. In the cold smoking trial, six randomly chosen fillets of each group were dry salted and cold smoked. Before salting and after each processing step, cylindrical samples were punched out of the salmon fillets and stored at −80 °C for later analyses (Fig. 1). After smoking, all fillets were vacuum packed and stored in a refrigerated room (4 °C) for 14 days. Throughout each processing step (salting and smoking) and 14 days refrigerated storage, the following parameters were monitored; mass transfer (water and sodium chloride), stability of carotenoids, color and fatty acids. Moreover, a reflective profile of a vertical cut of the Norwegian Quality Cut (NQC) was conducted at end of storage (14 days).

2.2. Salting and smoking procedure

All fillets were covered with NaCl (fine-refined salt, minimum 99.8% NaCl, GC Rieber, Norsal, Trondheim, Norway) three days postmortem and stored on grids in a refrigerated room (20 h, 4 °C). All fillets were then rinsed in cold water (approximately 8 °C) to remove excess of NaCl. Salt-cured fillets of both groups were randomized on grids and dried at 22 °C for 180 min, then cold smoked for 180 min at 22–24 °C in a Kerres smoke-air® show smoker CS700 EL MAXI 1001 smoking cabinet (Germany).

2.3. Mass transfer (weight loss, dry matter and contents of NaCl)

The weight loss (WL) from the fillets during processing was calculated as the difference in fillet weight between raw, and salted and smoked fillets, respectively (Eq. ((1)). Moreover, the WL during 14 days vacuum

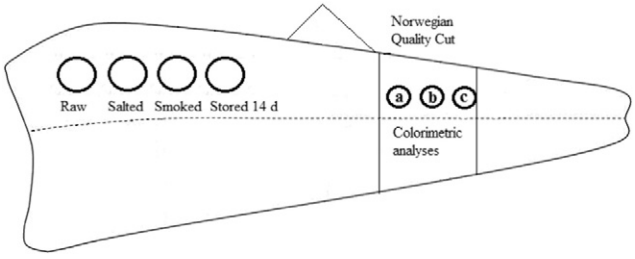

Fig. 1. Schematic illustration showing the areas upon the right fillet where analyses were conducted. Areas raw, salted, smoked and stored 14 days represent sampling areas for chemical analyses after respective processing or 14 days storage. Areas a–c represent areas in the Norwegian Quality cut (NQC) where colorimetric analyses were performed.