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Thermochimica Acta 445 (2006) 168–178
thermochimica acta
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Thermal stability, texture, liquid holding capacity and colour of smoked salmon on retail level☆

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Available online 5 July 2005

Abstract

Retail samples of vacuum-packed sliced cold smoked salmon were investigated for changes in texture, colour and expressible moisture approximately 1 week before expiry date and on the best before date. For comparison, retail samples of gravelax were also investigated. To gather information on alteration in protein caused by processing and refrigerated storage, DSC measurements were performed at the same samples and furthermore on hot smoked salmon and frozen raw material, *Salmo salar*. Texture parameters varied markedly between the retail samples; however, almost no clear tendencies were observable with increased refrigerated storage time while expressible moisture raised. Colour also differed considerably between the samples. Gravelax behaved almost comparable to cold smoked salmon. DSC curves taken from cold smoked salmon and gravelax were almost comparable and demonstrated that muscle proteins being largely denatured by the influence of salt and cold smoking temperature compared to the raw material.

Keywords: Cold smoked salmon; Quality parameters; DSC; Texture; Colour; Liquid holding capacity

1. Introduction

At frequent intervals, German consumer magazines like "Test" and "Öko-Test" have published results of investigations on the quality of smoked salmon products commissioned by both magazines. By order of the foundation "Warentest" vacuum-packed sliced cold smoked salmon products from 22 processors were investigated for microbial quality, pollutants, description of sensory quality by experts on the best before date, chemical composition, packaging and labelling [1]. Description of the sensory quality by experts included appearance, texture as well as odour and taste. Results published by the magazine "Öko-Test" included microbial investigation of samples from 19 processors on the best before date as well as investigation of colorants, pesticides, organotin compounds, animal drugs and chlorinated plastics [2]. Result of this investigation can be summarised briefly by headings of the articles published. It could be read in 2002: "Spoiled too early. Very seldom top in taste, often untimely flea-bitten, this is the conclusion of the test. Especially disappointing: the expensive organic-farmed and wild salmon come off badly than some smoked bulk commodity from fish farms [1]." In 2003 results were comparable: "Contaminated by mould spores and spoiled. At Christmas and New Years' eve smoked salmon sell like hot cakes. Looking at the results of our test, the appetite can be lost. Many products were spoiled, some others contained artificial colorants. Only six times we were satisfied by the quality [2]." While only safety aspects of smoked salmon were checked by "Öko-Test", the foundation "Warentest" took also quality aspects into account.

Not only in Germany but also in France and Italy such market surveys were performed [3]. In both cases, results have been alarming. In France, the main criticisms on the quality of the product refer to the appearance, the texture related to fat content, the level of salt, and the taste. In Italy, the hygienic quality of the smoked salmon was found to be poor

☆ The paper was presented at the 16th Ulm-Freiberger Kalorimetrietage, Freiberg, Germany, 16–18 March 2005.

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doi:10.1016/j.tca.2005.05.021

on the expiry date. Apparently triggered by the bad results of the market studies performed some scientific activities dealing with the quality of smoked salmon are to be noticed recently [3,4]. Smoked Atlantic salmon was collected from a French hypermarket every second month during a period of 1 year [4]. Salmon origin were Norwegian, Scottish and Irish, but were all salted and smoked within France by four commercial smoking houses. Differences between smoking houses were manifested in salt and sucrose content. Also, visible colour and gaping (fractures in the perimysium) differed between the smokehouses tested as did the liquid loss. Increases in variance of the quality variables were observed during the 2 months preceding Christmas including a higher bacterial count. Samples of different brand names of cold smoked salmon products were purchased in supermarkets in six different European countries (Belgium, Denmark, France, Germany, Italy and United Kingdom), to classify and select products of smoked salmon for preference establishment [3]. According to the results, samples could be classified into 11 groups according to specific sensory properties evaluated by a trained panel. The main discriminating factors were found to be colour, intensity and characteristic of smoke note, amine note and salty perception. Some of the chemical and physical measurements were found to be rather good indicators of sensory properties.

Changes in the quality of vacuum-packed cold smoked salmon (*Salmo salar*) were evaluated by biochemical, microbiological and sensory analyses during storage at different temperatures (0, 2, 4, 6 and 8 °C) [5]. TVB, TMA, K value, total aerobic and anaerobic counts and *Lactobacillus* spp., showed significant correlation ($P < 0.05$) with storage time, temperature and sensory quality. Shelf lives of smoked salmon stored at 0, 2, 4, 6 and 8 °C were 26, 21, 20, 10 and 7 days, respectively.

From the results obtained in the different market surveys, it becomes evident that the sensory quality of vacuum-packed sliced cold smoked salmon fluctuates remarkable when quality were assessed on the best before date. In particular, the German surveys show a lack of physical methods to characterise colour, texture and water holding. These methods allow a fast and less laborious determination of food properties of importance to consumers. The objective of the present study was therefore the use of physical methods for texture and colour measurement as well as liquid loss to monitor if there are differences between the products of different processors. Furthermore it was examined whether the differences in evaluation of these parameters on day of purchase and on the expiry date were significant or not. Additionally, the thermal stability of smoked products were investigated to answer questions regarding the native state of salmon muscle proteins or their changes caused by marginal heat treatment during cold smoking and by the adjacent refrigerated storage of the smoked products. For comparison, the thermal stability of raw material and other salmon products was investigated too. To our knowledge, DSC measurement on smoked salmon has not been performed so far.

2. Material and methods

Vacuum-packed sliced cold smoked salmon (six retail packs of 200 g each) from different processors was purchased in supermarkets in Hamburg, Germany, in the period of July to August 2004. In all cases, approximately 1 week was between the date of purchasing and the best before date. According to the label, all smoked products originated from farmed Norwegian salmon, *S. salar*. The products were stored in the institute at 7 °C and investigated 1 day after purchasing and on the expiry date. Later also vacuum-packed gravelax (eight retail packs of 150 g each) produced also from Norwegian farmed salmon was purchased and analysed in same way. In contrast to smoked salmon, gravelax is cured and spiced fillet of salmon and is not thermally treated during processing. Fig. 1 shows visual differences between the samples, their composition according to labelling and dates of investigation. Samples for thermal analysis include ordinary muscles of farmed and wild salmon as well as those of hot smoked salmon, called “Stremellachs” in Germany.

Texture of salmon slices was characterised by instrumental texture profile analysis (TPA) for hardness, gumminess, chewiness, springiness, cohesiveness and adhesiveness, by measuring tensile force (TF) as well as penetration force (PF) measured on homogenised samples using a Texture Analyser TA.XT2 (Stable Micro Systems, Godalming, England). Measurements were performed at room temperature and were described in detail elsewhere [6,7]. For tensile force measurements specimens were cut out of the slices transversally to the backbone using a template (6.8 cm × 2.8 cm). Three specimens were fixed on top of each other on a modified “pizza tensile rig” and tensile force measured as described earlier [8]. The specimens directed to TPA measurements were cut out from three slices on top of each other by using a cork borer (Ø 15 mm). The liquid holding capacity (LHC) were also measured using the Texture Analyser as described previously [7,9]. For colour measuring a spectral colorimeter spectro pen® (Dr. Lange, Düsseldorf, Germany) working at CIELab system was used. Three slices were put on top of each other and colour was measured on the top slice six times. On each retail package measurement was repeated five times, that means for calculating the arithmetic mean altogether 30 measures were used. In the CIELab system, L^* denotes lightness on a 0–100 scale from black to white; a^*, (+) red or (−) green; b^*, (+) yellow or (−) blue. ΔE^*, the colour difference, denotes the square root from ($\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}$). Comminuting (60 s) of slices was performed using a Krups3Mix 8008 (Krups, Solingen, Germany). The homogenate was filled bubble-free into Petri dishes where both PF and colour were measured.

Thermal analysis was performed using a MicroDSC VII (SETARAM, Caluire, France). Samples (300–500 mg) were weighed accurately (±0.1 mg) and heated from 25 to 95 °C with a scanning rate of 0.3 K/min. Measurements were performed in duplicate.

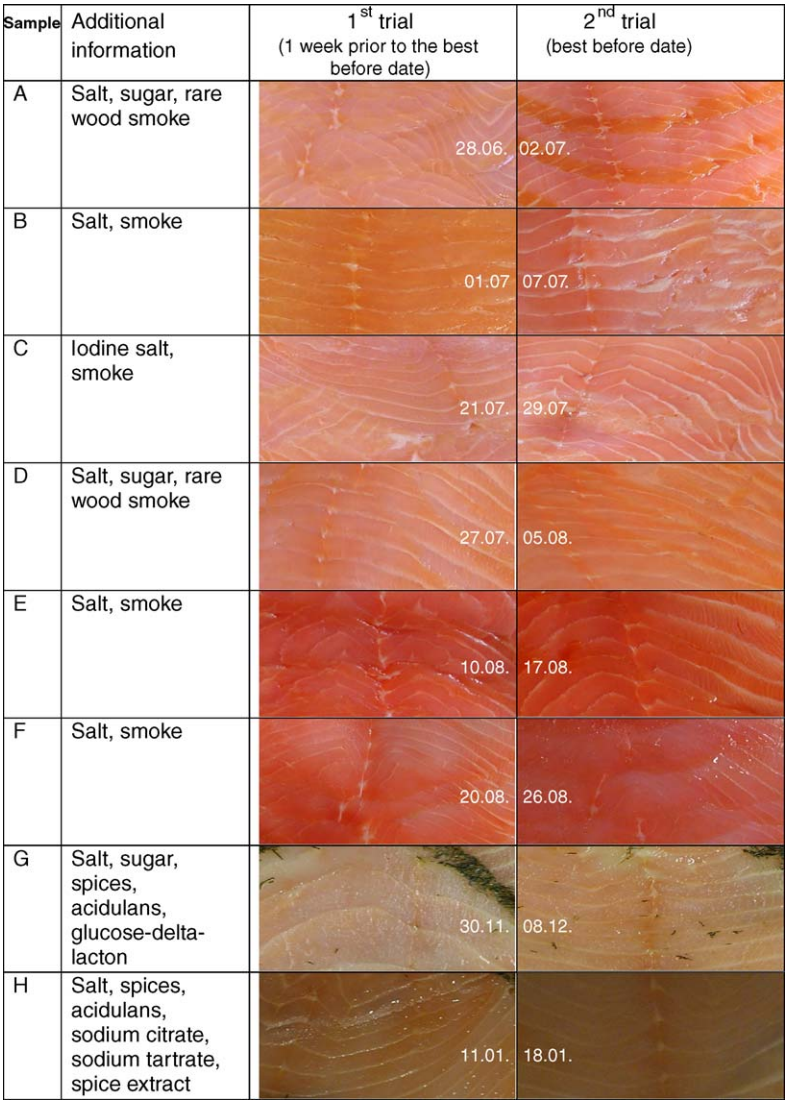

Fig. 1. Date of investigation and appearance of samples: (A–F) cold smoked salmon; (G and H) gravelax.

The results were statistically evaluated using the software package STATISTICA StatSoft, Inc. (1996), Tulsa, OK, USA.

3. Results and discussion

3.1. Texture

TPA allows to evaluate different texture attributes like hardness, chewiness, gumminess, adhesiveness, springiness and cohesiveness (Table 1). Hardness of the samples varied between 17.8 and 25.5 N at 1st measurement and between 14.6 and 24.4 N at the 2nd. Comparing the results of both measurements it becomes obvious that no consistent trends for an increase or decrease in hardness were noticeable. However, only for two products (A, F) the difference between the 1st and 2nd measurement was significant ($P < 0.05$). The reason for increasing hardness in sample A or decreasing hardness in sample F after reaching the expiry date can possibly be seen in biological variability of the raw material. In general, in both trials the hardness between products did vary substantially as shown by numerous significant differences in hardness between samples. Hardness measured on gravelax matched the hardness range of cold smoked salmon (Table 2). Hardness between 1st and 2nd trial was not significantly different. However, between the samples there was a remarkable difference ($P < 0.05$). Gumminess of both cold smoked salmon and gravelax behaved comparably to hardness (Tables 1 and 2). Between both trials no significant differences were found, however, differences between samples were partly remarkable. Also, chewiness behaved similarly to hardness and gumminess. For sample B, a significant difference ($P < 0.05$) was found when results of both trials were compared and as for hardness and gumminess, within both trials chewiness of the samples varied remark-

Table 1
Texture profile analysis of cold smoked salmon slices, arithmetic mean ± standard deviation ($n = 15$)

Attribute	Trial	Sample					
		A	B	C	D	E	F
Hardness (N)	1st	19.58* a ± 4.95	17.83 ad ± 4.62	25.53 bc ± 6.20	19.43 da ± 3.99	22.66 c ± 2.92	18.90* f ± 2.34
	2nd	14.61** a ± 5.27	21.71 bc ± 4.93	24.24 bc ± 3.02	20.15 bd ± 3.73	23.27 bce ± 3.55	23.69** bcf ± 3.92
Gumminess	1st	3.165 a ± 0.972	3.299 a ± 1.202	4.495 b ± 1.561	3.565 ab ± 1.233	3.929 abc ± 0.656	3.600 ab ± 0.783
	2nd	2.706 a ± 1.005	4.331 b ± 1.636	4.509 bc ± 0.747	3.889 b ± 1.039	3.823 bd ± 0.831	4.318 b ± 0.986
Chewiness	1st	0.910 a ± 0.267	0.885* a ± 0.344	1.414 b ± 0.599	0.967 ae ± 0.422	1.185 bcde ± 0.325	1.432 bd ± 0.498
	2nd	0.836 a ± 0.426	1.283** b ± 0.543	1.371 bc ± 0.293	1.140 ab ± 0.416	1.057 abg ± 0.292	1.349 bd ± 0.404
Adhesiveness ($N\,s^{-1}$)	1st	−1.03* a ± 0.26	−1.05* a ± 0.22	−0.93 a ± 0.33	−1.02 a ± 0.24	−0.53 b ± 0.08	−0.41* c ± 0.22
	2nd	−0.65** a ± 0.16	−1.27** b ± 0.25	−0.87 c ± 0.30	−0.97 cd ± 0.23	−0.54 ae ± 0.15	−0.72** ac ± 0.19
Cohesiveness	1st	0.490* a ± 0.028	0.491 ae ± 0.069	0.509* ae ± 0.028	0.514 aeb ± 0.036	0.526* ace ± 0.031	0.561* d ± 0.019
	2nd	0.520** a ± 0.041	0.472 b ± 0.040	0.483** b ± 0.024	0.520 a ± 0.032	0.487** b ± 0.022	0.520** a ± 0.025
Springiness	1st	0.601 a ± 0.063	0.727 b ± 0.041	0.612 ad ± 0.080	0.729 b ± 0.076	0.662 acd ± 0.072	0.706 abcd ± 0.037
	2nd	0.638 a ± 0.056	0.741 b ± 0.077	0.577 c ± 0.079	0.729 b ± 0.077	0.635 a ± 0.068	0.716 b ± 0.046

Different letters (a–g) within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples A–F according to Fig. 1.
* Significant differences ($P < 0.05$) between 1st and 2nd trials.
** Significant differences ($P < 0.05$) between 1st and 2nd trials.

able. Adherence of slices of both cold smoked salmon and gravelax possibly connected with blow them into small pieces is objectionable. As indicator for this behaviour the adhesiveness can be seen. From the results (Tables 1 and 2), it can be deduced that the difference between samples became stronger on expiry date because the occurrence of significant differences increased as also the adhesiveness of half of the samples was significantly different between both trials ($P < 0.05$). However, tendencies of changes were not uniform (Table 1). Gravelax samples behaved differently (Table 2). Future attempts should be reserved to scrutinise whether or not a relationship exist between adhesiveness and the behaviour of slices when separated from the pack. Most significant differences between 1st and 2nd trial were found for cohesiveness. On expiry date, cohesiveness decreased, indicating a loss of integrity of the slices (Tables 1 and 2). In contrast, no significant differences between both trials were found for springiness (Tables 1 and 2). Therefore, this texture attribute cannot be seen as concise texture attribute of both cold smoked salmon and gravelax slices. In connection with springiness, the results of TF measurements should be evaluated (Tables 3 and 4).

Table 2
Texture profile analysis of gravelax slices, arithmetic mean ± standard deviation ($n = 15$)

Attribute	Trial	Sample	
		G	H
Hardness (N)	1st	22.70 a ± 4.29	15.94 b ± 2.49
	2nd	24.87 a ± 2.91	17.11 b ± 2.08
Gumminess	1st	4.311 a ± 1.184	2.544 b ± 0.521
	2nd	4.571 a ± 1.019	2.850 b ± 0.462
Chewiness	1st	1.400 a ± 0.500	0.668 b ± 0.170
	2nd	1.516 a ± 0.426	0.781 b ± 0.158
Adhesiveness ($N\,s^{-1}$)	1st	−0.65 ± 0.15	−0.79* ± 0.24
	2nd	−0.65 a ± 0.26	−1.03** b ± 0.18
Cohesiveness	1st	0.594 a ± 0.027	0.491 b ± 0.038
	2nd	0.570 a ± 0.041	0.473 b ± 0.038
Springiness	1st	0.785 a ± 0.047	0.618 b ± 0.052
	2nd	0.748 a ± 0.045	0.625 b ± 0.101

Different letters (a and b) within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples G and H according to Fig. 1.
* Significant differences ($P < 0.05$) between 1st and 2nd trials.
** Significant differences ($P < 0.05$) between 1st and 2nd trials.

Within the cold smoked products only sample B showed a higher TF compared with the other samples. This sample was also pronounced elastic (Table 1). A significant difference in TF between both trials was only found for sample C. However, for gravelax a significant increase in TF with prolonged chilled storage was detected (Table 4). In PF, the most number of significant differences between the 1st and 2nd investigation was found. However, tendencies on expiry date were not consistent while differences between samples decreased remarkable (Table 3). For gravelax, PF became smaller when achieving the expiry date (Table 4). Levelling of or decrease in PF can possibly be caused by reduced ability of the homogenate for setting or aggregation after filling in Petri dishes due to increasing denaturation of muscle proteins.

When investigating the effects of different parameters in the smoking process on microstructure and texture of salmon fillet, it was found that the force required to shear the smoked

Table 3
Tensile force ($n = 6$), penetration force ($n = 9$) and expressible moisture ($n = 15$) of cold smoked salmon slices, arithmetic mean ± standard deviation

Attribute	Trial	Sample					
		A	B	C	D	E	F
Tensile force (N)	1st	0.80 a ± 0.27	1.86 b ± 0.68	1.19* a ± 0.23	0.79 a ± 0.51	1.01 a ± 0.38	0.93 a ± 0.12
	2nd	0.72 a ± 0.38	1.91 ab ± 0.86	0.76** a ± 0.32	0.58 ac ± 0.32	1.13 a ± 0.37	0.94 a ± 0.19
Penetration force (N)	1st	1.44* a ± 0.05	1.50 a ± 0.06	1.94* b ± 0.09	1.38* c ± 0.03	1.73 d ± 0.14	2.01* e ± 0.07
	2nd	1.59** a ± 0.13	1.51 ab ± 0.11	1.80** cd ± 0.08	1.53** ab ± 0.04	1.67 cd ± 0.15	1.52** ab ± 0.09
Expressible moisture (%)	1st	3.93 a ± 0.67	2.85* b ± 0.56	3.34* c ± 0.43	4.25 a ± 0.74	2.90* b ± 0.40	2.81 b ± 0.34
	2nd	4.09 a ± 0.48	4.19** ab ± 0.70	4.17** ab ± 0.84	4.51 b ± 0.63	3.46** c ± 0.53	3.08 d ± 0.50

Different letters (a–e) within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples A–F according to Fig. 1.
* Significant differences ($P < 0.05$) between 1st and 2nd trials.
** Significant differences ($P < 0.05$) between 1st and 2nd trials.

fillets was significantly higher than for the unprocessed fillets, but was not found to be related to the different salting and smoking processes [10]. The force required to shear the salted and smoked salmon fillets was found to be not significantly different between the processing treatments, brine and dry salting and smoked at different temperature (20 and 30 °C) as well as electrostatic smoking. When the influence of freezing/thawing on the shear force of smoked salmon fillets were compared with that of smoked salmon fillets processed from fresh raw material, results were not consistent. While in some cases no difference was found, in others shear force of smoked fillets processed from thawed raw material was significantly lower [11]. Stress prior to slaughter did not significantly influence shear force of smoked salmon fillets compared to those processed from stress-free fish. Also, starving before slaughtering did not significantly influence shear force of smoked salmon fillets [12]. Hardness of smoked salmon fillet was found to be higher in fillets smoked at 29.9 °C compared with those smoked at 21.5 °C [13]. It was tried to establish a relation between reduced extractability of muscle proteins and hardness. The force at 90% compression of 25-mm thick cutlets, using the 23- and 12.5-mm diameter cylinder on raw and smoked samples, respectively, was found to be a suitable parameter for predicting sensory hardness of smoked salmon [14,15]. Unfortunately, this recommendation cannot be followed when investigating sliced salmon fillet. No statistically significant relationship between hardness of smoked fillets and fat content of raw material was found [16] and the texture of fresh and smoked fillets were also not significantly affected by dietary oil (soybean oil, fish oil and a 50/50 mixture of both) which was included in the diets fed to the salmon [17].

Table 4
Tensile force ($n = 6$), penetration force ($n = 9$) and expressible moisture ($n = 15$) of gravelax slices, arithmetic mean ± standard deviation

Attribute	Trial	Sample	
		G	H
Tensile force (N)	1st	0.97 ± 0.51	0.75 ± 0.45
	2nd	0.81 ± 0.13	0.67 ± 0.17
Penetration force (N)	1st	1.33 ± 0.02	1.50* ± 0.13
	2nd	1.29 ± 0.04	1.38** ± 0.12
Expressible moisture (%)	1st	4.38 a ± 0.50	5.01 b ± 0.75
	2nd	4.81 ± 0.86	4.58 ± 0.67

Different letters within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples G and H according to Fig. 1.
* Significant differences ($P < 0.05$) between 1st and 2nd trials.
** Significant differences ($P < 0.05$) between 1st and 2nd trials.

3.2. Liquid holding capacity (LHC)

LHC decreased with increasing storage time at refrigerated temperature (Table 3). Expressible moisture measured at 2nd trial is invariably greater than that of 1st trial. In samples B, C and E, differences were significant ($P < 0.05$). This can be seen as an indication of increasing visual impression of moistness. Changes in LHC can be caused by gradually denaturation of muscle proteins with increasing refrigerated storage time influenced by thermal treatment at low temperatures during smoking and by additives, particularly salt. This behaviour was partly confirmed by gravelax (Table 4). LHC was not significantly affected by dietary oil [17]. However, in agreement with results reported here, increased storage time (5–15 days) and storage temperature (4–14 °C) reduced strongly LHC of smoked salmon. Investigating different brand names of cold smoked salmon products for LHC, a mean value of 7.7% with a minimum and maximum ranging from 5.1% to 12.7% was found [3]. This is remarkable higher than the values presented here. A possibly explanation for the differences is given with the advice that the salting method has an effect on expressible moisture [3]. When the injection salting technique is applied, a salt brine is injected into the fish muscle using needles. This procedure will modify the integrity of the muscle structure, which on the other hand may increase the expressible moisture. Differences in liquid loss between the smokehouses in France tested were found [4]. However, no significant differences in LHC between samples

smoked at 21.5 and 29.9 °C could be detected [13]. In smoked salmon, the fat content was found to be inversely correlated with LHC and shear force [18]. Recently, it was stated that the effects of cold smoking temperature and dietary oil source on quality were in general low to moderate, and indicate that salmon represents a fairly robust raw material for cold smoke processing [19].

3.3. Colour

The multitude of possibilities to influence the colour of smoked salmon is mirrored in Fig. 1. It shows the visual impression of the consumer after opening the package. Strong differences in lightness and the intensity of redness of smoked salmon were to be seen although, according to labelling, farmed Norwegian salmon was used by the different processors. Gravelax differed from cold smoked salmon by an intense brown colour, particularly noticeable in sample H. Compared with the smooth surface of cold smoked salmon slices, the surface of gravelax looked porous. Altogether, the consumer will notice a fairly inhomogeneous picture of both products. Colour measurements were performed on both the slices and the homogenate made of them (Table 5).

Lightness (L^*) of smoked salmon slices varied considerably in the 1st trial between 28.3 and 40.2. Except for sample D there were no marked differences between 1st and 2nd investigation. Same is valid for L^* measured on homogenates from cold smoked salmon although L^* values were remarkably higher caused by the increased surface due to comminution. Comparable results were also obtained for gravelax (Table 6). Redness (a^*) of smoked salmon and gravelax were pronounced higher compared with white-fleshed fish [20] and ranged from 5.2 to 7.9 for intact smoked muscle. By tendency an increase in a^* can be observed between the 1st and 2nd trial. As in L^*, comminution caused in increase in a^*. However, the before mentioned tendency between both trials did not continue. For gravelax, a^* values were a little smaller compared to smoked salmon (Table 6). Between 1st and 2nd trial, an increase in a^* could be seen, particularly when homogenates were measured. Yellowness (b^*) of the intact muscle of smoked salmon varied considerably between samples (Table 5) causing possibly the optical differences discussed in Fig. 1. The b^* values measured at 2nd trial were higher except for sample D, however, the difference between the samples maintained. The increase of both a^* and b^* during refrigerated storage indicate a development of colour and may not be undesirable. Same tendency can also be observed at homogenates (Table 6), in which the strong increase in b^* due to comminution being surprisingly.

The colour difference ΔE^* between the 1st and 2nd trial is pronounced by comminution and may also be visible by naked eyes at intact muscle except of samples E and H

Table 5
Lightness (L^*), redness (a^*) and yellowness (b^*) of cold smoked salmon slices ($n = 30$) (±standard deviation)

	Sample					
	A	B	C	D	E	F
Intact muscle						
L^*						
1st	38.89 a ± 2.74	38.41* a ± 2.53	37.26* a ± 3.83	28.25* b ± 2.75	33.81 c ± 2.25	40.19 d ± 2.30
2nd	37.89 a ± 1.99	36.02** b ± 1.95	35.43** b ± 2.10	42.56** c ± 1.87	33.96 d ± 2.35	41.00 e ± 1.94
a^*						
1st	6.07* a ± 0.94	6.62* b ± 0.90	7.57* c ± 1.88	5.18 d ± 1.16	7.87 c ± 0.73	7.04 cb ± 1.41
2nd	7.63** a ± 1.00	7.44** a ± 1.29	9.20** b ± 0.84	5.25 c ± 0.92	8.29 d ± 1.26	7.15 a ± 1.21
b^*						
1st	−0.57* a ± 2.41	1.64 b ± 2.08	4.72* c ± 2.92	1.55* b ± 2.20	3.26 d ± 1.24	1.47* b ± 2.36
2nd	1.24** a ± 1.95	2.46 b ± 1.74	7.55** c ± 1.25	0.13** d ± 1.82	3.63 e ± 2.29	2.82** be ± 1.61
Homogenat						
L^*						
1st	61.20* a ± 2.19	61.74* a ± 2.26	52.91* b ± 1.41	52.44* b ± 9.00	47.44* c ± 1.59	54.83* b ± 1.85
2nd	55.97** a ± 1.50	63.31** b ± 1.35	49.66** c ± 1.42	57.34** d ± 1.58	44.68** e ± 1.27	58.09** d ± 1.11
a^*						
1st	8.98* a ± 0.53	10.10* b ± 0.40	10.33* b ± 0.51	9.47 c ± 0.75	12.02* d ± 0.36	11.46* e ± 0.44
2nd	10.87** a ± 0.50	11.22** b ± 0.41	11.80** c ± 0.51	9.19 d ± 0.32	11.52** e ± 0.42	11.98** c ± 0.53
b^*						
1st	12.58* a ± 0.61	14.12* b ± 0.70	13.34* c ± 0.97	12.86* ac ± 1.63	13.81 bc ± 0.64	13.54* cb ± 0.74
2nd	14.41** a ± 0.95	14.55** a ± 0.68	14.95** b ± 0.63	12.11** c ± 0.72	13.68 d ± 0.94	14.26** a ± 0.53

Different letters (a–e) within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples A–F according to Fig. 1.

* Significant differences ($P < 0.05$) between 1st and 2nd trials.

** Significant differences ($P < 0.05$) between 1st and 2nd trials.

Table 6
Lightness (L^*), redness (a^*) and yellowness (b^*) of gravelax slices ($n = 30$) (±standard deviation)

	Trial	Sample	
		G	H
Intact muscle			
L^*	1st	38.80* ± 3.18	37.68 ± 2.11
	2nd	41.08** a ± 2.25	37.57 b ± 2.23
a^*	1st	4.91* ± ± 1.32	5.35 ± 1.54
	2nd	6.07** ± 1.16	6.07 ± 1.48
b^*	1st	0.75* ± 1.73	0.50 ± 2.54
	2nd	1.90** a ± 2.39	0.36 b ± 1.95
Homogenate			
L^*	1st	46.14* a ± 1.43	59.63* b ± 2.02
	2nd	46.90** a ± 0.96	61.66** b ± 1.59
a^*	1st	7.50* a ± 0.46	9.20* b ± 0.52
	2nd	8.67** a ± 0.36	10.61** b ± 0.51
b^*	1st	9.06* a ± 0.72	12.79* b ± 0.75
	2nd	11.12** b ± 0.84	14.14** b ± 0.73

Different letters (a and b) within a row indicate significant differences ($P < 0.05$) between retail products; 1st trial: sample measured 1 week before expiry date; 2nd trial: sample measured on the best before date; samples G and H according to Fig. 1.
* Significant differences ($P < 0.05$) between 1st and 2nd trials.
** Significant differences ($P < 0.05$) between 1st and 2nd trials.

Table 7
Colour difference ΔE^* between 1st and 2nd trial using cold smoked salmon and gravelax slices

	Sample							
	A	B	C	D	E	F	G	H
Intact muscle	2.60	2.66	3.74	14.38	0.58	1.58	2.80	0.74
Homogenate	5.85	1.98	3.91	4.96	2.81	3.38	2.48	2.82

(Table 7). For clarification of the colour differences between retail samples being important to the consumer, sample A was randomly chosen as control and on this basis the colour differences between samples were calculated (Table 8). Between gravlax samples ΔE^* was 1.2 and 3.8 in the 1st and 2nd trial, respectively.

It can be said that colour differences between the retail samples notwithstanding the labelled use of Norwegian farmed salmon in all products were considerable and will be realised by an attentively consumer. Colour of cold smoked salmon is of outmost importance for the quality evaluation and purchasing decision by consumers [4,21–24]. It is not only important that the fish have a satisfactory flesh colour, but that the flesh colour also be uniform [25]. Cultured salmon

Table 8
Colour difference ΔE^* between cold smoked salmon slices (intact muscle), sample A was randomly chosen as control

	Sample				
	B	C	D	E	F
1st trial	2.33	5.74	10.86	6.47	2.61
2nd trial	2.24	6.95	5.36	4.65	3.52

are typically reared on diets containing either astaxanthin or canthaxanthin. Both colorants were affected in a slightly different way by frozen storage and smoking of salmon fillets [26]. Canthaxanthin-fed fish seem to be better for smoking although, when frozen, they lose colour more rapidly than astaxanthin-pigmented fish. Therefore, a combination of astaxanthin and canthaxanthin in the diet may be required to produce fish capable undergoing frozen storage and/or smoking. A multitude of factors influences success of the coloration of smoked salmon. Method of salting, smoking temperature and storage conditions [27], but also the pH [28] have to be taken into account. A significant correlation was found between fat content and instrumentally measured colour in both raw and smoked salmon fillet. With a 30 °C smoking temperature, b^* values were greater than a^* values, i.e. products had a more intense yellowish tone, whereas with smoking at 20 °C, a^* values were higher and the red tone more intense. Regardless of the raw material, b^* values for raw and smoked fillets were higher when fish had been frozen [29]. In contrast, the colour values were found far-reaching not affected by smoking temperature [19]. The measured colour of the 114 smoked salmon samples clearly reflects the above-discussed variability [3]. L^* values of the samples ranged from 45.4 to 61.8 and the values of red and yellow colour, a^* and b^*, ranged, respectively, from 13.4 to 34.2 and from 16.9 to 33.7. A good correlation between slice colour score (pink or orange) given by the panel and the instrumental values L^*, a^* and $b^*$was found. The L^* value was low for orange colour products and increased for pink colour samples. Instrumental hue values, a^* and b^*, showed a high relationship with the panel score for orange colour [3]. On smoked salmon processed by French smokehouses L^* values were measured in the range from 43.6 to 55.5, a^* from 9.3 to 17.2 and b^* from 8.1 to 19.8 [4]. Differences between salmon provenance were found as Norwegian separated clearly from Irish salmon, with the Scottish salmon in between. This separation mainly was due to the colour appearance of the cold smoked salmon as Irish salmon contained more canthaxanthin, less astaxanthin, redder (higher a^*), more yellow (higher b^*) and had a higher hue as compared to the Norwegian salmon. The Scottish fish had values in between Norwegian and Irish salmon. In L^*, Scottish fish had highest values followed by Norwegian and Irish salmon. Recently, it was tried to differentiate between wild, conventionally and organically farmed salmon by analysing the ratio of the configurational isomers of astaxanthin in salmon flesh. All studied conventionally farmed salmon were found to be fed with synthetic astaxanthin and frequently with canthaxanthin [30]. A significant correlation between fat content and colour measurements of both raw and smoked fillets was found [16]. L^*, a^* and b^* increased with fat content giving a more overall colour to smoked fillet.

Comparing our results (Tables 5 and 6) with those reported in the literature, it becomes obvious that they are partly remarkable lower. The reason is to be seen in the use of different instruments. While for own measurements a spec-

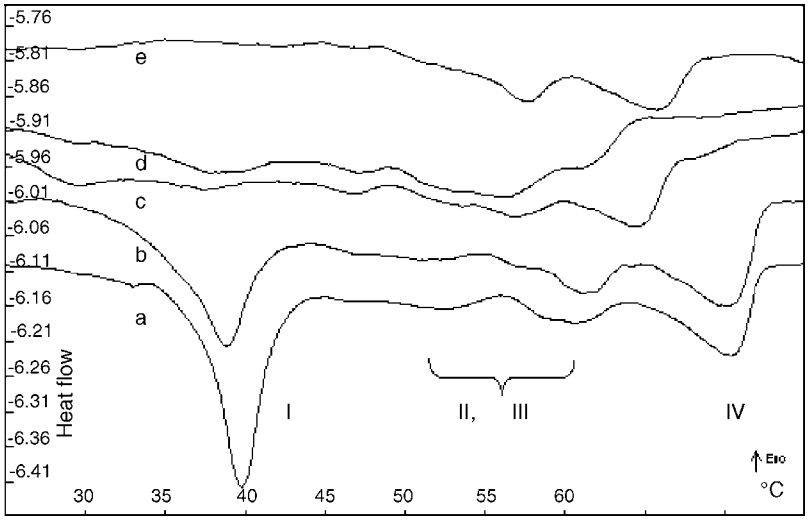

Fig. 2. DSC curves of salmon and salmon products: (a) farmed salmon; (b) wild salmon; (c) gravelax; (d) cold smoked salmon; (e) "Stremellachs".

tral colorimeter spectro pen® was used, the published results based on the use of a Hunterlab Miniscan/EX [3,29] or a MINOLTA Chroma Meter CR 200 [4,16,19]. The instruments were calibrated by different standards, which explains the different results. This has to be taken into account when absolute colour measurements are compared.

3.4. Thermal stability

Differential scanning calorimetry is frequently used to investigate the effects of different technological operations on fish muscle proteins, e.g. heating, freezing, pressurising [7,9,31–40]. Fig. 2 shows DSC curves taken from differ-

Table 9
Transition temperatures and enthalpies of several salmon products (*Salmo salar*)

Sample	Transition temperatures (°C) and enthalpies (J/g)											
	T_{on}	T_{max}	ΔH	T_{on}	T_{max}	ΔH	T_{on}	T_{max}	ΔH	T_{on}	T_{max}	ΔH
Wild salmon	35.0	38.8	0.525	45.3	50.8	0.056	58.5	61.1	0.123	65.5	70.4	0.299
Farmed salmon	37.3	39.8	1.429	48.9	52.3	0.146	56.8	60.6	0.205	65.7	70.5	0.640
Stremellachs	–	–	–	54.5	57.3	0.255	61.0	65.5	0.268	–	–	–

Table 10
Transition temperatures and enthalpies of cold smoked salmon (A–F) and gravelax (G and H) slices measured on the expiry date and 1 week before the expiry date

Sample	Date	Trial	Transition temperatures (°C) and enthalpies (J/g)								
			T_{on}	T_{max}	ΔH	T_{on}	T_{max}	ΔH	T_{on}	T_{max}	ΔH
A	28.06.	1st	34.7	37.7	0.055	49.6	56.6	0.439	–	–	–
	02.07.	2nd	–	–	–	49.4	56.5	0.429	–	–	–
B	01.07.	1st	30.5	33.9	0.117	49.6	55.9	0.358	65.7	67.7	0.012
	07.07.	2nd	26.2	29.7	0.153	47.9	55.2	0.527	65.3	68.7	0.019
C	21.07.	1st	27.1	29.9	0.111	51.1	57.3	0.677	67.3	70.1	0.032
	29.07.	2nd	27.8	30.4	0.151	51.5	57.3	0.771	67.3	69.7	0.048
D	27.07.	1st	24.5	29.7	0.386	51.9	58.2	0.670	–	–	–
	06.08.	2nd	31.8	37.4	0.166	50.6	56.3	0.508	–	–	–
E	10.08.	1st	34.6	38.2	0.243	48.8	55.9	1.348	67.3	69.5	0.037
	17.08.	2nd	34.9	39.1	0.313	47.2	56.6	1.209	67.5	69.0	0.040
F	20.08.	1st	29.0	38.0	0.184	48.9	57.6	0.464	59.5	62.8	0.093
	26.08.	2nd	27.3	29.8	0.147	48.3	56.4	0.527	–	–	–
G	30.11.	1st	24.0	29.7	0.401	50.6	56.6	0.460	–	–	–
	08.12.	2nd	24.2	29.7	0.235	49.4	55.0	0.406	–	–	–
H	11.01.	1st	–	–	–	50.8	57.1	0.599	–	–	–
	18.01.	2nd	–	–	–	47.4	56.1	0.682	–	–	–

ent salmon products and verifies the influence of different processing steps and additives on them. Farmed and wild salmon characterise the raw material, “Stremellachs” exemplified the hot smoked salmon product, sliced cold smoked salmon and gravelax are examples of the study subjects and characterise the changes caused by addition of salt and/or acidifiers as well as by temperature applied during the cold smoking process (from 20 to 30 °C). Corresponding transition temperatures and enthalpies (Tables 9 and 10) clarify the dramatic changes of muscle proteins caused by salting and smoking. DSC curves of farmed and wild salmon did not show any significant differences. The peaks can be attributed to myosin (I), connective tissue and sacoplasmic proteins (II, III) as well as actin (IV).

The curve of Atlantic salmon complies with that of coho salmon (*Oncorhynchus kisutch*) [41]. Myosin was shown to be very sensitive against the basic operations salting and smoking. Surprisingly, already during processing of gravelax it became almost completely denatured. As an effective agent in this processing, salt comes into consideration, which obviously also affected actin in shifting the denaturation temperature and decreasing the denaturation enthalpy. Following the salting process of coho salmon, already after 1 day of salting with 15% brine the enthalpy decreased noticeable, and after 10 days myosin has completely disappeared with a further decrease in enthalpy [41]. The salt content of coho salmon muscle was estimated to be 4.4% and agreed with that of gravelax in our investigation.

The DSC curve of cold smoked salmon made clear that both myosin and actin peak had almost disappeared. Because cold smoking temperature varies in the range from 20 to 30 °C, the main reason for denaturation of myosin and actin can be seen in the influence of salt. Taking this into account the conclusion drawn by Hultmann et al. [13] regarding the influence of cold smoking temperatures on changes of protein solubility and composition of proteins becomes question-

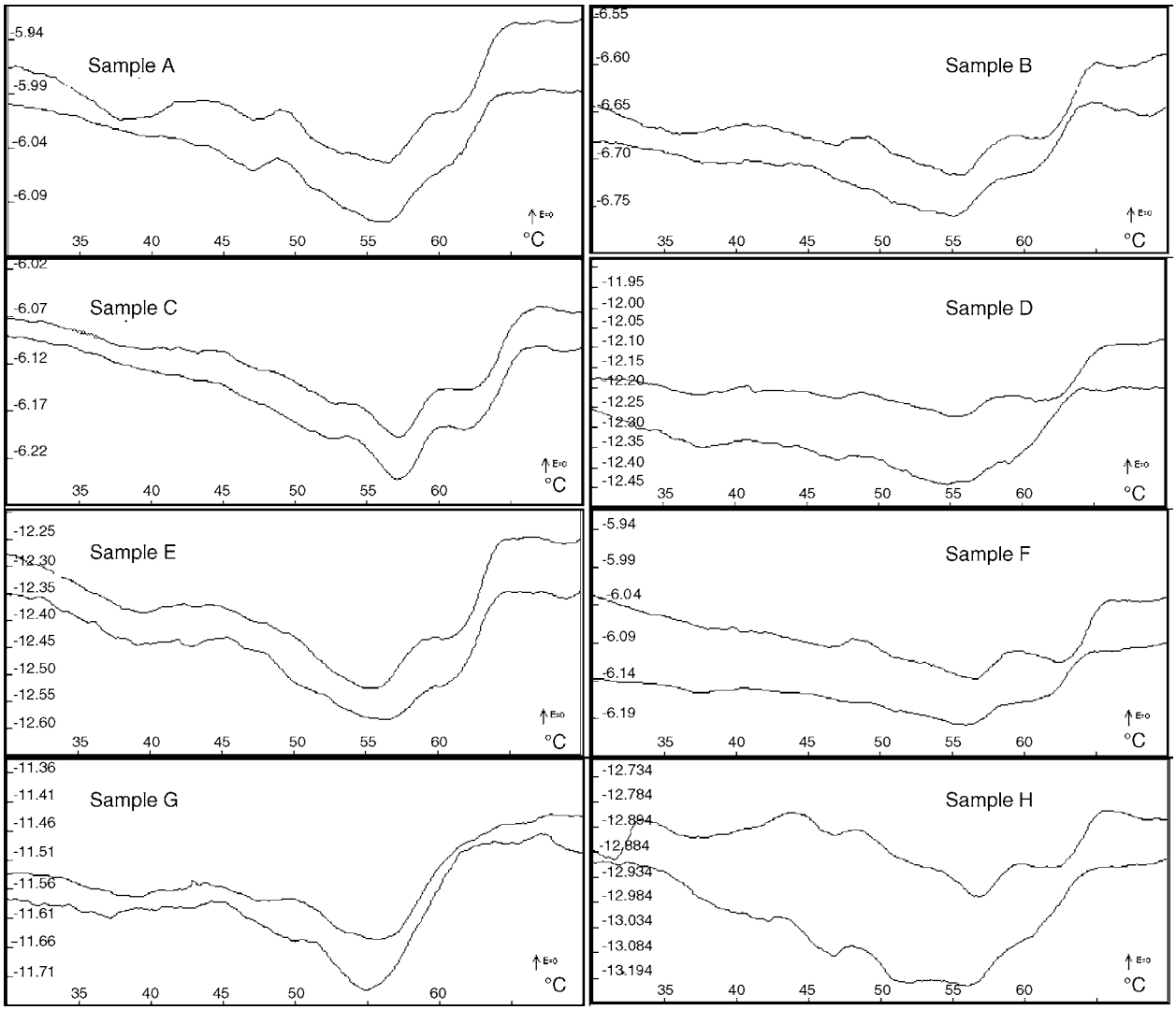

Fig. 3. DSC curves (*y*-axis, heat flow; *x*-axis, furnace temperature) of cold smoked salmon (A–F) and gravelax (G and H) taken on the best before date and 1 week before expiry date (upper curves).

able. Surprisingly, the DSC curve of "Stremellachs", the hot smoked product, exhibited a peak in the range from 54 to 59 °C with a T_{max} of 57.3 °C. This led to the conclusion that during processing of this hot smoked product the minimum temperature of 60 °C postulated in the Guidelines of the German Food Book were not followed. This policy has to be seen as critical from the microbial point of view and can only be explained by the effort of the processor to gain higher yield.

The DSC curves of retail samples obtained at 1st and 2nd investigation at which the temperature range from 30 to 70 °C was excised (Fig. 3) as well as derived temperatures and enthalpies of transition (Table 10) did not verify a significant difference between both measurements. The strong influence of salting in connection with cold smoking became visible. The curves of samples G and H (gravelax) seemed to suggest more pronounced changes of myofibrillar proteins compared to cold smoked samples. While it was possible to identify two peaks at the G curve, only one could be derived from H curve. A possible explanation can be seen in higher water activity found in gravelax because its processing does not include a drying step as it does in processing of cold smoked salmon which benefits enzymatic and microbial degradation of muscle proteins. For cold smoked samples A–F, by the majority, three peaks with T_{max} of approximately 30, 55 and 60 °C could be identified. However, an attribution of these peaks to selected protein fractions will be speculative. Take it that myosin becomes fully denatured it can be assumed that the first both peaks were attributed to sarcoplasmic and connective tissue proteins while the last peak at higher temperature represented the still not denatured part of actin.

4. Conclusions

The aim of the study included the application of physical methods for quality assessment on retail samples of vacuum-packed sliced cold smoked salmon. For comparison, retail samples of gravelax were also investigated. Results obtained verify marked differences of the texture parameter between the retail samples; however, almost no clear tendencies were observable with increasing refrigerated storage. Only the cohesiveness as well as the penetration force seemed to be decreasing on expiry date. The same was observed for liquid holding capacity.

Colour as one of the most decisive parameters for purchasing differed considerably between samples and according to calculated colour differences samples could be discriminated by naked eyes. Gravelax behaved almost comparable to cold smoked salmon.

These differences between retail samples are signs of the high biological variability of the raw material since in all cases farmed Norwegian salmon was used. Farming as well as processing are obviously not able to compensate biologically caused differences. Therefore, consumers have to be aware of the fact that cold smoked salmon will vary in colour, texture and water binding even when same raw material as well as processing method was used. It is recommended that the products should be consumed as early as possible to avoid storage-caused alteration in cohesiveness and LHC. Results of DSC measurement inform on the reason of the texture, LHC and colour changes observed which are to be seen in that muscle proteins being largely denatured or degraded by the influence of salt and cold smoking temperature. Furthermore, DSC proved to be useful in detecting abnormalities in temperature schedules regulated by law as in the case of hot smoked salmon products.

Acknowledgement

The skilful technical assistance of Ms. Isabella Delgado Blas is acknowledged.

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