Sensorial and Physicochemical Characteristics of Salmon (*Salmo salar*) Treated by Different Smoking Processes during Storage

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This study compares the effects of four different smoking processes on the sensorial and physicochemical characteristics of Atlantic salmon (*Salmo salar*) fillets. Two commercial liquid smoke flavourings (FA and FB) and two types of wood used for cold-smoking wood smoke generation (BS: Beech wood and OS: Oak wood) are investigated. Comparisons were made over a 45 day storage period. Control salmon samples (Cn) (i.e., samples that underwent no smoke treatment of any kind) were characterised by their low colour intensity, firmness, fat release and fibrousness and high adhesiveness, pH, TBARS and TMA values, and a strong amine odour. Fillets treated with smoke flavouring FA showed characteristics very similar to those of the Cn samples, however their colour and smoke odour are more intense and their adhesiveness, amine odour and TMA values lower. Fish treated with smoke flavouring FB show low brightness and pH, but high firmness, elasticity, colour intensity and a high expressible water content. Salmon samples smoked with BS or OS smoke had a low intensity amine odour as well as low brightness, pH, TBARS and TMA values, high colour and smoke odour intensities, and a high fat release value. The effect of storage time on sensorial and physicochemical parameters was evident: the values recorded for certain characteristics decrease, such as, colour intensity, elasticity or firmness, and others increase, such as, amine odour, expressible water content or TMA, and some showing a linear relationship with time (elasticity or amine odour intensity).

Key Words: liquid smoke flavourings, smoking, Atlantic salmon, sensorial attributes, storage

INTRODUCTION

Smoking is one of the oldest fish preservation processes. The antioxidant and antimicrobial activities attributed to certain smoke components increase the shelf life of fish flesh (Suñen et al., 2001). However, fish products are now mainly smoked for the attractive smell and flavour conferred upon them (Martinez et al., 2007). The conventional smoking process is gradually being substituted by the use of smoke flavourings (Guillén and Ibargoitia, 1998) which offers several advantages over traditional smoking methods (Pszczola, 1995), for example, they can be purified to remove undesirable compounds, such as polycyclic aromatic hydrocarbons.

A number of authors have studied the composition (Baltes and Sochtig, 1979; Edye and Richards, 1991), antimicrobial activity (Poysky et al., 1997; Suñen et al., 2001), antioxidant effects (Barclay et al. 1997; Guillén and Ibargoitia, 1998) and the influence on physicochemical characteristics (Goncalvez and Prentice-Hernandez, 1998) of smoke flavourings. However, limited information is available regarding their effects on the sensory characteristics of fish (Cardinal et al., 2006; Kostyra and Barylko-Pikielna, 2006).

Farmed salmon is commonly subjected to salting and smoking, affording a ready-to-eat and normally vacuum-packed product with a shelf life under refrigeration of 3–6 weeks (Rorvik et al., 1991). The processes that reduce the shelf life of fishery products are largely due to enzyme (Laksmanan et al., 2003) and microbial activity (Truelstrup et al., 1998; Bugueño et al., 2003). Physicochemical indices, such as the trimethylamine (TMA) level (Leroi and Joffraud, 2000), the concentration of 2-thiobarbituric acid reactive substances (TBARS), pH (Espe et al., 2002) and the liquid-holding capacity (Rora et al. 2003; Hultmann et al., 2004) are commonly used to estimate the degree of spoilage of fish and fish products (Dondero et al., 2004). However, sensorial analysis is probably the best way to estimate shelf life (Leroi and Joffraud, 2000).

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The aim of the present study was to evaluate the effects of two commercial liquid smoke flavourings (FA and FB) on several sensorial and physicochemical characteristics of salmon fillets, and to compare these with the effects of beech wood (BS) and oak wood (OS) cold-smoking over a 45 day storage period.

MATERIALS AND METHODS

Fish Material and Treatments

The experimental material consisted of 60 farmed Atlantic salmon (*Salmo salar*) weighing 2.5 ± 0.3 kg. All were supplied by a commercial Spanish fish processing plant. After slaughter (gill cut and bleeding) fishes were eviscerated, cleaned and placed on ice for transport to the laboratory. Within 2 days of slaughter, all fish were filleted and trimmed by hand to remove skin, bones, fins and visible adipose tissue. Fillets were salted with brine (210 g/L salt) and left for 16 h at 4°C. They were then drained for 30 min at room temperature. Once drained, 15 fillets from the right side of the fish were treated by immersion for 30 s in a commercial smoke flavouring, FA, composed mainly of phenol derivatives (carbonyl compounds, 2.6%; phenol derivatives, 72.7%; Guillén and Ibargoitia, 1996; Martínez et al., 2004). Another 15 right-side fillets were treated by immersion for 30 s in another commercial smoke flavouring, FB, which is rich in carbonyl compounds (phenol derivatives, 30.0%; carbonyl compounds, 60.0%) as principal components (Guillén and Manzanos, 1996; Martinez et al., 2004). The further 15 right-side fillets were smoked in an oven supplied with smoke generated by combustion of the chips from BS for 3 h at 25°C. The remaining 15 right-side fillets were treated in the same way with smoke generated from OS.

All left-side fillets were used as control samples (Cn); these underwent no smoking treatment.

Finally, all the fillets were packed under vacuum in an oxygen-impermeable bag and stored at 4°C until analysis at 2, 9, 19, 32 and 45 days.

Methods

Expressible Liquid

The expressible liquid content was determined using a TA.XT2 Texture Analyser (Stable Micro Systems, Godalming, UK). Fish samples (slices of $2 \times 2 \times 2\,cm^3$) were compressed between layers of preweighed (W_1) filter paper (Whatman No 1) at a pressure of $1\,kg/cm^2$ for 4 min. They were then removed and the wet paper (W_2) weighed before drying at 65°C to a constant weight (W_3). The percentage liquid loss was calculated from the weight of the fluid absorbed by the filter paper and the sample weight (W). This measurement includes the water (EW) and fat (FR) release values:

$$\%EW = \left(\frac{W_2 - W_3}{W}\right) \times 100$$

$$\%FR = \left(\frac{W_3 - W_1}{W}\right) \times 100$$

Determination of the Trimethylamine Concentration and pH

The TMA concentration was determined using the AOAC official method (Colorimetric method) (AOAC, 1995) employing salmon homogenates. The results are expressed as mg TMA/100 g sample. The pH was determined by homogenising 10 g of salmon with 10 mL of distilled water and introducing a Crison Basic 20 pH meter.

Concentration of 2-thiobarbituric Acid Reactive Substances

TBARS concentrations were determined spectrophotometrically using the method of Burk et al. (1980) as modified by Mourente et al. (2002). Briefly, samples (up to 30 mg) were extracted with 1.5 mL of 20% trichloroacetic acid (w/v) containing 0.05 mL of 1% BHT in methanol. Thiobarbituric acid was then added (2.95 mL of a 50 mM solution) before heating at 100°C for 10 min. After cooling the mixtures were centrifuged at $2000 \times g$, to remove protein precipitates. The supernatant was analysed using a spectrophotometer at 532 nm. The TBARS concentration was calculated by comparison with a standard curve obtained by reacting known amounts of 1,1,3,3-tetraethoxypropane with thiobarbituric acid. The results are expressed as mg TBARS/kg.

Sensorial Analysis

Sensorial evaluation of the salmon fillets was undertaken by 10 trained assessors. Four training sessions were organised to make sure that the descriptors were understood and to analyse the performance of each assessor (ISO, 1993). Samples of commercial smoked salmon were described by the panel during those sessions.

Each assessor evaluated a slice of salmon cut at right angles to the fillet surface. This was repeated after 2, 9, 19, 32 and 45 days of storage.

The panellists rated the sensorial attributes on a continuous unstructured linear scale from low intensity (1) to high intensity (9). The following attributes were tested visually: smoke odour intensity (SI), amine odour (AO), colour intensity (CI) and brightness (B).

Elasticity (E), firmness (F), fibrousness (FS) and adhesiveness (A) were assessed in mouth.

Statistical Analysis

Three determinations were made for each physicochemical characteristic examined. The results were analysed by ANOVA and significance was set at $p \leq 0.05$. The effect of storage time was modelled as $Y_{i,\mathrm{sk}} = \beta_{0i,\mathrm{sk}} + \beta_{1i,\mathrm{sk}} t + \varepsilon$, where $\varepsilon \approx N\ (0,\ \sigma_\varepsilon)$. Pearson correlation analysis was performed to determine the relationships between the variables. Principal component analysis (PCA) was used to describe the differences and similarities between groups.

All calculations were performed using Statgraphics STSC Inc. software (version 5.0).

RESULTS AND DISCUSSION

Figures 1 and 2 display the values for the sensorial and physicochemical characteristics of the salmon fillets (Cn, FA, FB, BS and OS) after 2, 9, 19, 32 and 45 days of storage. These data were subjected to PCA analysis to identify similarities and differences among samples. Three principal components (PC1, PC2 and PC3) were obtained which accounted for 79.94% of the total variance (Figure 3). PC1 explained 49.97% of the variance and was mainly associated with adhesiveness (A), colour intensity (CI), firmness (F), fat release (FR), fibrousness (FS), amine odour (AO), pH, smoke odour intensity (SI), TBARS and TMA. PC2, which accounted for 17.72% of the variance, was mainly associated with brightness (B), elasticity (E), firmness (F), fat release (FR) and fibrousness (FS). Finally, PC3 represented 12.24% of the total variance and was mainly associated with brightness (B), expressible water (EW), pH and TBARS.

The Cn samples showed positive values with respect to PC1, and were characterized by low colour intensity (CI), firmness (F), fat release (FR), and fibrousness (FS), but high adhesiveness (A), amine odour (AO), pH, TBARS and TMA values (Figure 4). As observed in Figures 1 and 2, these samples showed the lowest CI and FS values and the highest AO, A and TMA values of all the salmon fillets analysed.

The fillets treated with BS and OS showed similar traits (Figure 4) and might indeed form a single group characterised by low amine odour (AO), brightness (B), pH, TBARS and TMA values and high colour intensity (CI), smoke odour intensity (SI) and fat release (FR) values. Hassan (1988) indicated that smoking reduced the pH, perhaps due to a loss of moisture, an absorption of smoke acid, and the reaction of phenols, polyphenols and carbonyl compounds with protein SH and amino groups. The smoking process (smoke generated by combustion of wood chips) enriched the headspace of fish with smoke components, which, in addition to providing aroma and taste, hindered the oxidation of the lipid component (Guillén et al., 2005). The headspace of salmon smoked with beech or oak smokes had small concentrations of aldehydes, ketones or alcohols, probably coming from lipid oxidation (Guillén et al., 2005); this would explain the low TBARS values shown by the present samples. The low TMA and AO values of those samples might be explained by the antibacterial action of the smoke. Cardinal et al. (2004) showed a positive correlation to exist between the sensorial perception of an amine odour and the TMA content, and between the latter and the total microflora content. The present results also show a positive correlation ($r = 0.619$) between the AO intensity and TMA concentration (Table 1).

Smoking has been reported to affect the colour of food (Espe et al., 2004).The formation of the smoke colour is believed to originate from an uptake of coloured smoke constituents, oxidation and polymerization of smoke compounds, and reaction of smoke compounds with proteins (Toth and Potthast, 1984); therefore, condensation reactions take place between carbonyls and amines, leading to the appearance of the typical smoke colour. On the other hand, results showed a positive correlation ($r = 0.545$) between FR and CI (Table 1).

It should be noted that the BS fillets showed lower smoke odour intensity (SI), fat release (FR) and TMA but higher amine odour (AO) and TBARS values than the OS fish. The OS fillets showed the lowest brightness (B), amine odour (AO) and TBARS values and the highest smoke odour intensity (SI) and fat release (FR) values of all the samples examined (Figures 1 and 2). The differences between these groups may be explained by the composition of the beech and oak smokes. Certainly, Toth and Potthast (1984) indicated there to be a relationship between smoke composition and the different types of wood used to produce it. Guillen et al. (2005) reported that beech and oak generate different fish headspace compositions and, therefore, different flavours in salmon flesh. The headspace of salmon smoked with oak smoke is richer in phenol derivatives than samples smoked with beech smoke. Toth and Potthast (1984) and Cardinal et al. (2004) indicated that colour development depended mainly on carbonyls, while the flavour afforded was largely due to the type and amounts of phenolic compounds present. These compounds also influence the antioxidant effect of the smoke. The present results agreed with those of these authors, and in addition showed a negative correlation to exist between FR and AO ($r = -0.601$) and a positive correlation between FR and SI ($r = 0.486$) (Table 1).

The two groups of fillets treated with liquid smoke flavourings (FA and FB) showed very different characteristics, both with respect to one another and the other groups. The FA fillets showed positive values with

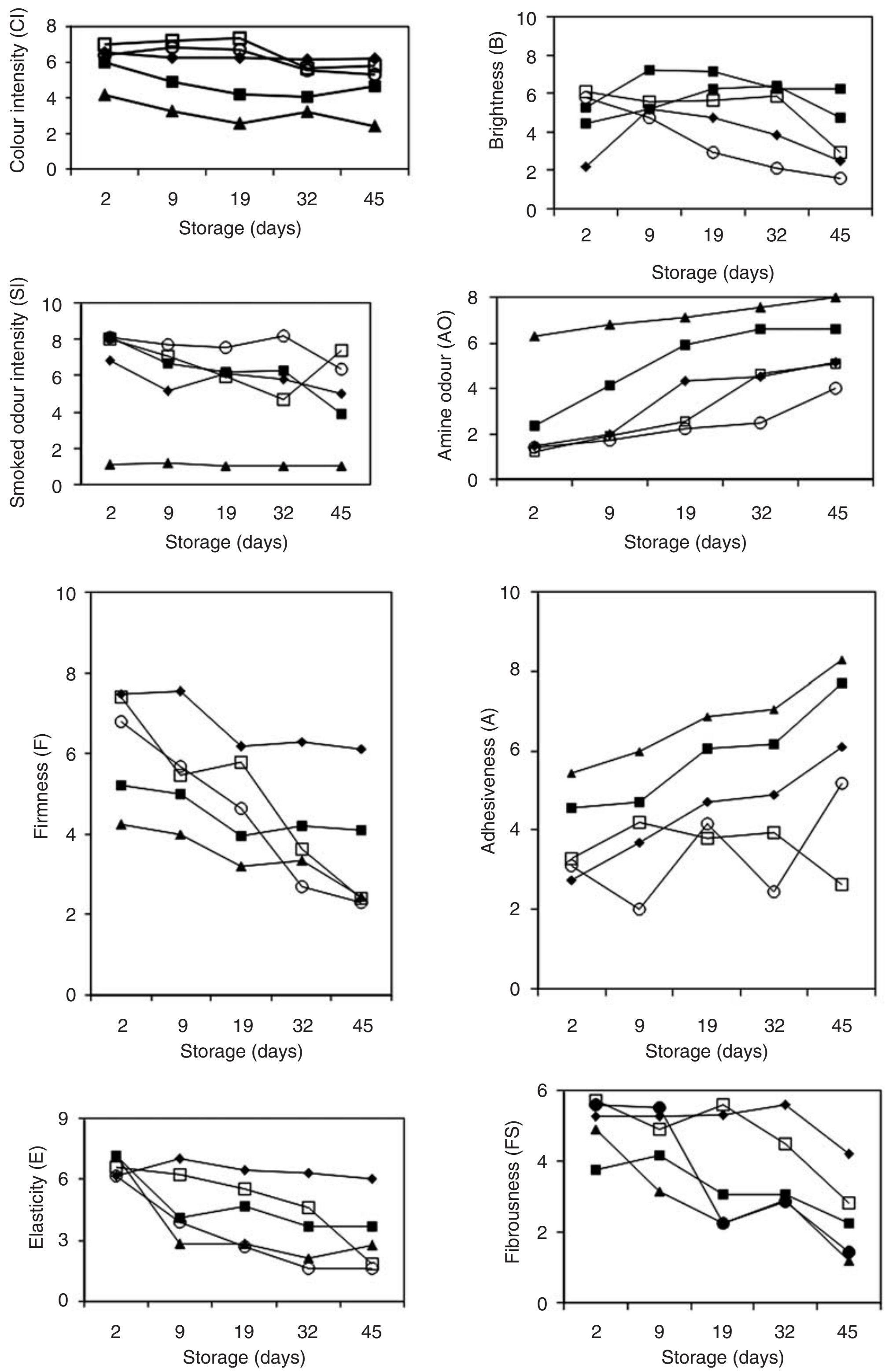

Figure 1. Sensorial properties of salmon treated by different smoking process: changes over a 45 day storage period: (▲) Cn (control group); (■) FA (salmon smoked with different smoke flavourings); (◆) FB; (□) BS (cold-smoked salmon with smoke from beech wood); and (○) OS (cold-smoked salmon with smoke from oak wood).

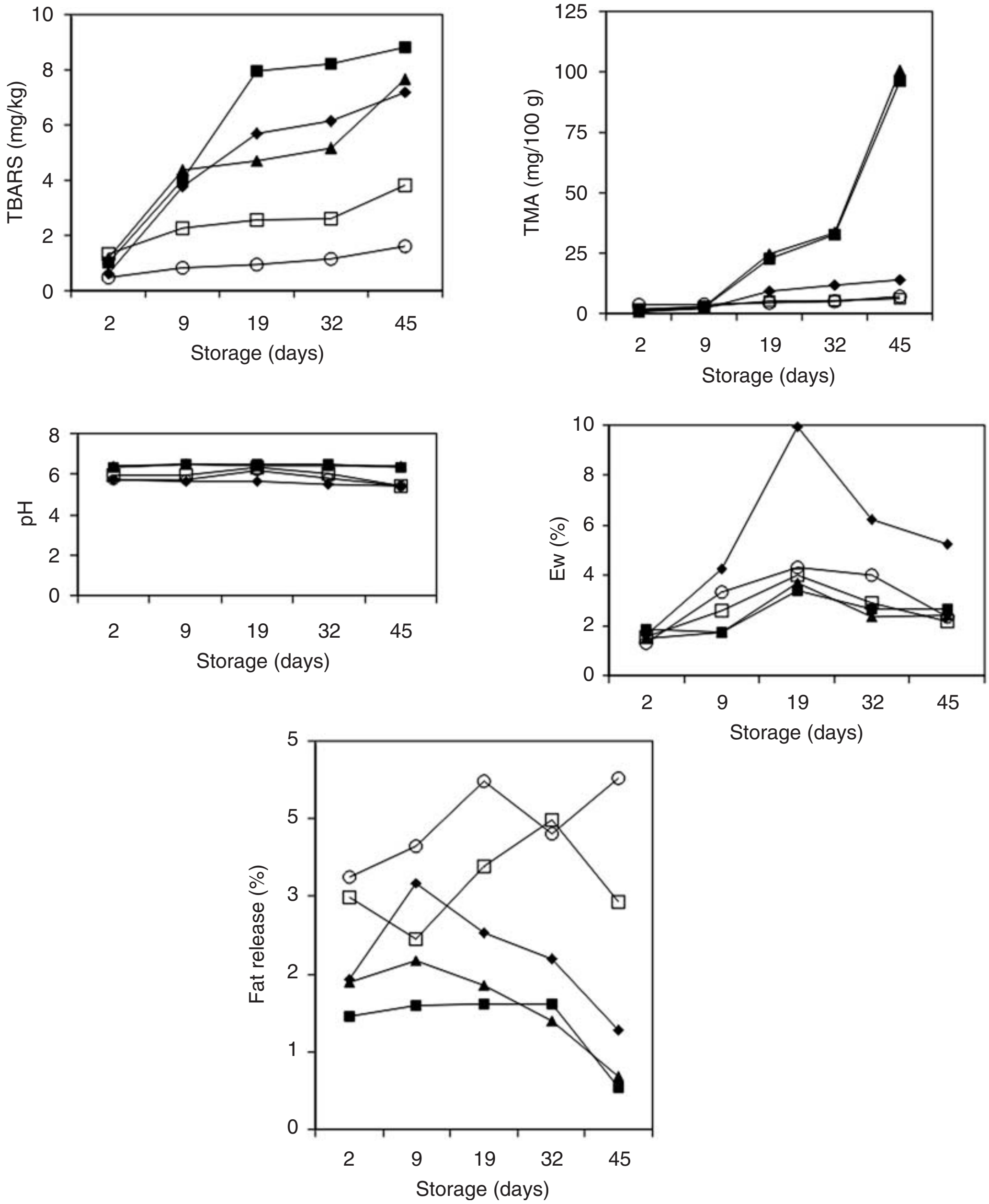

Figure 2. Physicochemical properties of salmon treated by different smoking process: changes over a 45 day storage period: (▲) Cn (control group); (■) FA (salmon smoked with different smoke flavourings); (◆) FB; (□) BS (cold-smoked salmon with smoke from beech wood); and (○) OS (cold-smoked salmon with smoke from oak wood).

respect to PC1, and therefore had characteristics very similar to those of Cn fish. However, they had higher colour intensity (CI) and smoke odour intensity (SI) values and lower adhesiveness (A), amine odour (AO) and TMA values than the Cn samples, differences attributable to the action of the components of the flavouring since the Cn samples underwent no smoke treatment of any kind.

The FB fish showed negative values with respect to PC1, and positive values with respect to PC3; these fillets were therefore mainly characterized by their low brightness (B) and pH but high firmness (F), elasticity (E), colour intensity (CI) and expressible water (EW) values. This group also had the lowest pH and the highest firmness (F), elasticity (E) and expressible water (EW) values (Figures 1 and 2). The effect that FB smoke flavouring has on the textural attributes of salmon should be noted. Guillen and Carton (2005) showed that the headspace of salmon smoked with a flavouring of composition similar to FB was much richer in carbonyls than that of fish smoked with an FA-like flavouring. During the surface treatment of fish or meat products with smoke, the formation of a secondary skin is observed; this is largely caused by the reaction between

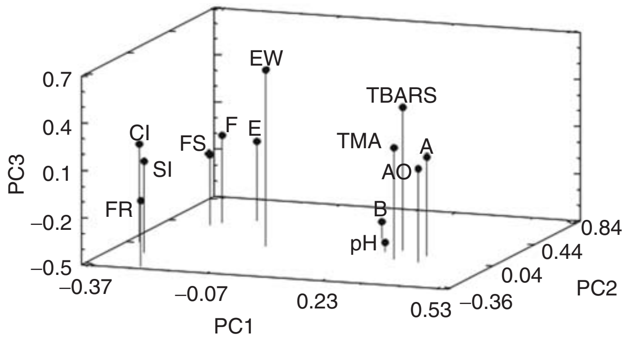

Figure 3. Projection of variables of principal component analysis on sensory and physicochemical descriptors. CI – colour intensity; B – brightness; SI – smoke odour intensity; AO – amine odour; E – elasticity; F – firmness; FS – fibrousness; A – adhesiveness; FR – fat release; EW – expressible water.

Table 1. Correlation matrix between sensorial and physicochemical characteristics.

Sensorial and physicochemical variables[a]	PH	FR	EW	TBARS	TMA
CI	−0.597*	0.545*	0.225	−0.527*	−0.560*
B	0.684*	−0.352	−0.187	0.297	0.234
SI	−0.463*	0.486*	0.072	−0.426*	−0.469*
AO	0.470*	−0.601*	−0.001	0.739*	0.619*
E	−0.148	−0.148	0.159	−0.165	−0.322
F	−0.311	0.038	0.198	−0.240	−0.389
FS	−0.323	0.180	0.186	−0.369	−0.564*
A	0.536*	−0.687*	0.012	0.754*	0.740*

[a]CI – colour intensity; B – brightness; SI – smoke odour intensity; AO – amine odour; E – elasticity; F – firmness; FS – fibrousness; A –adhesiveness; FR – fat release; EW – expressible water; TBARS – 2-thiobarbituric acid reactive substances; TMA – trimethylamine.
*Values are statistically significant ($p < 0.05$).

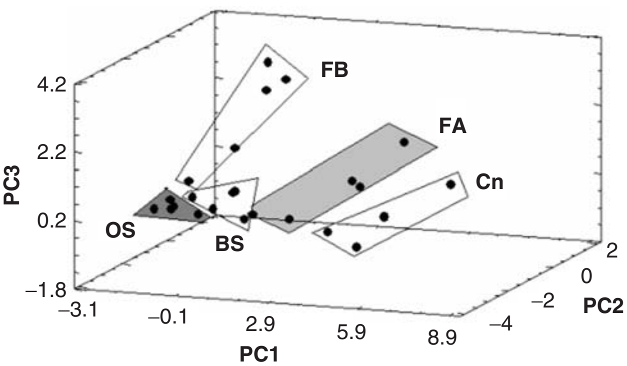

Figure 4. PCA plot showing the distribution of salmon groups over storage time, with respect to sensorial and physicochemical data. Cn – control group; FA and FB salmon smoked with different smoke flavourings; BS and OS, cold-smoked salmon with smoke from beech and oak wood.

carbonyls and proteins: the tanning effect (Toth and Pottash, 1984). This imparted firmness to such products (Guillen et al. 1998). In addition, Jonsson et al. (2001) and Birkeland et al. (2004) reported that a lower water holding capacity gives a higher expressible mixture content and higher shear strength in muscle, while Indrasena et al. (2000) indicated firmness and break strength to be inversely related to the water content of smoked salmon. Cardinal et al. (2004) reported that samples with the highest colour intensity generally are correlated to the highest expressible liquid values.

There was an evident effect of storage time on the sensorial and physicochemical parameters of all the fish samples (Table 2). The amine odour (AO), TBARS and TMA values increased and showed a linear relationship with storage time. Other values (EW and CI) increased or decreased over storage time in all the treatment groups, although no significant linear relationship with time was seen. Finally, several variables in certain treatment groups showed significant linear relationships with storage time, e.g., adhesiveness (A) in Cn fish, FA and FB fish, and elasticity (E), firmness (F) and fibrousness (FS) in the BS and OS fish. Several researchers have reported a linear relationship to exist between certain physicochemical properties, such as TMA, TBARS, EW, and storage time (Rora et al., 1998; Jonsson et al., 2001, Dondero et al., 2004), and between sensorial scores and storage time (Maga, 1988; Sigurgisladottir et al., 2000; Dondero et al., 2004).

Taking only sensorial qualities into account, the fillets were rejected by the assessing panel when they showed signs of softening, low elasticity and high adhesiveness, amine odour, discolouration and low brightness. The Cn fillets were rejected at 19 days, the FA fish at 32, and the other salmon groups at 45 days of storage. These results agree with those of Truelstrup et al. (1998), Dondero et al. (2004) and Leroi et al. (2001), who estimated the shelf life of whole, vacuum-packed, cold-smoked salmon fillets to range between 32 and 49 days at 5°C.

The longer shelf life of salmon treated with FB rather than FA flavouring might be due to their different compositions; FB contains all the compounds of traditional smoke in similar proportions while FA contains mostly phenolic compounds.

In conclusion, treatment of salmon with FA and FB leads to changes in its physicochemical and sensorial attributes. Although the FB salmon had a shelf life similar to that of salmon treated with OS or BS, the characteristics it imparted were judged not to be very favourable: these fillets showed notably greater firmness, acidity and expressible water contents than the BS and OS fillets. However, the FA smoke flavouring conferred colour and smoke intensity characteristics that were positively valued by the panel, even though this flavouring afforded the shortest shelf life of all the treatments tested.

Table 2. Results from linear regression against storage time.

Sensorial and physicochemical variables[a]	Cn β_0	Cn β_t	FA β_0	FA β_t	FB β_0	FB β_t	BS β_0	BS β_t	OS β_0	OS β_t
CI	3.75	−0.030	5.37	−0.028	6.42	−0.006	7.41	−0.038	6.88	−0.034
B	6.35	0.003	5.13	0.012	4.00	−0.015	6.46	−0.057	5.51*	−0.097*
SI	1.13	−0.003	7.92*	−0.079*	6.35	−0.026	7.19	0.026	8.18	−0.028
AO	6.34*	0.037	3.06*	0.095*	1.59*	0.087*	1.01*	0.095*	1.16*	0.055*
E	5.19	−0.077	5.98	−0.062	6.63	−0.011	7.20*	−0.105*	5.32*	−0.098*
F	4.27*	−0.038	5.04	−0.025	7.49	−0.035	7.25*	−0.107*	6.75*	−0.108*
FS	4.30	−0.066	4.07*	−0.038*	5.49	−0.017	5.96*	−0.058*	5.62*	−0.097*
A	5.41*	0.061	4.30*	0.071*	2.91*	0.070*	3.95	−0.017	2.42	0.044
PH	6.40	−0.000	6.43	−0.001	5.72*	−0.007*	6.13	−0.010	5.89	−0.005
FR	2.25*	−0.031	1.74	−0.017	2.74	−0.024	2.88	0.012	3.44	0.023
EW	1.94	0.018	2.00	0.021	3.96	0.069	2.47	0.008	2.70	0.016
TBARS	1.99*	0.122	2.33*	0.171*	1.79*	0.134*	1.49*	0.047*	0.49*	0.023*
TMA	−14.06*	2.172	−13.21*	2.07*	0.61*	0.324*	2.13*	0.099*	3.17*	0.076*

(Salmon groups: Cn, FA, FB, BS, OS)

[a]CI – colour intensity; B – brightness; SI – smoke odour intensity; AO – amine odour; E – elasticity; F – firmness; FS – fibrousness; A – adhesiveness; FR – fat release; EW – expressible water; TBARS – 2-thiobarbituric acid reactive substances; TMA – trimethylamine.
*Values are statistically significant ($p < 0.05$).

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