

Characteristics of dry- and brine-salted salmon later treated with liquid smoke flavouring

Olaia Martínez*, Jesús Salmerón, María D. Guillén and Carmen Casas

*Departamento de Farmacología y Ciencias de los Alimentos, Facultad de Farmacia,
Universidad del País Vasco (UPV) 01006-Vitoria, Spain.*

**e-mail: olaia.martinez@ehu.es*

The use of smoke flavourings for the processing of salmon has begun to substitute traditional smoking methods. This review examines the quality issues associated with salted salmon ‘smoked’ by this technique along the salting and smoking steps. Firstly, the evidence is examined to determine whether dry or brine salting is better for salmon flesh destined to be treated by liquid smoking. Secondly, influence of liquid smoking on the sensorial, physicochemical and textural characteristics of the flesh are described, as are its effects on potential spoilage organisms.

Key-words: Salmon, liquid smoke flavouring, dry and brine salting.

Introduction

Atlantic salmon (*Salmo salar*) is an economically and nutritionally important cultured fish species (Dondero et al. 2004). About 40–50% of farm-reared Atlantic salmon reaches the consumer as traditional cold-smoked gourmet food products (Birkeland and Bjerkeng 2005); indeed, a number of countries have long traditions of producing and consuming smoked food products (Birkeland and Skara 2008).

The process of cold-smoked salmon includes salting and drying before any type of smoking, and the final product typically contains between 2.0–3.9% salt in the water phase (Bannerman and Horne 2001, Huang et al. 2002; Oenhlenschlager 2007, Bocker, et al., 2008). Salmon thus salted is categorized as “lightly preserved” (Leroi 2010). Salt functions as a flavour enhancer, increasing the perception of the fullness, thickness and sweetness of food (Gallart-Jornet et al. 2007a). It may be added by injection, by dry salting or by brine

salting, the latter two being the most commonly used in the salmon processing industry (Birkeland and Bjerkgeng 2005).

Smoking impregnates high-protein foods with aromatic components. These lend flavour and colour to the finished product as well as playing a bacteriostatic and antioxidant role (Kristinsson et al. 2008). Along the last decades traditional smoking methods have given way to the use of smoke flavourings. Treatment with these flavourings is much cheaper and has a much less toxic effect on the environment (Pszczola 1995, Underwood and Shoop 2007). In addition, their use avoids the formation of polycyclic aromatic hydrocarbons, a drawback of the traditional process (Guillen et al. 1996). Smoke flavourings of different composition are available and can be combined to obtain products with different sensorial qualities (Abu-Ali and Barringer 2007, Gedela et al. 2007).

The optimisation of the individual operations involved in the processing of smoked salmon, i.e., salting, drying and smoking, is important in the economic success of this sector which has small profit margins (Birkeland et al. 2004). This paper summarises the available information on the salting procedures employed and tries to determine whether dry salting or brine salting is better for use with salmon to be smoked with liquid smoke flavourings. Moreover, the most outstanding features imparted by liquid smoke flavouring to salmon flesh after salting by different methods are discussed.

Salting

The uptake and distribution of salt in fish fillets depends on the salting method used, the species in question, the thickness of the fillet, the fish/salt weight ratio (Gallart-Jornet et al. 2007b, 2007c, Bras and Costa 2010), and intrinsic flesh factors such as the composition and structure of the muscle and the rigor condition (Aursand et al. 2009, 2010). Lipids in flesh play an important role as a limiting factor during the salting and drying steps, either replacing the aqueous phase that serves as a vector for

transfers during these steps or acting as physical barrier (Cardinal et al. 2001).

When a salt solution or dry salt is used for salting, two main simultaneous fluxes occur: the uptake of salt by the muscle and the loss of water from it (Gallart-Jornet et al. 2007b, Czerner and Yeannes 2010), a consequence of the differences in the osmotic pressure of the muscle cells and the salting agent (Barat et al. 2002). Table 1 shows several salting protocols and their effect in the flesh quality. In dry salting, a water interface is created by the extraction of the intercellular water to the surface of the flesh. In brine salting, however, the products are soaked in a solution which reduces the outward diffusion of water (Rora et al. 2004, Bellagha et al. 2007). The use of dry salt causes fiber shrinkage (Sigurgisladottir et al. 2000, Bocker et al. 2008), the cross-sectional area of the muscle fibers becoming smaller after such treatment than after brine salting. Brine-salted salmon can, however, show a wide variation in muscle fiber size, with some fibers expanding, others shrinking and others still showing no change. This might be an effect of an uneven salt distribution within the muscle.

Montero et al. (2003) reported that differences in protein solubility (sarcoplasmic and myofibrillar fractions) between salmon processed using different salting methods were not significant, and that protein solubilisation was not influenced by the salt level. However, salt is well known to affect the structural proteins of muscle (Larsen et al. 2008) and the changes in rates of salt penetration closely follow changes in the amount of extractable protein (Minh et al. 2011).

Brine salting causes the solubilisation of some of the muscle proteins, which are released into the brine (Unlusaying et al. 2010). Martinez et al. (2005) and Martinez-Alvarez and Gómez-Guillén (2006) indicate that the loss of nitrogenous components during brine salting may be due to the enhancement of protein solubility, a consequence of the increasing salt content of the tissues. Salt-induced protein destruction would be followed by the leaching of protein components into the brine. At the same time, the cations introduced into the flesh might also induce conformational changes and affect protein/water interactions, and hence protein

Table 1. Different smoking protocols proposed for smoking of various fish species: salting and smoking methods are described. As different objectives were stated for each work, it is difficult to find measurements of the same quality parameters. Total yield, water holding capacity (WHC) and texture are shown for some of them.

Author(s)	fish species	Salting process				Smoking process				After smoking	
		method	time (h)	T (°C)	method	time (h)	T (°C)	total yield ² (%)	WHC (%)	texture-shear force (N)	
Muratore et al. (2007)	<i>Xiphias gladius</i>	Dry-salting	24	-	liquid-smoking1, 5% (DS)	5	-	-	-	-	
		Brine -salting (30%)	24	-	liquid-smoking1, 10% (DS)	5	-	-	-	-	
					liquid-smoking1, 5% (BS)	5	-	-	-	-	
					liquid-smoking1, 10% (BS)	5	-	-	-	-	
Goulas and Kotominas (2005)	<i>Scomber japonicus</i>	Brine-salting (125 g/l, ratio 1:1 w/v)	2	8 + 1	Hot-smoking (%50 smoke)	0.5	70 + 1	77.58	-	-	
Montero et al. (2003)	<i>Salmo salar</i>	Dry-salting	12	12 + 1	cold-smoking (DS)	2.5	20 + 1	-	62.3 + 1.7	30-32	
		Brine-salting (360g/l, ratio 50/50 w/w)	6	12 + 1	cold-smoking (DS)	2.5	30 + 1	-	63.9 + 1.2	36-37	
					cold-smoking (BS)	2.5	20 + 1	-	66.0 + 1.6	27-28	
					cold-smoking (BS)	2.5	30 + 1	-	64.4 + 0.9	33-35	
Cardinal et al. (2001)	<i>Salmo salar</i>	Dry-salting	6	12 + 1	cold-smoking, beech (DS)	2.5	20 + 1	90.9-91.9*	-	-	
		Brine-salting (360 g/l, ratio 50/50 w/w)	6	12 + 1	cold-smoking, beech (DS)	2.5	30 + 1	92.7-93.1	-	-	
					cold-smoking, beech (BS)	2.5	20 + 1	94.15-94.6*	-	-	
					cold-smoking, beech (BS)	2.5	30 + 1	94.9-95.0	-	-	
Sigurgisladottir et al. (2000)	<i>Salmo salar</i>	Dry-salting	6	12 + 1	cold-smoking, beech (DS)	5	20 + 1	91.1-92.2	-	62-65	
		Brine-salting (360 g/l)	6	12 + 1	cold-smoking, beech (DS)	5	30 + 1	92.7-93.1	-	70-74	
					cold-smoking, beech (BS)	5	20 + 1	94.2-94.6	-	69-71	
					cold-smoking, beech (BS)	5	30 + 1	95.0	-	65-76	

¹Composition: pH, 2.7; phenol level, 12–24 mg/g; carbonyl level, 14–25 mg/100 ml; acids, 11–12%; benzo(a)pyrene, <10 ppm; *Preferred from a sensorial point of view;

² Calculated taking the first clean fillet weight as the initial measurement; WB, Warner-Bratzler; DS, Dry-smoked; BS, Brine-smoke

solubility. Hultmann and Rustad (2004) and Carton et al. (2009) suggest that the conformation of the myofibrillar proteins may change as a result of the increased salt content of the muscle rendering the proteins more susceptible to attack by endogenous proteases.

Birkeland et al. (2004) and Gallart-Jornet et al. (2007b, 2007c) report that fillets subjected to dry salting show a significantly higher total liquid loss than fillets subjected to brine salting. However, brine salting shows great water losses and smaller water phase in protein matrix when saturated brine (25% w/w) is used (Barat et al. 2002). This lead to a lower water holding capacity, comparing with less saturated brines (20% w/w) and important changes in texture (Sannaveerappa et al. 2004, Thorarinsdottir et al. 2004). In fact, Instrumentally measured texture parameters (Force, Area) show an exponential increase with respect to the NaCl concentration in the liquid phase (Barat et al. 2002). Sigurgisladottir et al. (2000) report the shear force required for cutting dry salted fillets to be lower than that required to cut brine-processed fillets, for certain fish species and in a season dependent way. Nevertheless, most authors (Birkeland et al. 2004, Gallart-Jornet et al. 2007b) describe harder textures in fish treated with saturated brines and even harder for dry-salted fish fillets. Texture of fish is related to the diameter of the muscle fibers: smaller diameters and higher number of fibers give harder textures and larger diameters but less number of fibers, softer (Hatae et al. 1990). The greater reduction of the cross sectional area in dry-salting processes has been suggested as the reason for their firmer texture when comparing them with the not saturated brine-salted ones. However, fish texture is known to be a multifactorial quality in which fiber size is not necessarily the major determinant (Johnston et al. 2006, Morkore et al. 2009).

Cardinal et al. (2001) reported that dry and brine salting have little effect on the sensorial properties of salmon. However, Birkeland et al. (2003) indicate dry salting to be a 'more gentle' curing method that helps retain the intactness of the fillet surface and its colour - important consumer quality criteria. Moreover, Gallart-Jornet et al. (2007b) report dry-salted fillets and the more saturated brines salted

ones to show significantly greater firmness and less elasticity than low concentrated brine-salted fillets. The same tendency is observed when comparing early and last salting stages with saturated brines. Finally, several authors (Aubourg and Ugliano 2002, Guillen et al. 2004, Goulas and Kontominas 2005, 2007, Yanar et al. 2006, Alfonso and Sant'Ana 2008) report that the contact of the salt with the flesh enhances lipid oxidation. Some studies have shown that the stimulation of lipid oxidation occurs through the activation of iron. Sodium ions displace the iron from macromolecules such as myoglobin, increasing the availability of the latter for the catalysis of lipid oxidation (Thiansilakul et al. 2010, Kashiri et al. 2011). Several authors indicate that brine salting offers the major advantages of preventing rancidity by precluding contact with the air and of affording a higher weight yield caused by the uptake of water (Andrés et al. 2005, Gallart-Jornet et al. 2007b,c). However, Muratore et al. (2007) indicates brine-salted liquid-smoked salmon to have poorer sensorial qualities, as judged by a tasting panel. Moreover, the soluble component of the fillets can leach out during brine salting (Larsen et al. 2007). Thus, brining may have economic advantages such as increasing the yield but nutritional components are lost from the flesh during the process (Larsen et al. 2008).

Salting has a noticeable preservative effect. This is mainly due to the reduction in water activity and the consequent prevention of the growth of many spoilage microorganisms, along with the formation of a more membranous surface which further inhibits microorganism growth (Muratore et al. 2007, Frangos et al. 2010).

Smoking

Smoking is a centuries-old food preservation technique, but nowadays fish products are mainly smoked because of the attractive flavour and colour this process confers upon them (Guillen and Manzano 1996). It is well known that smoking food enriches it in the aromatic compounds contained in the smoke. Processes of adhesion, condensation,

diffusion and/or absorption occur between the food and the smoke. As a consequence, generally desirable changes occur in the colour, taste, texture and composition of the food. These changes vary depending on the composition of the smoke or smoke flavouring used, the composition of the food itself, and the conditions under which either type of smoking is undertaken (Toth and Potthast 1984) (Table 1).

The treatment of salmon with liquid smoke leads to changes in its physicochemical and sensorial attributes, depending on the composition of the liquid flavouring (and therefore on the type of wood originally used to produce it) (Toth and Potthast 1984). Guillén et al. (2005) reported liquid beech and oak flavours to generate different fish headspace compositions and, therefore, different flavours in salmon flesh. The headspace of salmon smoked with liquid oak smoke is richer in phenol derivatives than samples smoked with liquid beech smoke.

Little attention has been paid to the physicochemical attributes of fish treated with liquid smoke. Bugueño et al. (2003) reported that salmon treated in this way showed no significant changes in any of the chemical or physical variables they investigated (pH, total volatile nitrogenous bases, etc.). However, Martinez et al. (2007a, 2009) reported changes in non-protein nitrogen, proteins, and in the fat and moisture contents. These authors used two liquid smokes of different composition to smoke salmon, one rich in phenolic compounds, the other rich in carbonyl compounds. The fish treated with the latter showed larger quantities of non-protein nitrogen and smaller quantities of protein (both sarcoplasmic and myofibrillar), fat and moisture.

It should be remembered that the sensorial attributes of a food are vital for consumer acceptance, and this may be no more true than with smoked foods. The following lines indicate the changes these attributes may undergo in salmon treated with liquid smoke.

The aroma and flavour of smoked foods are mainly owed to volatile compounds in the liquid smoke adhering to the flesh. Of special importance are phenolic compounds such as syringaldehyde

and coniferaldehyde, which are strongly retained by food and intensify the aroma of smoked fish very well (Varlet et al. 2007b). Their adhesion also prevents them from being lost over time by evaporation (Guillén and Manzanos 1996)

The aroma of liquid-smoked salmon depends on the type of liquid smoke used, the surface composition of the fish, and the conditions under which the treatment is performed (Sérot et al. 2004). The volatile aldehydes responsible for the aroma of smoked fish are generated by two main pathways: the Maillard reaction (i.e., interactions between smoke carbonyl groups and food amino groups), which provides smoke aromas, and lipid oxidation, which provides fishy aromas (Varlet et al. 2007b). The compounds making up the aromatic profile of liquid-smoked salmon are different to those associated with traditional smoking; derivatives of pyridine have been detected, along with the products of lipid oxidation (Varlet et al. 2007c, 2007d). Cardinal et al. (1997) reported that, depending on the type of liquid smoke used, the products of lipid oxidation may be so abundant as to mask the product's own fishy odour.

Guaiacol and its derivatives have been described responsible for the 'smoked' taste and syringol and its derivatives for the smoked smell. Other compounds mainly associated with this smoke aroma and flavour include phenol, p-cresol, o-cresol, guaiacol, 4-methylguaiacol, 4-ethyl guaiacol, eugenol, 4-propylguaiacol, and isoeugenol (Sérot and Lafficher 2003, Varlet et al. 2006, Varlet et al. 2007a). The final aroma of the salmon is, however, a product of a much more complex mix of compounds (Daun 1972, Maga 1987).

The taste of liquid-smoked salmon is also very different to that produced by the traditional technique, especially its in terms of the descriptor "salty" (Varlet et al. 2007c). This could mean that liquid smoke, as well as generating aromas, is involved in physical interactions that influence saltiness.

The conspicuous pink coloration of salmonid fish flesh is owed to carotenoid pigments, notably astaxanthin (3,3'-dihydroxy- β,β -carotene-4,4'-dione) and canthaxanthin (β,β -carotene-4,4'-dione), that the fish accumulate through their diet (Choubert et al. 2005,

Rora et al. 2005, Webb et al. 2007). After smoking, the colour of fish flesh can vary depending on the pigments present, the quantity and composition of smoke deposits, and the interactions between these and the flesh (Sirkoski et al. 1998). However, the colour of the product is mainly due to Maillard-type reactions (Ruiter 1979). Oily fish commonly go browner because of a reaction between proteins or amino acids and the carbonyl derivatives of lipids. This reaction is influenced by the same factors that influence lipid oxidation (temperature, oxygen water activity, and the presence of oxidants and antioxidants). In salmon, non-enzymatic browning caused by Maillard-type reactions typically occurs at high water activities, while at low water activities browning is usually caused by the above protein-lipid derivative interactions. The two types of reaction can, in fact, inhibit one another.

Toth and Potthast (1984) and Cardinal et al. (2004) indicate colour development to depend mainly on carbonyls, while the flavour in their samples was largely owed to the type and quantity of phenolic compounds present. Martinez et al. (2007a) reported a strong colour intensity in salmon smoked with liquid smoke rich in carbonyl compounds. However, Daun (1972) indicate that certain high molecular weight phenols in the smoke vapour phase contribute to the colour of the product. These phenolic compounds would appear to have sufficient hydroxyl groups to be able to enter into lattices (via hydrogen bonding) with collagen at multiple sites. Volatile aldehydes such as coniferaldehyde and syringaldehyde give rise to orange colours in liquid-smoked fish (Clifford et al. 1980).

One of the most important quality characteristics of fish flesh is its muscle texture. In traditional hot-smoked foods, texture changes are mainly owed to the denaturing of proteins by heat (Gill et al. 1992), while in liquid-smoked fish it is mainly a consequence of the action of endogenous proteases hydrolysing the proteins more easily given the latter's salt-induced changes in conformation (Hansen et al. 1996, Lund and Nielsen 2001, Hultmann et al. 2004).

Some authors report an increase in the firmness of traditional cold-smoked fish (Sigurgisladdottir et al. 2000, Birkeland et al. 2004) – an increase that

is greater when the temperature reaches closer to 30 °C than 20 °C (Gómez-Guillén et al. 2000, Hultmann et al. 2004).

The water content of fish flesh strongly influences its texture (Rongrong et al. 1998), with lower water contents producing firmer products. Montero et al. (2003) showed the water content of salmon fillets to be reduced after traditional cold smoking. Martinez et al. (2007a), working with salmon smoked with liquid smoke, reported a reduction in the water content and an increase in its hardness, fracturability and cohesiveness, especially if the liquid smoke was rich in carbonyl compounds. Thus, the components of the smoking liquid also influence the textural quality of smoked foods (Daun 1972, Sink and Hsu 1981). Hassan (1988) showed that smoking causes a reduction in flesh pH, perhaps due to smoke acid absorption, a loss of moisture and the reaction of phenols, polyphenols and carbonyl compounds with proteins, SH groups and amino groups respectively.

Finally, it should be remembered that the one of the major problems faced in the marketing and distribution of smoked seafoods is their perishability and hygiene, i.e., contamination by spoilage and pathogenic microorganisms. When foods are rejected on the grounds of their sensorial properties it is reasonable to assume them to be contaminated by both types. Nevertheless, it is not always true. Sometimes developing of off-odours or off-flavours occurs when hygienic quality is still between acceptable margins (Gomez-Guillén et al. 2009). Some other times, a product is accepted, attending to sensorial criteria even when spoilage bacterial growth is already too high (Jorgensen et al. 2001) or the product is not acceptable from a safety perspective (Gram 2001a, 2001b, Dressler 2005).

The initial bacterial load of fish living in temperate waters is dominated by Gram negative organisms – psychrophilic bacilli of the genera *Pseudomonas*, *Alteromonas*, *Moraxella*, *Acinetobacter*, *Flavobacterium* and *Vibrio*. However, after capture and handling, qualitative and quantitative changes in this initial flora can occur, and great variation in microorganisms and their numbers have been reported in salmon from different smoking facilities. This variability is due to differences in the

raw material and processing variables (Hansen et al. 1998).

Generally, the vacuum packaging of smoked salmon inhibits the growth of *Pseudomonas* and favours the proliferation of *Shewanella putrefaciens* plus organisms such as *Photobacterium phosphoreum*, both of which are tolerant to CO₂ and psychrotrophs (Gram et al. 2002). Lactic acid bacteria and members of *Enterobacteriaceae* are the largest group spoilage organisms affecting traditional cold-smoked salmon (Rachmana et al 2004, Gram and Huss 1996).

Authors working with liquid-smoked salmon that was later vacuum packed and stored refrigerated reported smoke concentrates to have a certain antibacterial action. A shelf-life of 25–45 days has been estimated for salmon processed this way (Table 2). Indeed, both the phenolic and carbonyl fractions show antimicrobial properties (Maga 1987, Painter 1998, Suñén 1998, Suñén et al. 2001, Suñén et al. 2003). However, liquid smokes with a low pH and a high carbonyl content are those with

the greatest antimicrobial potential against both Gram negative and positive organisms (Milly et al. 2005). Martinez et al. (2005) reported that a liquid smoke flavouring rich in carbonyl compounds had greater antimicrobial activity than another rich in phenolic compounds.

With respect to pathogenic bacteria, the greatest risk is posed by the growth of *Listeria monocytogenes* (Gram 2001b, Ward 2001) since it can grow at low temperature and in high salt concentrations. However, good manufacturing practices and adequate storage can eliminate this risk (Autio et al. 1999, González-Rodríguez et al. 2002). Spoilage organisms can act as a barrier to the entry of possible pathogenic species (Giménez and Dalgaard 2004, Tome et al. 2006), and strains of *Carnobacterium* are being studied for their possible use as bioprotectors against *Listeria monocytogenes* in smoked salmon (Connil et al. 2002, Brillat 2004, Nilsson et al. 2004, Brillat et al. 2005).

Table 2. Shelf-life of smoked Atlantic salmon (*Salmo salar*) treated with liquid smoke flavourings.

Authors	Smoking method	Storage conditions	Criteria	Shelf life
Martinez et al. (2010)	Liquid smoking: Scansmoke, Broste A/S (high phenolic content)	vacuum-packed refrigerated storage	sensory	30 days
Bikerland and Skara (2008)	Liquid smoking (Smoke 5096 Salmon Smoke)	vacuum-packed refrigerated storage	sensory	< 31 days
Martinez et al. (2007a,b)	Liquid smoking: a) Scansmoke, Broste A/S (high phenolic content) b) AFS-10 SOL, Amcan Ingredientes (high carbonyl content)	vacuum-packed refrigerated storage	sensory	a) 32 days in vacuum-packed refrigerated storage b) 45 days in vacuum-packed refrigerated storage
Bugueño et al. (2003)	Liquid smoking: 5 BF 4046 (Taberner, S.A., Spain)	a) vacuum-packed refrigerated storage b) modified atmosphere, refrigerated storage	microbial growth	25 days
Leroi and Joffraud (2000)	Cold smoked:a) 2% NaCl (w/w) and 0.8 mg phenols/100g or, b) 3% NaCl (w/w) and 0.45 mg phenols/100g	vacuum-packed refrigerated storage	sensory	28 days

Conclusion

Dry salting is the best method for salting salmon to be liquid smoked; this technique reduces economic and nutritional losses. Dry salting and treatment with liquid smoke flavouring can help improve the physiochemical and sensorial characteristics of salmon better than dry or brine salting followed by traditional smoking. Autolytic deterioration and the growth of spoilage bacteria would appear to be similar in both types of product. The microbiological quality of salmon liquid-smoked with flavourings rich in carbonyl compounds would appear to be better than that achieved with flavourings rich in phenolic compound.

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