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Review

The microbiology of cold smoked salmon

Trond Løvdal*

Nofima – Norwegian Institute of Food, Fisheries and Aquaculture Research, Department of Process Technology, N-4068 Stavanger, Norway

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ABSTRACT

Concurrent with the growth of aquaculture salmon farming, there is a corresponding increase in the commercial production of cold smoked salmon (CSS). The definition of CSS is vague, but it is normally made from salmon fillets with low levels of salt (<6% in the water phase) subjected to traditional wood smoking for prolonged periods, but not exceeding 25–30 °C during the process, or subject to artificial smoke flavoring by the application of liquefied smoke preparations formulated from condensation of wood smoke and either water, oil, or emulsifiers as e.g. polysorbate. The present review summarizes recent literature with respect to microbiological quality and safety of modern, commercial CSS, including factors controlling these parameters, and emerging trends and risk analysis measures to improve them. Special weight is put on the use of salt and alternative organic salt formulations, their combination, and use in hurdle technology to improve the safety of CSS, which is in turn primarily dictated by the pathogen *Listeria monocytogenes*, but also *Clostridium botulinum*, and their growth potential related to their salt and temperature tolerance. The microbiological quality and shelf life of CSS is, dependent on packaging method and storage temperature, determined mostly by the presence of lactic acid bacteria and the primary spoilage bacteria *Shewanella putrefaciens*, *Photobacterium phosphoreum*, *Pseudomonas* spp., and marine *Vibrio*. Additionally, parasites and microbiologically derived biogenic amines relevant to CSS are briefly discussed.

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* Tel.: +47 51 84 46 80.
E-mail address: trond.lovdal@nofima.no.

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1. Introduction

Smoking is besides drying one of the oldest methods of preserving fish. There are fundamentally three stages of the cold smoke processing which contribute to the preservative effect; salting, dehydration and smoking. Salting and dehydration (the latter is a direct effect of smoking) lowers the water activity (a_W), thereby inhibiting the growth of bacteria and mould, which generally cannot grow at a_W lower than 0.86 in the presence of soluble salt (Sperber, 1983). In addition, the chlorine ions are toxic for some microorganisms. The bacteriostatic effect of smoke is mainly due to phenols. The mild temperatures applied for cold smoking (20–30 °C) does not kill the microflora.

Cold smoked salmon (CSS) is characterized by specific chemical properties, often based on the French standard NF V45-065; i. e. lipid <18% (w/w), water content <74%, a NaCl concentration of between 2.5 and 3.5% (w/w), and smoke treatment corresponding to 0.6 mg of phenol per 100 g of product (Leroi, Joffraud, & Chevalier, 2000, 2001). CSS are therefore classified under lightly preserved fish products (LPFP) which include fish products preserved with low levels of salt (<6% NaCl (w/w) in the water phase) and the addition of preservatives such as sorbate, benzoate, NO_2 or smoke for some products. These products have a high pH (>5.0), they are often packed under vacuum and must be stored and distributed at cool temperatures (≤5 °C). pH in CSS varies between 6 and 6.3 (Gram, 2001b). CSS is considered a delicacy commonly consumed as a 'ready-to-eat' (RTE) product without heat treatment (Gram & Huss, 1996).

CSS, as other cold smoked fish products, are often consumed as RTE with no heat treatment, although it is also suitable as a cooked ingredient in for example various casserole dishes. Anyway, the absence of thermal treatment makes the parameters salting and smoking utmost important in order to minimize the risk of foodborne hazards and spoilage. Salting and drying (also as an effect of smoking) are crucial steps to achieve the ideal water phase salt (WPS) level. Drying times, after salting, range from 1 to 6 h at 20–28 °C, smoking parameters at a maximum of 30 °C ranges from 3 to 6 h, and the recommended smoke chamber temperature combinations must not exceed 32 °C for more than 20 h, and 10 °C for more than 24 h (Anonymous, 2001b). Salt can be applied in dry form (dry salting), as brine, or by injecting brine. When liquid smoke (LS) is utilized as an alternative to traditional generated wood smoke, this is normally injected, sometimes combined with the brine, to achieve smooth and even colouring of the product.

Table 1 lists some previous reviews considering the microbiology of CSS and closely related topics. Since the seminal paper of Huss, Benembarek, and Jeppesen (1995), there have been few updates on the microbiology issues of CSS. Arguably, some more recent reviews exists, as for example Sikorski and Kolodziejska (2002), Rosnes, Skåra, and Skipnes (2011), and Arvanitoyannis and Kotsanopoulos (2012), but these are generic papers not specific for CSS and/or the cold smoke process, and thus less practical and accessible to those genuinely interested in CSS. There has been a lot of progress since the Huss et al. paper in 1995, and it is now time for an updated review on the microbiology of CSS. Especially with the emergence of modern packaging technology, and the increasing interest in the use of organic salts as a substitute or complement to NaCl, a summary of the literature from the last two decades is pertinent. The present review also discuss the emerging trends of high pressure processing (HPP) and the use of bacteriocins, which once were seen as promising, but have not been much practically implemented by the industry. Also new aspects of risk analysis are discussed. Parasites and biogenic amines are included as part of the 'microbiology' term, but the nutrition and sensory aspects of CSS is not covered by the present review.

2. Microorganisms in cold smoked salmon

Spoilage of fresh and readily preserved fish products is caused by microorganisms. Regarding bacteria, separation is made between i) spoilage bacteria, which in itself is not necessarily harmful to the consumer, but which degrade the product (taste, smell, colour, consistency) and thus restricting its shelf life. In addition, ii) pathogenic microorganisms that may be present in such small amounts that it does not lead to a directly observable effect (taste, smell, colour, consistency) of the product, but as by ingestion of minute quantities may still cause food poisoning and even death (Peck, 2006).

The main factors for bacterial contamination of seafood are contamination of the raw material from the environment and from the processing, and bacterial growth conditions (temperature, a_W, pH, microbial interactions, etc.). The specific factors those are relevant for CSS are discussed in more detail in Section 3.

2.1. Spoilage bacteria

The microbial spoilage flora in LPFP is poorly characterized, but several studies have shown that the microflora in this type of

Table 1
Some relevant review papers concerning the microbiology of CSS and closely related topics, sorted by publication year.

Reference	Title
Southcott and Razzell (1973).	*Clostridium botulinum* control in cold-smoked salmon: A review
Ben Embarek (1994).	Presence, detection and growth of *Listeria monocytogenes* in seafoods – a review
Huss et al. (1995).	Control of biological hazards in cold smoked salmon production
Duffes (1999).	Improving the control of *Listeria monocytogenes* in cold smoked salmon
Rørvik (2000).	*Listeria monocytogenes* in the smoked salmon industry
Ross, Dalgaard, and Tienungoon (2000).	Predictive modelling of the growth and survival of *Listeria* in fishery products
Gram and Dalgaard (2002).	Fish spoilage bacteria - problems and solutions
Sikorski and Kolodziejska (2002).	Microbial risks in mild hot smoking of fish
McLauchlin et al. (2004).	*Listeria monocytogenes* and listeriosis: a review of hazard characterisation for use in microbiological risk assessment of foods
Peck (2006).	*Clostridium botulinum* and the safety of minimally heated, chilled foods: an emerging issue?
Hong, Jie, and Donghua (2008).	Potential hazards in smoke-flavored fish
Adzitey and Huda (2010).	*Listeria monocytogenes* in foods: Incidences and possible control measures
Leroi (2010).	Occurrence and role of lactic acid bacteria in seafood products
Rosnes et al. (2011).	Recent advances in minimal heat processing of fish: Effects on microbial activity and safety
dos Santos and Howgate (2011).	Fishborne zoonotic parasites and aquaculture: A review
Arvanitoyannis and Kotsanopoulos (2012).	Smoking of fish and seafood: History, methods and effects on physical, nutritional and microbiological properties
Tusevljak et al. (2012).	Prevalence of zoonotic bacteria in wild and farmed aquatic species and seafood: A scoping study, systematic review, and meta-analysis of published research
Tocmo et al. (2014).	*Listeria monocytogenes* in vacuum-packed smoked fish products: Occurrence, routes of contamination, and potential intervention measures
Jami et al. (2014).	*Listeria monocytogenes* in aquatic food products-a review