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FACTORS AFFECTING SMOKED FISH QUALITY: A REVIEW

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Abstract
Smoked sprats (*Sprattus sprattus balticus*) from the Baltic sea are one of the most popular processed fish products in Latvia. The amount of catching and demand is annually increasing. For producers, it is important to provide stable quality throughout the year, which sometimes is challenging due to many factors. Smoked fish quality depends not only on the seasonality, but also on the applied technologies. The aim of the current study was to review research findings about factors affecting the smoked fish quality. The databases of Science Direct, Web of Science, Wiley Online Journals and Google Scholar were searched. The first parameter that affects quality of fish till processing is raw material, its catching place and season, as well as whether it is fresh or frozen fish, that includes not only microbiological parameters, but also physical and chemical changes in fish depending on the storage conditions. The second parameter is the applied pre-treatment methods (using salt, acids) before processing, which can improve fish texture and make better result for smoked fish. The third parameter is the used technology for the fish processing, heat treatment methods use of wood chips or liquid smoke, or adjustment of smoking conditions. These all together make a lot of sensorial and textural changes in the final product. If any of these parameters is changed during processing, they can affect the smoked fish quality. Therefore, to ensure constant quality of smoked fish, in-depth knowledge of parameters is extremely important.
Key words: pre-treatment, smoked sprat, seasonality, fresh and frozen sprats, smoking.

Introduction

Each year catching amount of sprats (*Sprattus sprattus balticus*) is increasing because of increased consumption of fish products. Besides the increased consumption, customers pay more attention to the quality – sensory parameters including textural parameters (consistency, juiciness) as well as nutritional components (lipids, protein). Fish consumption has a positive effect on human health. It is nutritionally valuable product, and good source of protein; it also contains valuable lipids (omega-3 fatty acids), minerals and vitamins (Mohanty *et al.*, 2019). Fish lipids contain polyunsaturated fatty acids (PUFA) with up to 6 double bonds - eicosapentaenoic acids (EPA) and docosahexaenoic acid (DHA) (Stołyhwo, Kołodziejska, & Sikorski, 2006).

Sprats are small commercial fish from *Clupeidae* family and their size from the sea is about 10–20 cm. They live in shoals and feed on zooplankton, spawning season usually varies depending on a geographical location, but in the Baltic sea it is from March till June (Timberg *et al.*, 2014). Sprats contain a lot of water (57–73%) and lipids (10–24%). There is inverse relationship between water and lipids, which means that lower water content makes higher lipid content and contrary (Timberg *et al.*, 2011). Sprats are rich in vitamin D, minerals like potassium, iron, zinc, iodine (Usydus, Szlifder-Richert, & Adamczyk, 2012). Baltic sprats are rich source of PUFA and stability of these fatty acids is influenced by the storage conditions and pre-treatment methods.

Raw product quality is the main parameter, which affects finished products quality. Fish is easily spoiled due to oxidation and developing off-flavours. Cooling can maintain freshness, but it does not eliminate microorganisms or enzymatic activity, the psychotropic bacteria will still live under chilled conditions (Wu, Pu, & Sun, 2019). As quality changes along the year, it is important to find the main technological parameters, which should be adjusted to ensure constant quality of the final product.

The aim of the current study was to review research findings about factors affecting the smoked fish quality.

Materials and Methods

The research was performed by using monographic method to review factors influencing smoked fish quality. The databases of Science Direct, Web of Science, Wiley Online Journals and Google Scholar were searched. No time restrictions were applied, and all articles were selected in January – February, 2020. The aim of the current study was to review research findings about factors affecting the smoked fish quality parameters, which can affect the quality of the product, find out the main quality parameters, and determine how to ensure the constant quality using some pre-treatment methods or selecting the most appropriate heat treatment method.

Results and Discussion

The smoked fish quality depends on various factors, which can be grouped as shown in Figure 1. To provide constant quality of the finished product all parameters should be considered and necessary adjustments made in the processing technologies.

Raw material

The raw material quality is the main factor affecting smoked fish quality. Raw material quality has intrinsic factors like size, fat content and skin properties, that

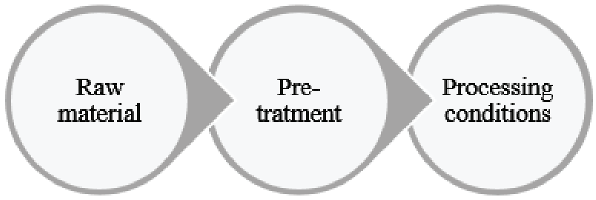

Figure 1. The main factors affecting smoked fish quality.

mean small fish like sprats spoil faster than large fish (Zugarramurdi *et al.,* 2004). Quality parameters are affected by seasonality, sex, age, and geographical location, these all make changes in fish lipids and proteins (Abbas *et al.,* 2008). Sprats are fatty fish and valuable dietary source of proteins, polyunsaturated fatty acids from n-3 family. Cooling or transporting conditions have great influence on processed fish quality. Fatty fish does not store as long as lean fish in aerobic conditions, because of fat oxidation processes. They also have higher influence on the quality of final products (Zugarramurdi *et al.*, 2004). There are no correlations established between lipid oxidation and content of lipids in thawed fish. Temperature and some smoke compounds can affect fish lipids and proteins (Kołodziejska & Sikorski, 2004).

According to Timberg *et al*. (2011) in spring, when is spawning season, the Baltic sprat lipid content was low 13 ± 1.6%, but in autumn, end of feeding season (October, November) the highest 22 ± 3%. Similar trend was reported by Usydus, Szlifder-Richert, Adamczyk (2012), see Table 1. Protein was stable through seasons, being about 15%. That means that autumn sprats (the end of feeding season and all wintering season) have the highest lipid content, but in spring (spawning season) – the highest water content. In spring and summer, the content of lipids is the lowest and it has influence on the textural and sensorial properties. It makes changes in sensorial parameters − less intense aroma and flavour and makes softer texture (Timberg *et al*., 2011). Additionally, it has been reported that proximate composition and fatty acids profile in muscle depend on seasonality of Baltic sprats. Fish up to 10 cm have different indicators than class 10−13 and over 13 cm (Usydus, Szlifder-Richert, & Adamczyk, 2012).

Raw material freshness and quality of the finished product have close relationship. For all fish products, its freshness has the most essential role. It includes shelf life of fish, bacterial flora, and storage conditions. Abbas *et al.*, (2008) reported that pH of European sea bass (*Dicentrarchus labrax*) increased from 6.39 till 6.69, trimethylamine − N (from trimethylamine volatile basis) from 0.20 till 1.25 N 100 g^{-1} flesh, total volatile basic − N from 17.22 till 30.58 mg N 100 g^{-1} flesh, free fatty acids from 1.78 till 2.73 g oleic acid per 100 g lipids, but content of trimethylamine oxide decreased from 22.08 till 12.55 mg N 100 g^{-1} flesh during storage period from 1 till 22 days in ice. Initial pH decrease occurs because glycogen in the fish muscle has been metabolized to lactic acids. Fresh live fish pH is 7, and during further storage it increases

Table 1

Proximate nutritional composition in muscle of Baltic sprat depending on catch season

(Usydus, Szlifder-Richert, & Adamczyk, 2012)

Indicator	Feeding season (July − October)	Wintering season (November − February)	Spawning season (March − June)
Moisture, %	66.40 ± 1.69	70.71 ± 2.43	77.48 ± 1.81
Protein, %	17.06 ± 0.46	16.74 ± 0.41	16.61 ± 0.33
Lipid, %	15.46 ± 2.02	11.34 ± 2.07	5.10 ± 0.87
Saturated fatty acids, %	28.37 ± 0.24	29.08 ± 1.55	28.64 ± 2.12
Monounsaturated fatty acids, %	32.78 ± 1.07	31.56 ± 5.96	35.63 ± 4.41
Polyunsaturated fatty acids%, including:	38.85 ± 0.96	39.28 ± 4.73	35.75 ± 2.36
-eicosapentaenoic acid, %	8.40 ± 0.65	8.05 ± 1.42	4.97 ± 1.29
-docosahexaenoic acid, %	17.67 ± 0.69	18.17 ± 2.20	17.93 ± 1.18
Individual weight, g	12.48 ± 2.87	12.38 ± 4.03	12.00 ± 1.93

because of production of alkaline enzymes, and if fish spoiling starts, there can be an increase in total volatile basic – N. Abbas *et al*. (2008) suggest to use fish pH as an indicator of fish freshness.

Wild fish can be harvested by a large variety of methods. To control stress produced by these conditions, it is necessary to control mainly fishing method and time. Incorrect handling can determine the quality changes during storage. If fish are caught in a highly stressed state, their lactic acid produced in muscle combined with high muscle temperature results in a dull muscle, and it makes acidic or metallic aftertaste (Borderías & Sánchez-Alonso, 2011). In this case, *rigor mortis* proceeds faster and quality is lower. The stiff and rigid condition of muscle tissues is *rigor mortis*, it starts about 1 till 6 hours after death (Hamada-Sato *et al.,* 2005). If large fish are killed faster, stress is less and quality is better. Stress before catching and before death have effect on quality. From biochemical factors after catch, its muscle cells contain more lactic acids from anaerobic respiration and *rigor mortis* sets sooner. Post-mortem pH in fish flesh on fish catching vessels have the effect on texture of fish, in that case it is very important to make faster cooling on vessels (Zugarramurdi *et al*., 2004). Chilling rate has an important role in the final product quality and especially in texture. In highly stressed fish all muscles enter *rigor mortis* very quickly all fish go very stiff and difficult to process. Texture of stressed fish was softer during storage (Borderías & Sánchez – Alonso, 2011).

Spoilage of fish starts as soon as the fish die after fishing, and spoilage varies with species, handling methods, hygienic and chilling conditions and methods; there is an influence from microorganisms (Solanki *et al*., 2016). Thiobarbituric acid (TBA) and peroxide value (PV) are two commonly used parameters for the evaluation of lipid oxidation and decomposition of protein (Wu, Pu, & Sun, 2019).

High moisture content and nutrients in fish facilitate the growth of many microorganisms including pathogens (*Listeria monocytogenes, Escherichia coli, Salmonella* spp.), which can affect not only the fish quality, but also product safety. *Listeria* spp. and *Salmonella* spp. are naturally present in aquatic environment and their presence can be contaminated with already infected fish. *Escherichia coli* indicates poor hygiene conditions during storage or transporting (Eizenberga *et al*., 2015). As sprats are cold-water fish, they can carry *Shewanella putrefaciens* and can spoil faster than warm water fish. Storage conditions using 40% ice and 60% water or with additionally injected ozone can increase shelf life up to 13 – 16 days, but it is prolonged by 8 days when normal ice is used. Ozone and organic acids have natural antioxidants (Sampels, 2015b). Free histidine is generally found in fatty fish, red meat fish and *Enterobacteriaceae, Clostridium* and *Lactobacillus* produce histidine decarboxylase and for growing histamine forming bacteria most important is coliform bacteria. Histamine forming bacteria naturally exist on the gills and in salt water fish. Only rapid chilling after catch immediately can prevent forming of these bacteria, and enzyme, bacteria can be inactivated by cooking, but once histamine is produced, it cannot be eliminated by heating or freezing. Fish may contain pathogenic bacteria *Clostridium botulinum* (type E), *Staphylococcus aureus*, *Vibrio parahaemolyticus* and it grows in raw fish. Its growth is decreased in frozen fish, or in cold storage (0 till 4 °C) (Köse, 2010). In fresh fish (sprats) the histamine was detected from 5 samples in 3 samples when fish were smoked. And if in fresh fish amount of histamine were determined 1.4 till 5.2 mg kg^{-1}, in smoked it increased to 1.8 till 24.1 mg kg^{-1} (Pawul-Gruba, Michalski, & Osek, 2014).

Freezing and thawing of raw material

Freezing slows the biological, chemical, and physical deterioration of food, degradation of food quality (colour, texture, lipid oxidation, enzymatic activity). Quality loss in frozen fish has been attributed to protein denaturation, which correlates strongly with loss of sensory quality. During freezing microbiological growth is suspended, but not enzymatic activity (Ruiz-Capillas, 2000). Biological and chemical reactions such as enzymatic activity and lipid oxidation have significant impact on fish quality during long-term frozen storage. The total lipid and ash content vary with size and catching season of the fish. Storage time and temperature affect quality loss and the shelf life of fish, lipid content decreased from 9.72% till 7.20% in tilapia (*Oreochromis niloticus*) (Dawson, Al-Jeddawi, & Remington, 2018). Red muscles contain high levels of lipids and are sequentially subject to lipid oxidation. Trimethylamine oxides are found within the red muscle that can be enzymatically or non-enzymatically degraded, resulting in products such as dimethylamine and formaldehyde. Some researchers – Dawson, Al-Jeddawi, & Remington (2018) – found fatty acid (C16:1) decrease in meat fat during frozen storage, while no decrease in polyunsaturated fatty acids (PUFA). Peroxide value is an early indicator of oxidation.

Freezing preserves fish longer time, but it also may have negative effect on structural and chemical properties of muscle. The faster and more homogeneous freezing proceeds, the smaller ice crystals are made and it makes less textural damage to muscle fibre (Sampels, 2015b). Slow freezing can result in formation of big ice crystals, which can destroy cell membranes and it increases a risk of oxidation, texture damage and loss of water holding capacity. During frozen fish storage it is very important to keep stable temperature to prevent the growth of ice crystals (Sampels, 2015a). During thawing, ice crystals melt, and if formed intracellularly or around muscle tissue, moisture would remain within the fish. Water holding capacity is commercially very important to appearance and texture.

Frozen fish storage leads to reduction of protein extractability and reduction of water holding capacity. Freezing before smoking has small physicochemical characteristic on flesh. In frozen fish storage, the myofibrillar proteins can lead to denaturation in the functional properties of fish muscle proteins and make changes in texture due to the loss of water holding capacity. Protein denaturation reduces amount of soluble proteins. Freezing before smoking has a negative effect on fish flesh adhesiveness, cohesiveness (textural properties), smoke odour intensity and colour intensity (Martinez *et al.*, 2010). Generally, sprats made from frozen thawed raw materials has the same texture as the same product made from fresh sprats. However, it is possible that sprats made from frozen thawed fish had a tendency to be harder and sour, the rancid taste developed more rapidly than samples made from fresh fish. Freezing and thawing may damage the protein native structure making it susceptible to further reactions (Timberg *et al.*, 2014).

Pre-treatment methods

Preserving fisheries products for a long storage time can be done by either lowering water activity (a_w) or changing pH of products. Preservation can also be carried out by applying antibacterial activity of salt and smoke components. Pre-treatment methods have not only preservation options, but also provide better sensorial properties of products.

Salting is one of the traditional preservation processes, when salt works as preservative that penetrates the tissue. Salt separates water from fish and replaces it with salt. Thus, water concentration in fish decreases. During salting, water activity a_w can reach 0.8 to 0.7. (Many pathogenic organisms cannot survive these conditions. Salting protected chub mackerel from oxidation (Sampels, 2015a). Replacing NaCl to KCl as well as the addition of ascorbic acid to the brine solution decreased lipid oxidation in salted mackerel. Replacing sodium with potassium about 25% can reduce amount of sodium in human dietary, but sodium and potassium have similar properties. If the amount is more than 25%, it makes a bitter taste. The uptake of salt into fish muscle depends on salting procedure, salt concentration used in brine, fish species, size, thickness. Protein loss depends also on the salt content (Sampels, 2015a). The size, thickness of the fish, with or without skin and scales, if fish is or not in rigor mortis, the freshness of fish it all affects the ripening process. The ripening of salted fish is a biochemical process, where enzymes cause degradation of fish muscle compounds. If pH increases, the quality of fish decreases (Bonoco & Kurt Kaya, 2018). Salting preserves fish from decomposition and minimize oxidation of the lipids. It reduces moisture in fish muscle. During salting characteristic flavour and texture of finished products are developed.

Brine concentration and brining time affected the texture development. There is little information about salt concentration effect on the shelf life of smoked fish (Yanar, Çelik, & Akamca, 2006). The flavour, odour and texture changed during the storage at rates depending on the storage temperature. The higher salt concentrations prevented some growth of halophiles. Storage in lower temperature with higher salt concentration increased shelf life of brined anchovies (Karaçam, Kutlu, & Köse, 2002). The highest water content in canned catfish was in 3% brine solution. That means that the use of different brine concentration of solution has an effect on nutrient values (Herawati *et al.*, 2016).

Marinating preserves fish through the simultaneous action of salt and organic acids. Marinating is used to tenderize, change textural and structural properties of raw material. It increases ionic strength and decreases the pH, it also makes tender texture, better structural properties and changes the taste (Çağlak, 2015). Salt and acids diffuse into the fish muscle, denature the protein and lower the pH value and activating the lysosomal cathepsins, which makes typical flavour. Texture is very important quality parameter. Low pH induced protein denaturation and makes harder texture (Serdaroglu *et al.*, 2015). Marinating improves flavour and textural properties, it slows down the bacterial and enzyme activity and provides taste, tenderness, textural and structural changes. In marinating process relative amounts of fat, protein, ash increases, because of water loss by penetration of salt into meat. Containing 10% NaCl and 4% acetic acid can extend the shelf life of the product in refrigerated storage conditions (Pop & Frunză, 2015).

Application of salting or brining prior to smoking improves functional properties. Toughness and hardness are important textural attributes, and they depend on the connective tissue containing collagen, which is responsible for tensile strength and the myofibrils consisting of myosin and actin (Burgaard, 2010). Dhanapal *et al.* (2013) advised fish dipped in 10% salt concentration for 60 min were found improving the colour and textural quality based on sensory evaluation. Fish brined with 8−10% salt about an hour was sufficient to remove slime and harden the fish flesh. Brining 15 min in salt solution makes 1.1−1.6% as NaCl in finished product. Adding 25% calcium chloride to 75% NaCl for 3 hour provides a proper firm texture to the meat (Zakipour Rahimabadi

& Faralizadeh, 2016). Cooked fish usually tend to become soft in texture comparing with raw fish, because the heat induces the conversion of collagen to gelatin in fish flesh, and darkening of the fish muscle because of Maillard reaction (Dhanapal *et al*., 2013).

Processing conditions

Smoking creates new products with specific sensorial characteristics and texture. Already in ancient times smoking was used as a fish preservation method, which added not only specific flavour and colour to the product, but also it made smoke compounds work as antimicrobial agents (Tahsin *et al*., 2017). It is critical to understand the changes occurring in the fish, because it may reduce the quality in processing.

Hot smoking is carried out in several stages, when the temperature is increased from 40 till 100 °C, while in the product it reaches at least 85 °C. The content of polycyclic aromatic hydrocarbons (PAH) depends on temperature of smoke generation (Stołyhwo & Sikorski, 2005). The smoking itself also has a drying effect, and it decreases the water activity and increases inhibition of bacterial growth. Combination of liquid smoke with traditional smoke inhibited lipid oxidation (Sampels, 2015a).

Over 400 compounds identified in wood smoke, so far 40 acids, 22 alcohols, 131 carbonyls, 22 esters, 46 furans, 16 lactones and 75 phenols. Wood smoke contains also about 61 compounds of PAH (Stołyhwo & Sikorski, 2005). According to the report of the European Food Safety Authority (EFSA) beech (*Fagus sylvatica*) wood is the most common wood used for smoking food. All smoke compounds arise during the pyrolysis of the wood compounds, and are responsible for preservation and antimicrobial effect of the smoke. The typical smoke flavour is mainly related to the phenolic compounds in the smoke. The most active wood smoke compounds in traditional smoking are pyrogallol, resorcinol, 4-methylguaiacol, less active is syringol, guaiacol (Stołyhwo, Kołodziejska, & Sikorski, 2006). In liquid smoke, traditional compounds in smoke are syringol and cresols that give cold smoke sensory attributes. The content of syringol in hardwood smoke is higher than the content of guaiacol due to the different structure of lignin in hardwood and softwood (Hitzel *et al*., 2014). Toledo (2008) observed that some of phenols in smoke are similar to spices, eugenol like cinnamon, pepper, and nutmeg. The flavour of smoke components depends on concentration. Lingbeck *et al.* (2014) found the amount of phenols in liquid smoke condensates is about 9.9 till 11.1 mg mL^{-1}. Recommended amount to use liquid smoke varies from 0.4% till 4%. But smoke compounds depend on smoke generation (kind of wood, wood moisture, temperature, air quantity) (Sérot *et al*., 2009).

Smoking increases shelf life of fish due to dehydration; it has antimicrobial and antioxidant effects from the smoke components such as formaldehyde, phenols and carboxylic acids. Stołyhwo, Kołodziejska, & Sikorski, (2006) found out that due to phenols ring structure with conjugated double bonds, which are able to build stable radicals, the phenolic smoke compounds have antioxidative effects, but that effect has an influence from the extent of water loss in smoking process.

The smoking decreased the content of saturated fatty acids and increased content of PUFA. The higher PUFAs content can be explained by the fact that saturated fatty acids and mono unsaturated fatty acids are largely represented in neutral lipids and are more prone to migration from processing (Zakipour Rahimabadi & Faralizadeh, 2016). Stołyhwo, Kołodziejska, & Sikorski, (2006) found out that by using liquid smoke the values of peroxide and TBA are lower than in traditional methods. Dry salting with addition of sugar before immersion in a liquid smoke makes product with lower oxidation, lower hardness, elasticity value (Sampels, 2015a).

After smoking the amount of most important amino acids, glycine and alanine were reduced, but glutamic acid gave fish umami taste (Swastawati *et al.*, 2016).

Texture is also one of the important properties of thermally processed food. Heating decreased water holding capacity of the muscle which resulted in loss of the muscle tenderness (Dhanapal *et al.*, 2013).

Colour is formed when smoke and food components react chemically at the elevated temperature and the combination of cold staining and heat induced Maillard reactions take place. Maillard and Strecker aldehydes are largely responsible for colour in smoked fish. Colour varies from golden yellow to dark brown according to the nature of the wood and intensity of smoking process (Varlet, Prost, & Serot, 2007). Toledo (2008) researched, when the product is heated, the carbonyl compounds react with the proteins in a Maillard reaction to produce the brown colour. Cold smoked products do not change colour, because there are not enough phenols to produce a stain and the Maillard reaction does not proceed far enough to develop the colour (Toledo, 2008).

Liquid smoke is one of the methods, which is becoming popular nowadays. Liquid smoke is easy to apply and easy to control (Swastawati *et al.*, 2012). For the use of liquid smoke, simple equipment is required, and concentration of smoke compounds is controlled. The best use is from 1% till 5%. Liquid smoke has not only bactericidal, but also bacteriostatic effect, and together they act as synergic preservative. It can inhibit all pathogenic bacteria (i.e. *Escherichia coli, Listeria monocytogenes, Staphylococcus aureus*). As sprats belong to the *Clupeidae* family fish, there is naturally occurring histidine in fish flesh.

Fish meat contains very little connective tissue and high natural cathepsin enzyme, so it is very easy to be digested by that autolysis enzyme, which makes softer the meat and makes it a good source for the growth of microorganisms − pathogenic bacteria and histamine-forming bacteria. Total bacteria count should not exceed 5 × 10^5 CFU g^{-1} (Dien, Montolalu, & Berhimpon, 2019). The application of liquid smoke lowers pH (5.56−5.58), which is caused by organic acids of condensation in smoking process (Dien, Montolalu, & Berhimpon, 2019). The use of liquid smoke produces high quality smoked fish products, less moisture content, and lower salt, and microbiological parameters are better compared to the traditionally smoked fish products.

Conclusions

Raw material quality and its storage conditions are the important parameters for the smoked fish quality. Better raw fish quality can be provided, when reaching low storage temperature as fast as possible after catching. The selection of proper pre-treatment methods and technology can provide and ensure constant quality. Smoking conditions have a significant influence on the shelf life of product, and make changes in volatile compounds, and provide better sensory parameters and texture. Therefore, systematic research of factors and their combinations is necessary in order to achieve stable quality of smoked sprats (*Sprattus sprattus balticus*) from the Baltic sea.

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