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Factors Affecting the Quality and Consumption of Fish Meat

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ABSTRACT *Fish meat belongs to important and nutritionally valuable food of animal origin. Among animal origin food it occupies an important place due to its structure and favourable dietary and protective effects on human health. Its consumption in the Czech Republic (CR) is in comparison with other countries low and is not at the level recommended for prevention of serious diseases. Popularity of fish and fish products is slowly increasing. Good availability of fresh fish from our own production in the CR as well as sea fish imports, high level of hygiene of fish farming, methods of treatment and handling of fish and its processing affect the quality and sensory properties of fish meat.*

To the resulting quality of the fish meat from factory farms in the CR contributes the whole process of fish farming, reflecting the care of the fish during the entire breeding period up to the strict criteria for processing technologies. Excellent conditions for breeding and handling of fish during the entire period including the method of harvesting and handling prior to slaughter are later reflected in the sequence of post-mortem changes in the muscle after the fish slaughter and consequently affects especially the sensory properties, quality and shelf life of fish meat.

The quality and shelf life of fish meat, its sensory properties, such as appearance, taste and smell are important factors in increasing the popularity and representation of fish meat in our diet.

This study focuses on the factors that may influence higher interest and consumption of sea and freshwater fish from our own production in the CR.

INTRODUCTION

Cardiovascular disease (CVD) is a major cause of mortality and death in the United States (U.S.) and many other countries. Fish meat is due to its composition, dietary properties and content of long chain omega-3 (LC*n*-3) fatty acids, such as eicosapentaenoic acid (EPA; 20:5*n*-3) and docosahexaenoic acid (DHA; 22:6*n*-3), an important preventive factor in the prevention of these serious diseases (Raatz et al, 2013). The significance of fish meat and its importance in the diet is still at the forefront of the recommendations of nutritionists. Consumption of fish meat and its effects in the prevention of cardiovascular diseases and other civilization diseases, including the effects against the development of metabolic syndrome has been confirmed by numerous scientific studies, e.g. (Jarvinen et al, 2006, Streppel et al, 2008, Yamagishi et al, 2008, De Goede et al, 2010). Therefore, in order to increase interest in the fish meat, fish as food of animal origin and its muscle must meet strict hygiene criteria. *For increasing the* consumption of fish is also important good availability and variety of fresh fish throughout the year. There is evidence that insufficient consumption of fish meat and deficit of LC*n*-3) fatty acids leads to an increased risk and incidence of cardiovascular diseases - documented already in older studies, e.g. (Kromhout et al, 1985, Burr et al, 1989, Mozaffarian & Wu, 2011, Garaiova et al, 2013).

Consumption of Fish Meat

In comparison with the European average and dietary recommendations, the consumption of fish in the Czech Republic is still low and remains for a long time at approximately the same level - less than 6 kg/person/year, while the European Union per capita is 11 kg/person/year. According to the Czech Statistical Office (CSO) data on food consumption in 2010 is a long-term average fish consumption in the CR 5.4 kg/person/year, out of which the consumption of freshwater fish is 1.4 kg/person/year (Internet, 2012). Globally, the fish consumption is much higher and is estimated at 16 kg/person/year (Ježek et al, 2012). The CR does not belong to the seaside countries, where is traditionally high consumption of fish per capita. Higher fish consumption among the population of coastal states is given by the availability of a rich menu of fresh sea fish and regional customs and traditional cuisine with a different food composition.

In the CR is traditional breeding of freshwater fish. According to the data of the Ministry of Health Czech Republic (MHCR), before the year 2009 was produced in the Czech Republic 20 thousand tons of fish, of which over 8 thousand tons were delivered to the domestic market. Of the total production is traditionally most represented the common carp (Cyprinus carpio) that makes up 85% of the production, salmonids 4%, tench 1.4% and predatory fish around 1% (Ženíšková & Gall, 2009). According to Mareš, Kopp, and Brabec (2012), the consumption of fish meat keeps at the same level in comparison with the previous years; according to some sources it slightly rises. A certain proportion of the consumption of freshwater fish is also eating fish from recreational fishing, which is in our country a very popular and widespread sport.

Fish such as salmon, trout, mackerel, tuna, high in fat are also a rich source of LC*n*-3 fatty acids. According to the data of the Agriculture Research Service (2012), the content of omega-3 fatty acids varies in fish of different species and depends on the total fat content, habitat, breeding conditions and food resources (Vácha, 2012, Raatz et al, 2013).

According to the data of Vácha (2012**),** the content differs from 2% (gadid fish, pike, zander, perch), up to 10% (halibut, salmon, trout, carp, catfish), over 10% (herring, mackerel, sprat, eel). Cod contains up to 65% fat in the liver, in muscle tissue, however, only 0.4%. Lipids in fish are different from mammalian lipids. The fish lipids contain up to 40% of fatty acids with long chain with 14 to 22 carbon atoms - unsaturated fatty acids. Unlike fish oil, the fat of mammals rarely contains more than two double bonds in one lipid molecule, while fish oil contains several fatty acids with five or six double bonds (Vácha, 2012).

From the United States Department of Agriculture (USDA, 2010) data, the highest content of LCn-3 has the farmed At-

Volume : 3 | Issue : 9 | Sept 2013 | ISSN - 2249-555X

lantic salmon with 2.359 g total omega-3 content/100g fish meat, wild Atlantic salmon with 1.723 g total omega-3 content/100 g fish meat, mackerel 1.334 g total omega-3 content/100 g fish meat and white tuna 0.880 g total omega-3 conntent/100 g fish meat (Raatz et al, 2013).

Health and Protective Effects of Fish Consumption

Many studies demonstrate a direct link between consumption fish meal and a reduced incidence of cardiovascular diseases, e.g. (Kris-Etherton et al, 2002, Mozaffarian & Wu, 2011). Mozaffarian and Wu (2011) based on a study of the effects of omega-3 fatty acids on clinical effect in humans, and recommend in accordance with the USDA a dose of LCn-3 at least 250 mg/day or using fish oil twice a week. Their study confirmed that LCn-3 are bioactive compounds that reduce the risk of cardiac death. These results are also confirmed by other authors dealing with the combined effects of plant sterols with fish oil and B group vitamins (Garaiova et al, 2013).

The estimated average intake of LCn-3 (EPA, DPA and DHA) for Americans is 60–170 mg/day, mostly through fish consumption (Whelan et al 2009, USDA, 2012).

In the USA, no Dietary Reference Intake (DRI) for EPA and DHA exists (Trumbo et al, 2002), but there is a strong support for the establishment of a DRI of 250–500 mg/day of EPA and DHA for CVD risk reduction (Harris et al 2009, Kris-Etherton et al, 2009). The current Dietary Guidelines for Americans (DGA) recommendation for fish intake is at least 8 ounces per week (approximately 220 g) of cooked selected fish or seafood that is rich in omega-3 fatty acids. The estimated daily intake of EPA and DHA in the U.S. is, however, only 20% of the proposed DRI from 2009 (USDA, 2010).

Many studies deal with the preventive effects of eating fish meat and fish products to influence the incidence of cancers of the gastrointestinal tract. A study by Salehi, Moradi-Lakeh, Salehi, Nojomi, and Kolahdooz (2013), dealing with the connection between the consumption of different types of meat, including fish and the incidence of esophageal adenocarcinoma (EAC) has shown that decreasing the consumption of red and processed meat and higher portions of fish might reduce the esophageal cancer (EC) risk. On the contrary, consuming an increased amount of fish meat in comparison with other kinds has not confirmed increased the esophageal cancer risk.

The survey results of fish meat consumption in the Czech Republic showed that older people prefer traditional species of freshwater fish such as carp and trout (Ježek et al, 2012). This may be due to regional conventions, knowledge of culinary preparation in traditional Czech cuisine and good availability of fresh meat from local carp production. Popularity of fresh and frozen fish fillets in the younger generation may be related, according to the authors of this study, with the rapid pace of life, lack of time and a quick and easy kitchen preparation of filleted fish portions. Nowadays is available on the market a good year-round supply of fresh packaged and frozen freshwater fish from domestic production as well as sea fish imports.

How to Increase the Consumption of Fish

One of the criteria for promotion of increasing consumption of fish meat are its excellent sensory properties. These must be achieved by complex processes already during the life of fish in their breeding environment. It is primarily the quality and composition of the aquatic environment in the tank, the availability of natural food and feed composition (supplementary feed and the natural diet). The quality of the fish meat is also determined by the method of handling fish, manipulation during harvesting, transporting and finally the last stage - method of stunning and handling of fish just before slaughter and processing. All these processes are subject to strict criteria of production technology and fish processing and they are supervised by the State Veterinary Administration of the Czech Republic (SVACR). All these processes can significantly affect the sensory properties of fish meat and other parameters like freshness and sustainability of fish muscle and later onset of autolytic processes and post-mortem biochemical changes.

Wholesomeness of fish muscle is defined by the applicable veterinary-hygienic regulations.

In the Czech Republic, production technology must meet the legislative Regulation (EC) No 852/2004 of the European Parliament and Council on the hygiene of foodstuffs, Regulation (EC) No 853/2004 of the European Parliament and of the Council laying down specific hygiene rules for food of animal origin and Regulation (EC) No 854/2004 of the European Parliament and of the Council laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. The companies has produced a Hazard Analysis and Critical Control Point (HACCP) document that includes an analysis of potential risks during fish processing.

Taste Characteristics and thus the quality of fish meat for consumers significantly affects the composition of supplementary feed and location where the fish comes from. In countries such as Hungary, Slovenia, Serbia, Croatia or Romania are applied other methods of freshwater fish breeding technology than in the Czech Republic. These differences are given by different natural conditions, climate, temperature conditions, length of growing season and other individualities of the local natural environment

Fish Odour is a criterion that determines the popularity fish meat. The smell can be significantly affected by the environment in the breeding tank, but also by the type and composition of the feed in case of fish fed with the supplementary feed. It is known that a massive expansion of cyanobacteria of the Oscillatoriales class may be a problem of some natural water reservoirs. Filamentous cyanobacteria of the genus Oscillatoria or Planctothrix produce metabolites causing earthy to musty odour (Mareš et al, 2012). In the autumn season after harvesting, the sensory quality of fish is usually balanced in different ponds during relaying. The fish usually stay in the storage ponds for seven weeks. During this period the fish do not intake any feed, live in this period in water of lower temperature, and there they lose any undesirable odours and muscle flavours (Vácha, 2012).

Factors Affecting the Quality of Fish Meat

The quality and excellent sensory properties of fish meat are influenced by many factors. In all living organisms is during their lives kept the homeostasis of the internal environment by means of physiological processes. In case of fish, for maintaining homeostasis must be met a number of conditions, including physical and chemical parameters of the aquatic environment. Sufficient concentration of dissolved oxygen in the water, its temperature, favourable chemical composition, supply of nutrients through food and above all the treatment and handling of fish prior to slaughter affect the condition of the organism and later processes that follow after the slaughter.

Slaughtering the fish changes the conditions of the organism, physiological processes are terminated and a complex of post-mortem biochemical processes is developing.

Biochemical changes post mortem

Generally, the post-mortem biochemical changes are divided in the first phase into autolytic processes catalysed by native enzymes. Autolysis has three stages - rigor mortis, meat maturation and deep autolysis. The muscle rigor mortis starts in fish in comparison with other animals very quickly and its duration depends on the species and many other factors, such as ambient temperature, condition of fish before killing and others. It can take several hours, but also several days. Ex-

Volume : 3 | Issue : 9 | Sept 2013 | ISSN - 2249-555X

hausted fish, which had not been treated well before killing is in the rigor mortis stage for only a short time (FAO,1995).

Rigor mortis
starts immediately or shortly after death if the fish is starved and the glycogen reserves are depleted.

The species differences between animals in the onset and duration of rigor mortis result from different chemical composition and content of glycogen in muscle tissue. Fish muscle contains compared to other animal species generally a small quantity of glycogen. The concentration of glycogen in the muscle of cod is 10 – 60 mg/100g, in case of cattle it is 50 – 180 mg of glycogen in 100 g and rigor mortis here comes within one hour since slaughtering. Also among fish, though to a lesser extent, there are differences in the content of glycogen and the onset of rigor mortis. In trout and carp the stiffness starts within half an hour after the killing, while in the redfish it is fully developed after 22 hours since slaughter (Ingr, 2005).

The role of temperature
Significant role in the onset of rigor mortis plays temperature. Is considered as more important factor to onset rigor (Abe & Akuma, 1991). Rigor mortis is more rapid at high temperatures, but observations, especially on tropical fish show the opposite effect of temperature with regard to the onset of rigor. The method used for stunning and killing the fish also influences the onset of rigor. Stunning and killing in iced water give the fastest onset of rigor mortis, while a blow on the head gives a delay of rigor up to 18 hours (Azam et al., 1990).

The reason for the onset of rigor mortis in the complex changes after killing the animal is the decrease in the ATP levels below 1 μmol/g and lowering the pH value to about 5.9. This fact is associated with a decline of adenosine triphosphate (ATP) . ATP is produced in glycolysis (FAO 1995). For most teleost fish, glycolysis is the only possible pathway for the production of energy once the heart stops beating. ATP is produced in glycolysis, but only 2 moles for each mole of glucose oxidized as compared to 36 moles ATP produced for each mole of glucose if the glycolytic end products are oxidized aerobically in the mitochondrion in the living animal. After death the anaerobic muscle cannot maintain its normal level of ATP. Intracellular levels of ATP decreases from 7-10 μmoles/g to 1.0 μmole/g tissue. The muscle enters rigor mortis. Post mortem glycolysis form lactic acid in anaerobic conditions and decreases the pH of the muscle. In cod, , the pH decreases from 6.8 to pH of 6.1-6.5. In mackerel, the ultimate rigor pH may be as low as 5.8-6.0 or 5.4-5.6 in tuna (FAO, 1995). The amount of lactic acid produced is related to the amount of glycogen in the living tissue. Fish muscle contains a relatively low level of glycogen compared to mammals, thus far less lactic acid is generated after death.

The reason for the onset of rigor mortis in the complex changes after killing the animal is the decrease in the ATP levels below 1 μmol/g and lowering the pH value to about 5.9. The reason for these processes is the lack of energy in muscles by exhausting the phosphocreatine and the onset of anaerobic conditions. The muscle gains the energy by cleaving the available glycogen. Its reserves vary among different animal species and they also depend largely on the nutritional status and overall condition of the animal prior to slaughter. Great influence on the level of glycogen has also stress before slaughter**.**

The primary stress response in fish can lead to release of catecholamines and activation of the hypothalamic–pituitary–interenal (HPI) axis. Corticotropin releasing factor from the hypothalamus acts on the pituitary to synthesise and release corticotropic hormone, which in turn stimulates the synthesis and mobilisation of glucocorticoid hormone cortisol (Schreck et al, 2001; Wendelaar-Bonga, 1997). Both catecholamines and cortisol initiate secondary and tertiary stress responses (Ashley, 2007). HPI activation leads to exhaustion of glycogen stores and an increase in plasma levels of glucose. In anaerobic conditions glycolysis increases the concentration of plasma lactate (Matty, 1985, Schreck, 2010).

According to the duration of stress it can significantly affect the levels of glycogen, maturing processes and thus the sustainability of meat.

Well-rested and well-fed fish contain more glycogen than exhausted fish. In a study of Japanese loach (Chiba et al., 1991) was shown that only minutes of pre-capture stress resulted in a decrease of 0.50 pH units as compared to non-fighting fish whose pH decrease only 0.10 pH unit in the same time period. The pH value at this stage is different for muscle of various types of animals. Bovine meat has at the time of the onset of rigor mortis the pH ranging from 5.5 to 5.7, poultry 6.2 and fish even pH 6.6 to 6.7. Lower pH provides greater protection of muscle cells against microbial contamination (Hultin, 1984). Also for this reason, the fish meat is more prone to decomposition processes and spoilage.

ATP is not only a source of energy for muscle contraction in the living animal, but is also a muscle plasticizer. Muscle contraction is controlled by calcium and an enzyme, ATP-ase, which is found in every muscle cell. When intracellular Ca^{+2} levels are 1 μM, Ca^{+2} - activated ATP-ase reduces the amount of free muscle ATP**.** It leads to the interaction between contractile proteins, actin and myosin (FAO, 1995).

The softening of the muscle during rigor mortis is coincidental with the autolytic changes . Among the changes, one of the first to be recognized was the degradation of ATP-related compounds.

Degradation of ATP to form adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphate (IMP), inosine (Ino) and hypoxanthine (Hx) can be used for determination of the freshness index. Saito, Arai, and Matsuyoshi (1959) first observed this pattern and to develop a formula for fish freshness. This index K is based on autolytic changes ATP. The "K" or „freshness index" gives a relative freshness rating based primarily on the autolytic changes (concentrations of ATP, ADP, AMP, IMP, Ino and Hx). This enzymatic reactions are useable for determination of freshness fish meat using biosensors. Biosensor can indicates concentration of metabolities in tissue and calculates the ratio of ATP/ADP and other metabolities. Than the factor of freshnes can be calculated and evaluated. Factor $K < 10\%$ = very fresh meat, $K < 40\%$ = fresh meat, $K > 40\%$ rotting meat (Seager & Slabaugh, 2000). This index is used in Japan.

Role of proteases
Many proteases have been isolated from fish muscle and the effects of proteolytic breakdown. The cathepsins are "acid" proteases. In living tissue, lysozomal proteases are believed to be responsible for protein breakdown at sites of injury. Thus cathepsins are for the most part inactive in living tissue but become released into the cell juices upon physical abuse or upon freezing and thawing of post mortem muscle.

Cathepsins are lysosomal cysteine proteases. They are used in many physiological processes in living organism and their research is of considerable interest not only because of the application in the process of post mortem and subsequent maturation of meat. In connection with the processes of meat maturation and their effects on improving the characteristics, especially meat tenderness, the cathepsins were studied already in the 50s of the 20th century (Kameník et al, 2012). Cathepsins are acidic proteases localized in lysosomes. They can occur in the cytoplasm and in the intercellular spaces in case of apoptosis and cell death due to lower pH. They are active in a slightly acidic environment. Lysosomes contain 13 types of cathepsins and are classified in four groups according to the active place into cysteine, aspartate, serine and

Volume : 3 | Issue : 9 | Sept 2013 | ISSN - 2249-555X

metalloproteinase (Chéreta et al, 2006). Cathepsins involved in the aging process and muscle maturation are cathepsins B (EC 3.4.22.1), L (EC 3.4.22.15), H (EC 3.4.22.16) and D (EC 3.4.22.5). Cathepsins B, H and L are regulated in vivo by a protease inhibitor cystatin (Chéreta et al, 2006).

A second group of intracellular proteases are calpains or calcium activated factor (CAF). They has been associated with fish muscle autolysis. The calpains are intra-cellular endopeptidases requiring cysteine and calcium. Most calpains are active at physiological pH, making it reasonable to suspect their importance in fish-softening during chilled storage (FAO, 1995). Cathepsins, along with other enzyme systems from the group of proteases – calpains, proteasome and caspases – are involved in the maturation process and are thus responsible for the final effect in the form of quality and delicate meat.

The study by Chéreta, Delbarre-Ladrat, Lamballerie-Anton, and Verrez-Bagnis (2007) dealt with the assessment of activity of calpains, cathepsins of groups B, H and L and calpastatin in the bovine and fish meat (sea bass Centropristis striga). The results showed significant differences between the meat of cattle and fish. Cathepsin H proved to be insignificant for both types of meat, while cathepsin B is significant only in the fish muscle and cathepsin L in both types of meat. The authors compared the results and found out that the cysteine endopeptidases of cathepsin B were detected in nearly 30 times higher levels in white muscle of sea bass than in bovine meat.

These relationships are affected by pH and the presence of Ca $^{2+}$ ions.

And according to other studies, differences are apparent in the post-mortem processes in the process of curing meat in fish muscle unlike other livestock. This is due, among other factors, the fact that the fish as poikilotermní animal moves in a substantially cooler environment than livestock. Just enzyme activity is regulated by temperature very much.

CONCLUSION

All these complex processes affect the organoleptic characteristics of meat. Knowledge of these processes and the application of scientific knowledge to care for the fish and their environment, careful treatment at every fish handling within the welfare and treatment technologies according to hygienic rules will be reflected in the final result and is very beneficial for production of quality fish and supports the increased interest in its consumption.

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