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STUDY ON NUTRITIONAL QUALITY OF SMOKED AND MARINATED PRODUCTS FROM HERRING *(CLUPEA HARENGUS)*

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Abstract

The study aimed a comparative analysis of the nutritional characteristics of smoked and marinated products from herring (Clupea harengus). Thirty products were analyzed, fifteen samples of smoked and fifteen of marinated herring, five samples for each type of study product (manufacturers codification: A, B, C, D, E and F). The catch areas of analyzed herring products from al manufacturers were FAO 27, North-East Atlantic. The proteins, lipids, collagen and water content was determined using the automated analyzer Food Check (infrared spectrophotometer); mineral substances were determined by calcination at 550 ^{0}C and the carbohydrates content and energy value were determined by calculation, using conventional relations. The most important differences between the marinated herring products analyzed, have targeted the content of lipids, with difference of 3% (13.10% lipids for product C compared with 16.11% lipids for product A). There are very significant differences ($p<0.001$), between the two product categories analyzed, marinated herring having over 50% more fat for product A than for the smoked one (5.54% for E and 7.45% for F product).

Key words: *marinated, smoked herring, proteins, lipids, salt.*

INTRODUCTION

The consumption of fish as well as fish products has significantly increased during the last two decades (FAO, 2016). The popularity of fish is mainly due to the overall high quality and the positive effects on human health. Fish and seafood products, have a high nutritional value regarding beneficial amounts of protein, lipids as well as essential micronutrients and have a high content of omega 3 long chain polyunsaturated fatty acids (n-3 LC PUFA) compared to land living animals (Khalili Tilami and Sampels, 2017; Tacon and Metian, 2013). Strong links between fish and seafood consumption and positive health effects, especially with the decreased risk of coronary heart and cardiovascular diseases, decreased inflammatory disease as arthritis and prevention of cancer have been shown by many researchers (Calder, 2004; Rudkowska et al.; 2010; Lund, 2013). The main effects of fish consumption have been attributed to the high content of n-3 LC PUFA; also other nutrients from fish have positive effects on human health.

Fish and other seafood have also a well-balanced amino acid composition; contain high proportions of taurine and choline, the vitamins D_3 and B_{12} and the minerals: calcium, phosphorus, iodine, selenium and also might provide significant proportions of vitamin A, iron and zinc (Lund, 2013). However, one of the problems of fish consumption is represented by the fact that this meat produces allergies, by the content of biogenic amines such as histamine, that play essential roles in the normal development, metabolism and physiological functions of humans (Smith, 1980, Bardocz, 1995; Halasz, et al., 1994; Ladero, et al., 2010). Along with this issue, apart from a few pathogenic species, most infections of fish meat are considered to be relatively innocuous (Feist, et al., 2004; Lazar et al., 2012).

Salting, marinating and smoking are popular methods of processing the fish. Different types of marinades and salads based on marinated fish have had an important share in fish consumption in Europe for many years. Because of seasonal availability of fish and distance from the fishing ground, the majority of marinades are produced based on frozen fish (Szymczak et al., 2012, 2013 and 2018). During ripening, proteolysis of herring meat occurs under the influence of endogenous enzymes. It results in the release of high amounts of free amino acids and peptides that impart the typical taste and aroma of the mature meat (Szymczak et al., 2015a, 2016a, 2016b). Hence, the degree of hydrolysis determines the sensory quality, nutritive value, and a high content of biologically-active compounds of a food product (Szymczak et al., 2015b; Felisiak, 2019).

The ripening of marinade meat proceeds as a result of multiple physical, biochemical, and microbiological transformations. Most of these transformations are associated with the hydrolysis of proteins and lipids and with their interactions. In marinades with low pH values, active are acidic aspartyl proteases (cathepsin D and E), as well as cysteine proteases (cathepsin B and L) and pepsin (Szymczak and Lepczynski, 2016; Szymczak and Kolakowsi, 2016; Szymczak, 2017).

Food smoking is one of the oldest preservation methods and is still widely used (Ledesma et al., 2015; Lingbeck et al., 2014; Stołyhwo and Sikorski, 2005). However, smoking is nowadays mainly used to obtain the desired colour, flavour, aroma, and appearance in the smoked food rather than for preservation purposes (Theobald, et al., 2012; Fasano et al., 2016, Hokkane, et al., 2018). The study aimed a comparative analysis of the nutritional characteristics of some smoked products from herring fillets and marinated herring medallions marketed in Iasi, Romania in spring of 2019.

MATERIALS AND METHODS

Thirty products were analyzed, fifteen samples of smoked and fifteen of marinated herring, five samples for each type of study product/ manufacturers (codification: A, B, C, D, E and F). The catch areas of analyzed herring products from al manufacturers were FAO 27, North-East Atlantic (Norway, Iceland, Faroe Islands, Scotland, Ireland and Netherlands).

The samples were chopped and homogenized with an electric shredder.

The water, proteins and lipids content were determined using the Food Check Near Infrared Spectrophotometer (NIRS technology); the energy value was determined by calculation using conventional formulas and crude ash content was assessed after AOAC, 1990, by calcinations (at 550°C for 16 h after a preliminary carbonization).

The energy conversion factors were: 4.27 for proteins, 9.02 for lipids and 3.87 for carbohydrates (according to FAO relations, 2003).

The achieved results were statistically processed through the main descriptors computation (arithmetic mean, $\bar{x}$, standard deviation, s, and coefficient of variation, V%, and by analysis of variance test (ANOVA multiple comparisons), using the GraphPad Prism 8.1 software.

RESULTS AND DISCUSSIONS

The most important differences between the marinated herring products analysed (Tables 1, 2 and 3) have targeted the content of lipids, with difference of 3% (13.10% lipids for product C compared with 16.11% lipids for product A).

Table 1. Chemical composition and energy value of marinated herring (A product)

Chemical components	$\bar{x} \pm s_{\bar{x}}$	s	V%	Min.	Max.
Lipids%	16.11± 0.84	1.68	10.44	14.30	17.75
Proteins%	17.95± 0.09	0.17	0.99	17.30	18.90
Collagen%	2.52± 0.03	0.06	2.07	2.66	2.80
Water%	61.15± 0.27	0.54	0.91	59.60	63.90
Ash%	3.78± 0.11	0.22	5.87	3.50	4.00
Salt%	3.21± 0.04	0.07	2.23	3.11	3.28
Dry matter%	38.13± 0.27	0.54	1.37	34.10	40.40
Organic matter%	34.35± 0.37	0.75	2.08	32.10	36.90
Carbohydrates %	0.81± 1.23	2.46	7.42	0.10	2.30
GE kcal/100g	222.84± 3.31	6.62	1.88	223.37	237.69
GE kJ /100g	932.37± 13.84	27.68	3.18	934.57	1094.51

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

On the same note, there are very significant differences between the two product categories analysed (Fig. 1, Tables 1-6), marinated herring having over 50% more fat for product A than for the smoked one (5.54% for E product, and 7.45% for F product). These differences can be attributed to the fact that the marinated herring is presented in the form of medallions, thus including abdominal muscles that are richer in fat compared to the fish fillet and eventually losses of fat from smoking process; at the same time, the season when the fish was cached it can`t be determined, knowing that the proportion of fat varies greatly with the season and the breeding cycle (Stroud, 2001; Nielsen et al., 2005). However, these mean values of the lipid content were lower than those determined by Szymczak et al. (2018), that found 18.70±0.30% in size 4-8 herring (149 g/fillet, and whole fish weight above 350-400 g).

Table 2. Chemical composition and energy value of marinated herring (B product)

Chemical components	$\bar{x} \pm s_{\bar{x}}$	s	V%	Min.	Max.
Lipids%	14.86±0.28	0.62	4.16	10.20	15.70
Proteins%	18.24±0.04	0.10	0.52	17.10	18.90
Collagen%	2.98±0.01	0.03	0.98	2.93	3.20
Water%	62.62±0.18	0.40	0.65	61.20	63.90
Ash%	3.54±0.01	0.01	0.36	3.53	3.56
Salt%	3.10±0.07	0.15	4.29	2.30	3.60
Dry matter%	37.38±0.18	0.40	1.08	37.10	37.80
Organic matter%	33.84±0.18	0.41	1.21	33.54	34.27
Carbohydrates %	0.74±0.31	0.70	94.70	0.44	1.87
GE kcal/100g	214.80±1.66	3.71	3.29	213.03	220.69
GE kJ /100g	898.72± 6.94	15.51	1.73	891.30	923.37

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

After some authors (Stroud, 2001; Nielsen et al., 2005; Wianecki, 2007; Tacon and Metian, 2013; Adeyemi et al., 2015), unlike most white fish, the chemical composition of herring varies considerably with the season and the breeding cycle; the fat content of herring may be less than 1% immediately after spawning, and more than 20% as spawning time approaches again.

Table 3. Chemical composition and energy value of marinated herring (C product)

Chemical components	$\bar{x} \pm s_{\bar{x}}$	s	V%	Min.	Max.
Lipids%	13.10±0.72	1.25	9.56	11.80	14.30
Proteins%	18.17±0.32	0.55	3.03	17.60	18.70
Collagen%	3.04±0.06	0.10	3.33	2.94	3.14
Water%	64.17±0.03	0.06	0.09	64.10	64.20
Ash%	3.60±0.04	0.11	0.18	2.89	3.98
Salt%	2.62±0.02	0.03	1.12	2.59	2.65
Dry matter%	35.83±0.03	0.06	0.16	33.80	37.90
Organic matter%	32.23±0.05	0.09	0.18	29.20	34.30
Carbohydrates %	0.97±0.38	0.67	68.88	0.40	1.70
GE kcal/100g	199.47±3.71	6.42	3.22	192.86	285.69
GE kJ /100g	834.60±15.51	26.86	1.37	806.94	978.59

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

The water content decreases as the fat content increases. In addition, the protein content varies with water content; as the water content increases, the protein content raises a little (Stroud, 2001).

Table 4. Chemical composition and energy value of smoked herring (D product)

Chemical components	$\bar{x} \pm s_{\bar{x}}$	s	V%	Min.	Max.
Lipids%	9.35±0.31	0.61	6.56	8.60	10.10
Proteins%	17.73±0.25	0.50	2.82	17.20	18.20
Collagen%	3.28±0.04	0.08	2.42	3.18	3.37
Water%	69.78±0.22	0.45	0.64	69.20	70.30
Ash%	2.90±0.03	0.06	2.16	2.81	2.96
Salt%	2.30±0.09	0.18	7.94	2.10	2.50
Dry matter%	30.23±0.22	0.45	1.49	29.70	30.80
Organic matter%	27.32±0.22	0.43	1.58	26.79	27.84
Carbohydrates %	0.25±0.31	0.62	247.85	0.06	0.79
GE kcal/100g	160.99±2.48	4.96	7.12	154.93	197.01
GE kJ /100g	673.57±10.38	20.77	3.08	648.24	798.78

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

Table 5. Chemical composition and energy value of smoked herring (E product)

Chemical components	$\overline{x} \pm s_{\overline{x}}$	s	V%	Min.	Max.
Lipids%	5.54±0.11	0.25	4.51	5.30	5.90
Proteins%	19.03±0.25	0.55	2.90	17.77	19.10
Collagen%	3.70±0.05	0.12	3.32	3.43	3.72
Water%	70.01±0.37	0.82	1.17	66.10	71.80
Ash%	4.94±0.08	0.15	3.09	4.83	5.15
Salt%	4.42±0.06	0.14	3.20	4.13	4.73
Dry matter%	29.51±0.37	0.82	2.79	29.20	31.00
Organic matter%	25.56±0.38	0.85	3.31	24.24	26.17
Carbohydrates %	0.48±0.23	0.51	51.49	0.34	0.67
GE kcal/100g	135.06±1.60	3.57	2.64	128.54	137.26
GE kJ/100g	565.08±6.68	14.93	2.64	537.81	574.29

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

The water content (Fig. 2) was higher for smoked herring (70.49% for E product, 69.78% for D product and 68.96% for F product) and smaller for marinated herring (61.88% for A product), this having the smallest average value of proteins (17.45%), and the highest value of lipids content (16.10%).

Table 6. Chemical composition and energy value of smoked herring (F product)

Chemical components	$\overline{x} \pm s_{\overline{x}}$	s	V%	Min.	Max.
Lipids%	7.32±0.10	0.23	3.20	6.05	8.46
Proteins%	18.80±0.29	0.50	2.64	17.60	20.20
Collagen%	3.94±0.06	0.14	3.52	3.66	4.11
Water%	68.96±0.64	2.56	3.72	64.50	72.80
Ash%	4.44±0.58	1.17	26.33	2.69	5.06
Salt%	3.48±0.38	0.99	28.50	2.10	4.50
Dry matter%	31.04±0.64	1.18	3.81	27.20	34.10
Organic matter%	29.07±1.05	1.56	5.35	25.16	33.00
Carbohydrates %	0.59±1.97	2.28	12.24	0.30	1.90
GE kcal/100g	145.61±5.55	5.77	3.96	112.90	168.90
GE kJ/100g	609.21±23.24	24.15	3.96	472.39	706.66

GE = Gross Energy; s= standard deviation; V%=coefficient of variation.

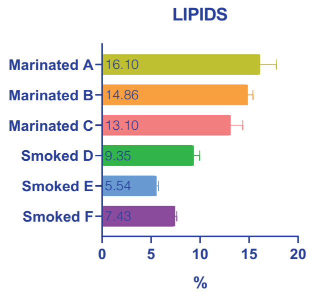

Figure 1. The lipids content of marinated and smoked herring

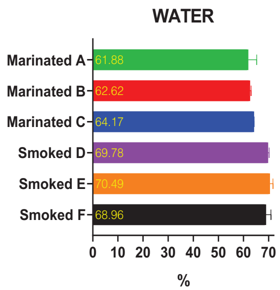

Figure 2. The water content of marinated and smoked herring

After Nielsen et al. (2005), the lipids content in herring meat was lower in February (in average 4.3%) and higher in July (17.6%) and September (17.3%).

The same authors found minim values of 1.3% lipids in February and 25.7% in July, these determinations showing how much it varies the chemical composition of this meat.

The proteins content (Fig. 3) was higher for smoked herring: E product (19.03%) and F product (18.69%); the lowest value was observed for marinated herring, product A (17.45%) this having the highest average values of lipids content (16.10%).

The collagen content (Fig. 4) was higher for smoked herring (3.94% for F product and 3.70% for E product) probably because the total proteins content was higher and, in the same time, the lipids content was lower (tables 5 and 6).

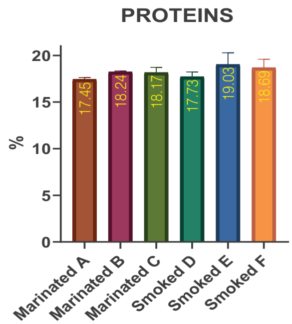

Figure 3. The proteins content of marinated and smoked herring

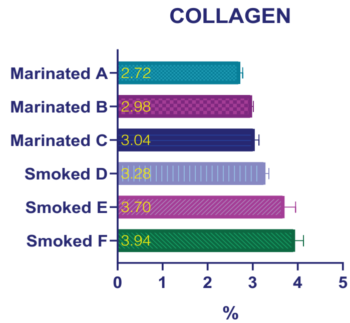

Figure 4. The collagen content of marinated and smoked herring

The ash content (Fig. 5) was the highest for product E (4.94%), this being and the saltiest product (4.42% salt), and the lowest value of ash (2.90%) and salt (2.30%), was observed for product D (fig. 6), both being smoked product (Tables 4 and 5).

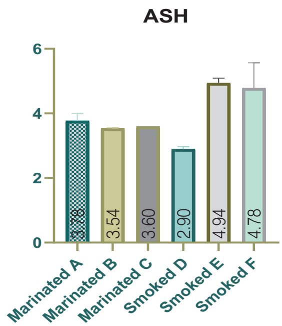

Figure 5. The ash content of marinated and smoked herring

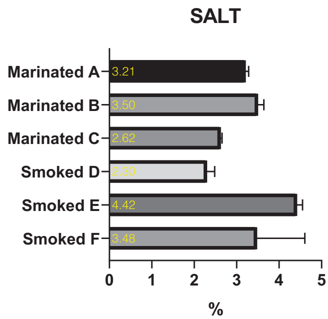

Figure 6. The salt content of marinated and smoked herring

The highest dry matter (DM), and in the same time the highest organic matter (OS) content of herring products analysed, was observed for the marinated one (39.85% for A product, 37.38% for B and 35.83% for C), the differences compared with the smoked one (D, E and F products) being on the base of lipid content that were found highest in this products (Fig. 7 and Fig. 8).

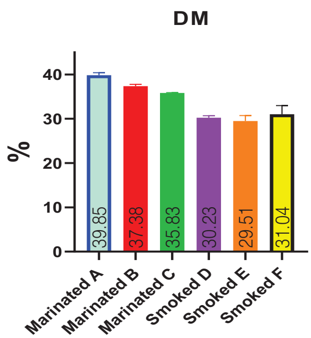

Figure 7. The dray matter content of marinated and smoked herring

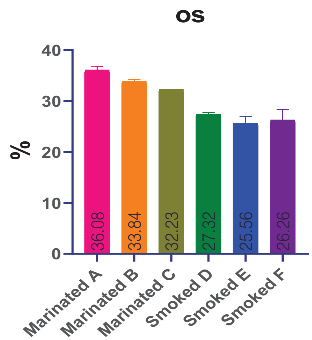

Figure 8. The organic matter content of marinated and smoked herring

The energy value (Fig. 9), was higher for marinated herring products (222.84 kcal/100g /898.37 kJ/100g for A manufacturer, 214.8 kcal/100g/ 898.2 kJ/100g for B manufacturer and 199.47 kcal/100g /834.60 kJ/100g for C manufacturer) compared with smoked herring, this having the highest lipids content.

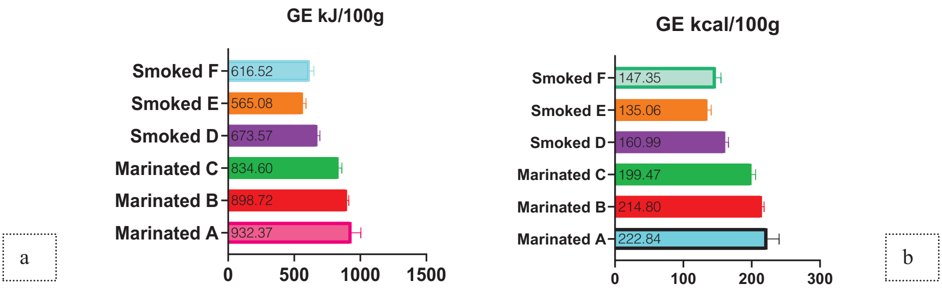

Figure 9. The gross energy content of marinated and smoked herring: a) kJ/100 g; b) kcal/100g

The statistical differences on chemical composition and energy value of marinated and smoked herring (Table 7) were preponderant significant, distinct significant and highly significant ($p<0.001$), with the exception of proteins and salt content where was found mostly not significant differences.

Table 7. The statistical significance of the differences on chemical composition and energy value of marinated and smoked herring (P value)

ANOVA	Lipids	Proteins	Collagen	Water	Ash	Salt	D.M.	O.S.	GE kcal/100g
A-B	<0.0001	0.0046	0.1751	0.9863	0.9738	0.9851	0.0696	0.1803	0.7156
A-C	0.0045	0.3785	0.1217	0.5206	0.9963	0.8484	0.0039	0.0127	0.0152
A-D	<0.0001	0.9246	0.0006	<0.0001	0.1367	0.3966	<0.0001	<0.0001	<0.0001
A-E	<0.0001	0.0864	<0.0001	<0.0001	0.0217	0.1041	<0.0001	<0.0001	<0.0001
A-F	<0.0001	0.3064	<0.0001	<0.0001	0.0191	0.9829	<0.0001	<0.0001	<0.0001
B-C	0.0025	0.9988	0.9950	0.8191	>0.9999	0.4714	0.5519	0.5946	0.1686
B-D	<0.0001	0.5481	0.0935	<0.0001	0.3732	0.1089	<0.0001	<0.0001	<0.0001
B-E	<0.0001	0.6889	<0.0001	<0.0001	0.0024	0.2709	<0.0001	<0.0001	<0.0001
B-F	<0.0001	0.8529	<0.0001	<0.0001	0.0012	>0.9999	<0.0001	<0.0001	<0.0001
C-D	<0.0001	0.9529	0.3942	0.0033	0.4122	0.9864	<0.0001	0.0010	<0.0001
C-E	<0.0001	0.5762	<0.0001	0.0005	0.0130	0.0117	<0.0001	<0.0001	<0.0001
C-F	<0.0001	0.9739	<0.0001	0.0042	0.0119	0.4010	<0.0001	<0.0001	<0.0001
D-E	0.1991	0.3554	0.0068	0.9887	<0.0001	0.0009	0.9552	0.4074	0.0015
D-F	0.0004	0.3062	<0.0001	0.9665	<0.0001	0.0642	0.8817	0.7831	0.1154

Moisture content is one of the determining factors for storage. Low moisture content is a good indicator against spoilage.

Protein and lipids contents of the smoked herring obtained by Atanda et al. 2015, were lower compared to the unsmoked fish. This loss may arise from the denaturing and exudation of protein occasioned by the loss of essential amino acid as lysine, which is labile at heat during the smoking process. Carbonyls present in the smoke might have reacted with lysine which caused the reduction. This is consistent with previous studies (Atanda et al, 2015; Oluwaniyi et al. 2009; Karthikeyan et al., 2012). The loss of lipids in the smoked fish in contrast to the unsmoked fish could also be due to exudation which agrees with a previous report (Akineye et al, 2007). Thus, high lipids content might lead to increase rancidity in the course of storage (Atanda et al., 2015).

Wianecki, 2007, found lower proteins content in fresh herring (15.4%), similar content of lipids (8.2%) and higher content of water (74.4%) that in this study. The same author found in frozen herring small differences in proteins content 15.6%, lipids 8.4% and water 73.9% (these being closer of those determined in this study).

Only in the last decade, research has focused on the beneficial health effects of fish protein in human nutrition (Rudkowska et al., 2010; Pilon et al., 2011).

Studies related to inflammation, metabolic syndrome, osteoporosis, insulin resistance, obesity-related comorbidity and development of cancer have been executed and fish protein, peptides or hydrolysates have shown of importance in nearly as many areas as fish lipids. For example, a sardine protein diet showed to lower insulin resistance, improved hyperglycemia and decreased adipose tissue oxidative stress in rats with induced metabolic syndrome (Madani et al., 2012).

The authors suggested fish protein as a possible prophylaxis against insulin resistance (Khalili Tilami and Sampels, 2017).

CONCLUSIONS

The most important differences between the marinated herring products analyzed, have targeted the content of lipids, with difference of 3% (13.10% lipids for product C compared with 16.11% lipids for product A). Between the two product categories analyzed were very significant differences, marinated herring having over 50% more fat for product A than for the smoked one (5.54% for E and 7.45% for F product); must be taken into account that the marinated herring was in the form of medallions, richer in fat, compared to the smoked one (fillet), eventually losses of fat from smoking process; and the season when the fish was captured.

REFERENCES

Adeyemi, O.T., Osilesi, O.O., Onajobi, F., Adebawo, O., Oyedemi, S.O. (2015). Variations in proximate composition of *Clupea harengus* (Fillet & Skin, Head and Bones (SHB)) after different heat treatment, *Journal of Nat Sci Res*, 5 (1), 117-121.

Akineye, J.O., Amoo, I.A., Adaraniwa, S.T. (2007). Effect of drying methods on the nutritional composition of three species of fish (*Bonga spp. Sardinella spp. Heterotis niloticus)*. *J. Fish. Int*., (2), 99-103.

Atanda, S.A., Adekalu, O.A., Agoda, S., Benson, O.B., Ihionu, G.C. (2015). The effect of wood type on the organoleptic properties of smoked Atlantic herring (*Clupea harengus*). *NISEB Journal*, 15(4), 137-141.

Bardocz, S. (1995). Polyamines in food and their consequences for food quality and human health. *Trends Food Sci. Tech*., 6, 341-346.

Calder, P.C. (2004). n-3 fatty acids and cardiovascular disease: Evidence explained and mechanisms explored. *Clin. Sci*., 107, 1–11.

Deabes, M.M., Naguib, K.H., Ayesh, A.M., El-Damaty, E.M., Rowayshed, G.H. (2018). Comparison of the HPLC and the TLC Techniques for the Determination of Biogenic Amines Spiked to Sausage and Smoked Herring Samples. Enliven: *Toxicol Allied Clin Pharmacol*., 5(1), 1-7.

Fasano, E., Yebra-Pimentel, I., Martınez-Carballo, E., Simal-Gandara, J. (2016). Profiling, distribution and levels of carcinogenic polycyclic aromatic hydrocarbons in traditional smoked plant and animal foods, *Food Control*, 59, 581–590.

Feist, S.W., Longshaw, M., Hurrell, R.H., Mander, B. (2004). Observations of Dermocystidium sp. infections in bullheads, Cottus gobio L., from a river in southern England. *J. Fish Diss*, 27, 225-231.

Felisiak, K., Szymczak, M., Kołakowski, E. (2019). Identification of non-protein nitrogen compounds separated by CZE without derivatization from TCA extract from salted herring meat. *Journal of Food Composition and Analysis*, 77, 108–114.

Hokkane, M., Luhtasela, U., Kostamo, P., Ritvanen, T., Peltonen, K., Jestoi, M. (2018). Critical Effects of Smoking Parameters on the Levels of Polycyclic Aromatic Hydrocarbons in Traditionally Smoked Fish and Meat Products in Finland Hindawi Journal of Chemistry, 1-14. https://doi.org/10.1155/2018/2160958

Food and Agriculture Organization (FAO 2016). The state of world fisheries and aquaculture, contributing to food security and nutrition for all. Rome.

FAO, 2003 FAO, 2003: Food energy – methods of analysis and conversion factors. Food and Agriculture Organization of the United Nations, Rome, Report of a technical workshop http://www.fao.org/uploads/media/FAO_2003_Food_Energy_02.pdf.

Halasz, A., Barath, A., Simon-Sarkadi, L., Holzapfel, W. (1994). Biogenic amines and their production by microorganisms in food. *Trends Food Sci Tech*., 5, 42-49.

Karthikeyan, M., Dhar, B., Kakati, B.K. (2012). Quality evaluation of smoked fish products from the markets of Manipur. *Central J. Inland Fish. Soc. India,* 44(1), 37-46.

Khalili Tilami S.K., Sampels S. (2017). Nutritional value of fish: lipids, proteins, vitamins and minerals. *Reviews in Fisheries Science & Aquaculture*, 26(2), 243–253.

Ladero, V., Calles-Enríquez, M., Fernández, M., Alvarez, MA. (2010). Toxicological effects of dietary biogenic amines. *Curr Nut Food Sci*., 6, 145-156.

Lazăr, M., Miron, L., Gostin, I., Rîmbu, C., Lazăr, R., Guguianu, E. (2014). Investigations in associated protozoa-bacterial infections of cyprinids from a fish farm situated on the Jijia river in N-E of Romania. *Arq. Bras. Med. Vet. Zootec*., 66(3), 688-696.

Ledesma, E., Rendueles, M., Dıaz, M. (2015). Spanish smoked meat products: benzo (a) pyrene (BaP) contamination and moisture," *Journal of Food Composition and Analysis*, 37, 87–94.

Lingbeck, J.M., Cordero, P., O'Bryan, C.A., Johnson, M.G., Ricke, S.C., Crandall, P.G. (2014). Functionality of liquid smoke as an all-natural antimicrobial in food preservation, *Meat Science*, 97(2), 197–206.

Lund, E.K. (2013). Health benefits of seafood; Is it just the fatty acids? *Food Chem*., 140, 413–420.

Madani, Z., Louchami, K., Sener, A., Malaisse, W.J., Yahia, D.A. (2012). Dietary sardine protein lowers insulin resistance, leptin and TNF-alpha and beneficially affects adipose tissue oxidative stress in rats with fructose-induced metabolic syndrome. *Int. J. Mol. Med*., 29, 311–318.

Nielsen, D., Hyldig, G., Nielsen, J., Hauch Nielsen, H. (2005). Lipid content in herring (*Clupea harengus L.*) - Influence of biological factors and comparison of different methods of analyses: Solvent extraction, *Fatmeter, NIR and NMR, LWT*, 38, 537-548.

Oluwaniyi, O.O., Dosumu, O.O. (2009). Preliminary studies on the effect of processing methods on the quality of three commonly consumed marine fishes in Nigeria. *Biokemistri,* (1), 1-7.

Pilon, G., Ruzzin, J., Rioux, L.E., Lavigne, C., White, P.J., Froyland, L., Jacques, H., Bryl, P., Beaulieu, L., Marette, A. (2011). Differential effects of various fish proteins in altering body weight, adiposity, inflammatory status, and insulin sensitivity in high-fat-fed rats. *Metab.Clin. Exper*., 60, 1122–1130.

Rudkowska, I., Marcotte, B., Pilon, G., Lavigne, C., Marette, A., Vohl, M.C. (2010) Fish nutrients decrease expression levels of tumor necrosis factor-alpha in cultured human macrophages. *Physiol. Genomics*, 40, 189–194.

Smith, T.A. (1980) Amines in food. *Food Chemistry*, 6, 169-200.
https://www.sciencedirect.com/science/article/pii/030881468190008X

Stołyhwo, A., Sikorski, Z.E. (2005). Polycyclic aromatic hydrocarbons in smoked fish—a critical review. *Food Chemistry*, 91(2), 303–311.

Stroud, G.D. (2001). *The Herring, Ministry of Agriculture, Fisheries and Food*, Torry Research Station-FAO (Torry advisory note no. 57). http://www.fao.org/3/x5933e/x5933e00.htm#Contents

Szymczak, M., Kołakowski, E., Felisiak, K. (2012). Influence of salt concentration on properties of marinated meat from fresh and frozen herring (*Clupea harengus* L.). *Int. J. Food Sci. Technol*., 47(2), 282–289.

Szymczak, M., Kołakowski, E., Felisiak, K. (2015a). Effect of addition of different acetic acid concentrations on the quality of marinated herring. J. Aquat. *Food Prod. Technol*., 24(6), 566–581.

Szymczak, M., Tokarczyk, G., Felisiak, K. (2015b). *Marinating and salting of herring, nitrogen compounds' changes in flesh and brine*. In: Preedy, V. (Ed.), Processing and Impact on Active Components in Food. CRC Academic Press, London, UK, pp. 439–445 Chapter 53.

Szymczak, M. (2016a). Distribution of cathepsin D activity between lysosomes and a soluble fraction of marinating brine. *J Food Sci*, 81, E1966–E1970. https://doi.org/10.1111/1750-3841.13375

Szymczak, M. (2016b). Recovery of cathepsins from marinating brine waste. *Int J Food Sci Technol,* 52, 154–160. https://doi.org/10. 1111/ijfs.13273

Szymczak, M. (2017). Effect of technological factors on the activity and losses of cathepsins B, D and L during marinating of Atlantic and Baltic herrings. *J Sci Food Agric*., 97, 1488–1496.

Szymczak, M., Kołakowski, E. (2016). Total volatile basic nitrogen in meat and brine during marinating of herring. *J Aquat Food Prod Technol*., 25, 373–387.

Szymczak, M., Lepczyn´ski, A. (2016). Occurrence of aspartyl proteases in brine after herring marinating. *Food Chem*., 194, 470–475.

Szymczak, M., Szymczak, B., Koronkiewicz, A., Felisiak, M., Bednarek, M. (2013). Effect of cover brine type on the quality of meat from herring marinades. *J Food Sci*., 78, 619–625.

Szymczak, M., Felisiak, K., Szymczak, B. (2018). Characteristics of herring marinated in reused brines after microfiltration. *J Food Sci Technol*., 55(11), 4395–4405.

Tacon, A.G.J., Metian, M. (2013). Fish matters: importance of aquatic foods in human nutrition and global food supply. *Rev. Fisher. Sci*., 21, 22–38.

Theobald, A., Arcella, D., Carere A., et al. (2012). Safety assessment of smoke flavouring primary products by the European Food Safety Authority, *Trends in Food Science & Technology*, 27(2), 97–108.

Wianecki, M. (2007). Evaluation of fish and squid meat applicability for snack food manufacture by indirect extrusion cooking, *Acta Sci. Pol. Technol. Aliment*., 6(4), 29-44.

*** AOAC, Official Methods of Analysis of the AOAC. 15th ed., Association of Official Analytical Chemists, Arlington, VA, 1990, USA.