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A Comparative Study of Microwave and Sous-Vide Cooking Effects on Pikeperch Fillets' Fatty Acid Composition and Quality Attributes

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Abstract: The aim of the study was to compare the effects of microwave and sous-vide cooking on chemical composition, including fatty acid composition, colour, and microbial and eating quality of fillets produced from wild-living pikeperch. Skinned fillets were sous-vide (SV)-cooked at 65 °C for 40 min. or cooked in a microwave oven (M) at 539 W for 3 min. Generally, cooking decreased moisture and increased protein contents in SV and M, and increased fat content in SV. Cooking increased lightness and yellowness while decreasing redness of fillets, but there were no differences between SV and M. SV fillets showed a significantly higher cooking loss than M samples. SV and M samples showed a similarly high sensory and microbial quality, although microwave cooking was more effective in total viable bacteria counts reduction. Similar fatty acid proportions and concentrations were noted in M and SV fillets, suggesting that both methods preserved well fatty acids in pikeperch meat tissue.

Keywords: fish; *Sander lucioperca*; nutrients; thermal treatment; safety; wild-living fish

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1. Introduction

Pikeperch is a predatory fish that lives in fresh water, belongs to the family *Percidae* (order *Perciformes*), and is found in Europe and North America. This fish is appreciated by consumers due to its white and tender meat, and low quantity of bones. The muscle tissue of pikeperch is lean (below 2% fat) and contains a high amount (approx. 20%) of highly digestible protein (approx. 98% of digestibility) with a higher content of exogenous amino acids than other popular fish species such as herring, perch, roach, bream, and eel [1], which makes this fish a valuable food product. There is a growing demand from retail and the HoReCa sector (hotels-restaurants-catering) for pikeperch [2] and therefore the influence of cooking methods on the quality and nutritional value of the fish is worth investigating.

Microwave and sous-vide cooking are thermal treatment methods which can be used in both the household and under industrial conditions. As all cooking methods, they are used to make a food safe for consumption and to change the sensory quality of food products by making them more attractive for consumers. In the sous-vide method, a raw product is vacuum-packed in plastic pouches and subjected to heating at precisely controlled temperatures [3]. According to Baldwin [4], vacuum-packaging prior to cooking has many benefits, which include the efficient heat transfer from the medium (water or steam) to the food and prolonging the shelf-life by: (1) reducing the risk of recontamination during storage and (2) by lowering the extent of oxidation and off-flavours occurrence. Moreover, vacuum-packaging prevents evaporative losses of flavour volatiles and moisture

during cooking, thus increasing cooking yields, and reduces aerobic bacterial growth [4] as compared with traditional cooking methods. With this technique, it is possible to extend a product's shelf-life up to 90 days if stored below 2.5 °C [4]. Sous-vide food can be regarded as ready-to-eat products and after termination of the cooking process they can be held in a chafing dish (so called "cooked-hold" or "cooked-served" sous-vide mode) at a min. 54.4 °C until served, or as ready-to-heat products ("cook-chill" and "cook-freeze" sous-vide mode), which can be stored at a low temperature or in a freezer and reheated before eating [5].

Microwave ovens are common devices in households worldwide and can be used for both preparing raw food products for consumption or reheating ready-to-eat meals. Microwave cooking being a volumetric heating, it allows to increase the temperature of a foodstuff quickly with low energy consumption; however, it can generate hot and cold spots in a dish and requires the use of specific types of packaging or containers [6]. Microwave cooking was used in our previous study in which the effect of thermal treatment on the fatty acid profile in northern pike was investigated [7]. It was noted that microwave cooking decreased the proportion of saturated fatty acids, increased the proportion of total polyunsaturated fatty acids (PUFAs), n-3 and n-6 PUFAs, compared with fresh fillets, and enabled fish products to obtain a more beneficial n-6/n-3 ratio than frying. Therefore, it was concluded that it was a better technique for pike fillet preparation in households that pan frying and steam cooking. However, despite the lack of scientific evidence, there is some consumer concern regarding the use of microwave ovens to prepare dishes [8]. In light of this, the sous-vide technique might be a promising alternative for preparing fish meals intended to be immediately consumed or even to be stored and consumed later. Therefore, in the present study, microwave cooking was compared with the sous-vide technique used to prepare pikeperch fillets. The effects of these two cooking methods were compared in terms of their impact on proximate and fatty acid composition, colour, and microbial and sensory quality of wild pikeperch fillets.

2. Materials and Methods

2.1. Experiment Design

In this study, twelve wild pikeperch (*Sander lucioperca*, 1.2 kg ± 0.2 kg mean body weight) were used. The fish were caught in November in Lake Wymój (Mazurian Lake District, northern Poland, water temperature 6.0 °C) using gill nets (mesh size length—55, 70, 80 mm). The way fish were processed was described in detail in [9]. From each fish, skinless fillets (average weight 0.57 kg) were prepared and were used to fabricate three samples used for chemical, microbiological, and sensory determinations (Figure 1). Samples M and SV were divided into two separate subsamples, which were processed at the same time in the cooking device. After termination of a thermal treatment, one subsample was used to assess microbial and sensory quality, and the other one to assess the proximate and fatty acid composition, cooking loss, and colour. Cooking loss was determined by weighing a subsample before and after cooking. SV subsamples were individually vacuum-packed in plastic bags suitable for sous-vide cooking and cooked in a sous-vide device (Hendi GN 2/3, Steenoven, Rhenen, Niderlanden) at 65 °C for 40 min. M subsamples were individually subjected to microwave cooking in a glass dish with a cover for 3 min. at a power of 539 W (microwave cooker Amica AMSF20M, Amica Wronki S.A., Wronki, Poland). The average inner temperature of M fillets measured with a thermocouple immediately after termination of cooking was 83 °C ± 4 °C.

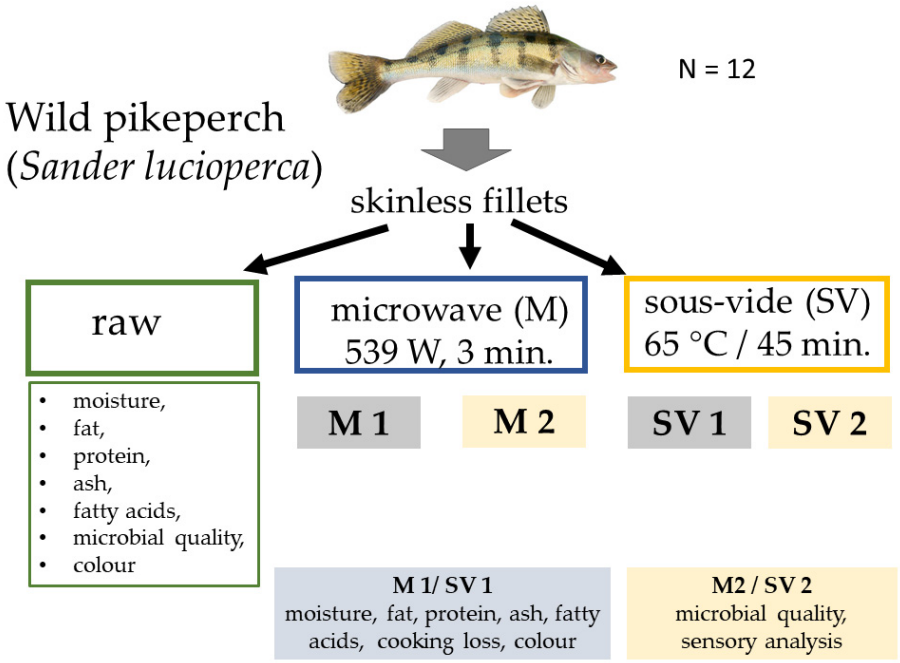

Figure 1. The experiment design in terms of performed analyses (M1—microwave-cooked sub-sample used to assess chemical composition, cooking loss, and colour; M2—microwave-cooked sub-sample used to assess microbial and sensory quality; SV1—sous-vide-cooked sub-sample used to assess chemical composition, cooking loss, and colour; SV2—sous-vide-cooked sub-sample used to assess microbial and sensory quality; the number of fish N = 12, the number of fillets n = 24; from each raw fish, M and SV samples were analysed).

2.2. Physico-Chemical Analyses

The colour was measured in triplicate in the dorsal part of raw and cooked fillets on their inner side with Konica Minolta CR-400 chromameter (Sensing Inc., Tokyo, Japan) [9]. Before chemical determinations raw, M and SV samples were ground (mesh size 4 mm). The determinations were performed in duplicate for each sample. Moisture content was determined by drying samples at 103 °C ± 2 °C (PN-ISO 1442:2000 [10]), fat content was measured using cold extraction Folch's method [11] (with chloroform/methanol, 2:1 v/v), protein content was determined according to Kjeldahl's method with 6.25 multiplier, and ash content was measured by sample mineralization at 550–600 °C (AOAC [12]). Cold-extracted fat was used to determine fatty acid composition according to the methodology described in detail in [13]. Separation was done using an Agilent Technologies 7890A gas chromatograph with a flame-ionization detector (FID) and a 30 m 0.32 mm internal diameter fused silica capillary column (matrix active group: poly(ethylene glycol)phase, Supelco, Bellefonte, PA, USA). The results were presented as the relative percentage (% total fatty acids) in raw, microwave cooked, and sous-vide fillets as well as their contents (mg/100 g), which were calculated using total fat content in a sample and coefficient 0.70 for lean fish [14].

2.3. Microbiological Analyses

Prior to microbial analyses, homogenates from pikeperch flesh were prepared using 10 g fish sample cut aseptically from three different positions of the fillet and 90 mL of sterile saline (0.85% NaCl) in a stomacher (Masticator Homogenizer Silver, IUL S.A., Spain). Then, serial dilutions were prepared with the use of the same diluent [1:10 (v/v)]. They were used for determinations of bacterial counts by spreading 0.1 mL of each dilution on the surface of the sterile dry media VRBL agar (Merck, Germany) for *Enterobacteriaceae* (incubation at 37 °C for 24 h), Baird-Parker agar (Merck, Germany) for *Staphylococcus* sp., ALOA agar (Merck, Germany) for *Listeria monocytogenes*, and Slanetz-Bartley agar (Merck,

Germany) for *Enterococcus* sp. (incubation at 37 °C for 48 h). The number of total viable counts (TVC) were determined using nutrient agar (Merck, Germany). An aliquot of 1.0 mL of the sample's serial dilutions was poured on a petri dish and 20 mL of liquid medium (50 °C) was added. The plates were kept at room temperature until the setting of the medium and then at 30 °C for 72 h. The counts were presented as colony forming units per gram (CFU/g) of fish tissue.

2.4. Sensory Analysis

The analysis was carried out just after the termination of each thermal treatment according to Modzelewska-Kapituła et al. [15]. Samples (approx. 2.0 cm × 2.0 cm) were evaluated by 6 assessors (in total, four sessions in which 6 samples were evaluated). Colour, aroma, texture, juiciness, and taste were determined using a 5-point scale, with detailed descriptions for each point and each attribute [15]. Briefly, in the case of colour, 5 points indicated that sample colour was homogeneous and typical, and 1 point that it was very inhomogeneous; for aroma, 5 points indicated a typical, clearly perceptible aroma, whereas 1 point referred to a strong foreign aroma; for texture, 5 points were given to firm, particularly tender samples, whereas 1 point corresponded to very soft or very hard, fibrous samples; for juiciness, 5 points indicated very juicy samples, whereas 1 point referred to very dry texture; for taste, 5 points were given to samples that exhibited desirable, typical, and intense taste with no foreign aftertaste, whereas 1 point indicated samples with atypical taste and strong foreign aftertaste [15].

2.5. Statistical Analysis

The results are presented as means with standard error of the mean (SEM). The experiment was a single factor design, completely randomized. Each variable, excluding sensory evaluation attributes, was tested for normal distribution using the Shapiro-Wilk's test and for homogeneity of variance with Levene's test. These variables, which showed a normal distribution and homogeneity of variance, were subjected to variance analysis and Tukey's honest significant difference (HSD) test to investigate differences between groups. In the case of variables that did not fulfil the assumption of normal distribution and/or variance homogeneity, a non-parametric Kruskal–Wallis test was applied. The following variables were analysed using a variance analysis: moisture, fat, exudative moisture contents, a*, and fatty acids proportions and contents, whereas L*, b* were analysed using the non-parametric test. The sensory quality scores were analysed with a non-parametric U Mann-Whitney test (Statistica 13.3, Tibco Software Inc., Palo Alto, CA, USA).

3. Results

3.1. The Influence of Cooking Method on Physico-Chemical Attributes and Sensory Quality

The proximate composition and colour of raw, microwaved, and sous-vide-cooked pikeperch fillets are shown in Table 1. As a result of cooking, irrespective of the method used, the moisture content decreased whereas the protein content increased ($p < 0.001$). The fat content in microwave-cooked samples resembled that of the raw material and it was lower than in sous-vide samples. Differences in ash content between samples were not of statistical significance ($p > 0.05$).

In terms of colour, regardless of the method used, cooking caused an increase in the lightness (L*) and the yellowness (b*), and a decrease in the redness (a*) (Table 1). In SV and M samples, negative values of a* were noted, indicating green hues in the colour of cooked pikeperch. However, there were no differences between SV and M samples, which indicates that they changed the ready-to-eat fillets colour in a similar way. Samples SV and M were scored similarly in the sensory assessment (Table 2, $p > 0.05$). Moreover, both treatments received high scores. Average scores for all evaluated sensory attributes were in the range of 4.5 to 4.9 in the 5-point scale, which indicated a very good eating quality.

Table 1. Comparison of the chemical composition and colour of raw and cooked wild pikeperch fillets (mean values with standard error of mean).

Attribute	Raw	Microwave Cooked	Sous-Vide Cooked	*p* Value
Moisture (%)	$78.88^{a} \pm 0.08$	$74.66^{b} \pm 0.40$	$74.37^{b} \pm 0.26$	***
Protein (%)	$19.02^{b} \pm 0.14$	$23.24^{a} \pm 0.48$	$23.37^{a} \pm 0.31$	***
Fat (%)	$0.40^{b} \pm 0.02$	$0.42^{b} \pm 0.03$	$0.52^{a} \pm 0.04$	*
Ash (%)	1.21 ± 0.01	1.15 ± 0.21	1.20 ± 0.03	NS
Cooking loss (%)	-	$9.21^{b} \pm 0.71$	$22.19^{a} \pm 0.66$	***
L*	$35.03^{b} \pm 0.29$	$63.15^{a} \pm 1.30$	$68.42^{a} \pm 1.01$	***
a*	$0.46^{a} \pm 0.08$	$-0.65^{b} \pm 0.11$	$-0.57^{b} \pm 0.09$	***
b*	$-0.99^{b} \pm 0.11$	$9.62^{a} \pm 0.73$	$10.91^{a} \pm 0.33$	***

[a,b]—mean values in rows with different superscript differ significantly; * $p < 0.05$; *** $p < 0.001$; NS—non-significant differences ($p > 0.05$); L*—lightness from 0 (black) to 100 (white); a*—positive values indicate red hues, negative values indicate green hues; b*—positive values indicate yellow hues, negative values indicate blue hues.

Table 2. Comparison of sensory quality of microwave- and sous-vide-cooked wild pikeperch fillets (mean values with standard error of mean).

Attribute	Microwave Cooked	Sous-Vide Cooked	*p* Value
Colour	4.8 ± 0.1	4.9 ± 0.1	NS
Aroma	4.6 ± 0.1	4.6 ± 0.1	NS
Texture	4.7 ± 0.1	4.6 ± 0.1	NS
Juiciness	4.5 ± 0.1	4.6 ± 0.1	NS
Taste	4.9 ± 0.1	4.8 ± 0.1	NS

NS—non-significant differences ($p > 0.05$); sensory quality points from 1 to 5.

3.2. The Influence of Cooking Method on Microbial Quality

Both thermal treatments reduced the number of microbiota detected in raw pikeperch muscle tissue such as TVC, total *Enterobacteriaceae*, and *Staphylococcus* sp. (Table 3). A lower number of TVC was found in M compared with SV samples (20 CFU/g compared with 485 CFU/g, respectively). Treatments did not differ in the counts of *Enterobacteriaceae*, *Enterococcus* sp., *Listeria monocytogenes*, and *Staphylococcus* sp., which were below the detection level of 100 CFU/g in cooked samples (Table 3).

Table 3. Results of microbial assessment of raw, microwave oven- and sous-vide-cooked pikeperch fillets (CFU/g).

Bacteria Species/Group	Raw	Microwave Cooked	Sous-Vide Cooked
TVC	4.04×10^{6}	2.00×10^{1}	4.85×10^{2}
Enterobacteriaceae	1.76×10^{6}	<100	<100
Enterococcus sp.	<100	<100	<100
Listeria monocytogenes	<100	<100	<100
Staphylococcus sp.	1.20×10^{2}	<100	<100

TVC—total viable counts; CFU/g—colony forming units.

3.3. The Influence of Cooking Method on Fatty Acid Composition and Contents

Fatty acid proportions in raw, M and SV samples are shown in Table 4. Slight differences between raw and cooked samples were detected. The only significant differences were noted in terms of C16:0, where SV samples showed a lower proportion compared with raw samples, and the sum of saturated fatty acids (SFAs), where lower values were noted in SV and M samples compared to raw pikeperch tissue.

Table 4. Proportions of fatty acids (% of total) in raw, microwave oven- and sous-vide-cooked pikeperch fillets (mean values with standard error of mean).

Fatty Acid	Raw	Microwave Cooked	Sous-Vide Cooked	*p* Value
Saturated fatty acids (SFAs)				
C 12:0	0.19 ± 0.02	0.16 ± 0.01	0.18 ± 0.02	NS
C 14:0	4.31 ± 0.19	4.02 ± 0.25	3.78 ± 0.07	NS
C 15:0	1.07 ± 0.06	1.02 ± 0.02	0.89 ± 0.09	NS
C 16:0	22.23 ^{a} ± 0.69	20.04 ^{ab} ± 0.51	19.33 ^{b} ± 0.55	*
C 17:0	0.92 ± 0.04	0.82 ± 0.04	0.88 ± 0.05	NS
C 18:0	4.03 ± 0.25	3.48 ± 0.24	3.43 ± 0.13	NS
C 20:0	0.15 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	NS
Monounsaturated fatty acids (MUFAs)				
C 14:1	0.19 ± 0.01	0.17 ± 0.02	0.17 ± 0.01	NS
C 16:1	9.10 ± 1.48	12.11 ± 1.14	11.63 ± 0.90	NS
C 17:1	1.31 ± 0.07	1.32 ± 0.10	1.23 ± 0.06	NS
C 18:1 cis9	16.93 ± 0.59	16.50 ± 0.41	16.04 ± 0.67	NS
C 18:1 cis11	4.31 ± 0.19	4.1 ± 0.17	3.92 ± 0.17	NS
C 20:1 n-9	0.51 ± 0.02	0.50 ± 0.01	0.53 ± 0.02	NS
Polyunsaturated fatty acids (PUFAs)				
C 18:2 n-6	4.61 ± 0.23	4.42 ± 0.24	4.55 ± 0.27	NS
C 18:3 n-6	0.41 ± 0.02	0.41 ± 0.02	0.40 ± 0.02	NS
C 18:3 n-3	4.23 ± 0.25	4.36 ±0.36	4.31 ± 0.26	NS
C 18:4 n-3	0.94 ± 0.07	0.99 ± 0.07	1.02 ± 0.07	NS
C 20:2 n-6	0.33 ± 0.01	0.32 ± 0.01	0.36 ± 0.02	NS
C 20:3 n-6	0.33 ± 0.01	0.33 ± 0.01	0.33 ± 0.01	NS
C 20:4 n-6	4.20 ± 0.14	4.22 ± 0.34	4.44 ± 0.22	NS
C 20:3 n-3	0.48 ± 0.03	0.50 ± 0.02	0.53 ± 0.03	NS
C 20:4 n-3	1.14 ± 0.07	1.17 ± 0.06	1.26 ± 0.12	NS
C 20:5 n-3 (EPA)	5.70 ± 0.19	5.84 ± 0.29	6.22 ± 0.44	NS
C 22:5 n-6	0.74 ± 0.05	0.74 ± 0.10	0.96 ± 0.11	NS
C 22:5 n-3 (DPA)	1.69 ± 0.07	1.80 ± 0.07	1.90 ± 0.09	NS
C 22:6 n-3 (DHA)	9.96 ± 0.52	10.45 ± 0.91	11.58 ± 0.98	NS
SFA	32.90 ^{a} ± 0.88	29.68 ^{b} ± 0.47	28.63 ^{b} ± 0.65	**
MUFA	32.35 ± 1.35	34.77 ± 1.64	33.51 ± 1.68	NS
PUFA	34.75 ± 0.78	35.55 ± 1.35	37.86 ± 1.57	NS
n-3	24.14 ± 0.64	25.11 ± 1.04	26.82 ± 1.50	NS
n-6	10.61 ± 0.24	10.44 ± 0.33	11.04 ± 0.15	NS
n-3/n-6	2.28 ± 0.06	2.40 ± 0.04	2.43 ± 0.13	NS

EPA—eicosapentaenoic acid, DPA—docosapentaenoic acid, DHA—docosahexaenoic acid; ^{a,b}—mean values in rows with different superscript differ significantly; * $p < 0.05$; ** $p < 0.01$; NS—non-significant differences ($p > 0.05$).

Samples SV and M differed significantly in terms of fat concentration, which resulted in significant differences in the contents of some fatty acids (Table 5). Generally, SV showed a higher content of total monounsaturated fatty acids (MUFAs), total PUFAs, n-3, and n-6 than raw fillet tissue, whereas there were no significant differences between SV and M, except for total n-6, C20:1 n-9 and C18:2 n-6. This indicates that PUFAs, which are valuable from a nutritional perspective and include eicosapentaenoic (EPA), docosapentaenoic (DPA), and docosahexaenoic (DHA) acids, were well preserved in pikeperch tissue and no losses were detected.

Table 5. Contents of fatty acids (mg/100 g) in raw, microwave oven- and sous-vide-cooked pikeperch fillets (mean values with standard error of mean).

Fatty Acid	Raw	Microwave Cooked	Sous-Vide Cooked	*p* Value
Saturated fatty acids (SFAs)				
C 12:0	0.50 ± 0.03	0.48 ± 0.04	0.66 ± 0.11	NS
C 14:0	11.94 ± 0.76	11.66 ± 0.70	13.74 ± 1.22	NS
C 15:0	2.94 ± 0.20	2.93 ± 0.17	3.22 ± 0.27	NS
C 16:0	62.10 ± 4.17	59.29 ± 5.42	70.87 ± 7.52	NS
C 17:0	2.60 ± 0.23	2.44 ± 0.28	3.23 ± 0.36	NS
C 18:0	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	NS
C 20:0	0.43 ± 0.03	0.43 ± 0.04	0.54 ± 0.05	NS
Monounsaturated fatty acids (MUFAs)				
C 14:1	0.52 ± 0.04	0.49 ± 0.04	0.59 ± 0.04	NS
C 16:1	25.58 ^{b} ± 4.13	34.69 ^{ab} ± 1.94	41.34 ^{a} ± 2.91	*
C 17:1	3.57 ^{b} ± 0.14	3.78 ^{ab} ± 0.09	4.40 ^{a} ± 0.32	*
C 18:1 cis9	46.39 ^{b} ± 1.68	48.48 ^{ab} ± 3.56	58.18 ^{a} ± 5.56	*
C 18:1 cis11	11.79 ± 0.49	12.10 ±0.47	14.13 ± 1.16	NS
C 20:1 n-9	1.41 ^{b} ± 0.06	1.47 ^{b} ± 0.09	1.94 ^{a} ± 0.21	**
Polyunsaturated fatty acids (PUFAs)				
C 18:2 n-6	12.55 ^{b} ± 0.51	12.83 ^{b} ± 0.72	16.29 ^{a} ± 1.18	**
C 18:3 n-6	1.13 ^{b} ± 0.05	1.19 ^{ab} ± 0.04	1.43 ^{a} ± 0.09	*
C 18:3 n-3	11.59 ^{b} ± 0.68	12.65 ^{ab} ± 1.00	15.3 ^{a} ± 0.74	*
C 18:4 n-3	2.60 ^{b} ± 0.22	2.86 ^{ab} ± 0.17	3.65 ^{a} ± 0.34	*
C 20:2 n-6	0.9 ^{b} ± 0.07	0.96 ^{ab} ± 0.09	1.32 ^{a} ± 0.12	*
C 20:3 n-6	0.90 ^{b} ± 0.04	0.96 ^{ab} ± 0.04	1.18 ^{a} ± 0.09	**
C 20:4 n-6	11.77 ± 0.83	12.61 ± 1.69	16.34 ± 1.76	NS
C 20:3 n-3	1.33 ^{b} ± 0.11	1.47 ^{ab} ± 0.13	1.92 ^{a} ± 0.18	*
C 20:4 n-3	3.21 ± 0.30	3.46 ± 0.32	4.59 ± 0.59	NS
C 20:5 n-3 (EPA)	16.01 ^{b} ± 1.15	17.30 ^{ab} ± 1.79	22.85 ^{a} ± 2.65	*
C 22:5 n-6	2.10 ^{b} ± 0.23	2.23 ^{ab} ± 0.44	3.55 ^{a} ± 0.49	*
C 22:5 n-3 (DPA)	4.68 ^{b} ± 0.28	5.29 ^{ab} ± 0.44	6.86 ^{a} ± 0.55	**
C 22:6 n-3 (DHA)	28.30 ^{b} ± 2.65	31.35 ^{ab} ± 4.36	42.75 ^{a} ± 5.28	*
SFA	91.92 ± 6.08	87.58 ± 7.30	104.90 ± 10.83	NS
MUFA	89.25 ^{b} ± 4.93	101.02 ^{ab} ± 4.67	120.58 ^{a} ± 9.89	**
PUFA	97.08 ^{b} ± 6.04	105.17 ^{ab} ± 9.75	138.05 ^{a} ± 12.94	*
n-3	67.7 ^{b} ± 4.66	74.38 ^{ab} ± 7.19	97.94 ^{a} ± 9.93	*
n-6	29.37 ^{b} ± 1.42	30.79 ^{b} ± 2.58	40.12 ^{a} ± 3.34	**

EPA—eicosapentaenoic acid, DPA—docosapentaenoic acid, DHA—docosahexaenoic acid; ^{a,b}—mean values in rows with different superscript differ significantly; * $p < 0.05$; ** $p < 0.01$; NS—non-significant differences ($p > 0.05$).

4. Discussion

Fat content and its composition are important quality attributes from a nutritional perspective. Wild pikeperch fillets used in this study showed a very low fat content (0.4%), therefore they could be recommended as part of weight-loss diets. Wild pikeperch are recognized as lean fish, but upon comparing results with findings of other authors, it was found that the fat content in the muscle tissue of fish used in this study was lower than that reported by Bouriga et al. [16] (1.9%) and higher than in a pikeperch from the Vistula Lagoon reported by Polak-Juszczak and Adamczyk [1] (0.13%).

It was noted that SV resulted in a significant increase in fat content compared with raw fish and microwave-cooked samples. It might be explained by a higher cooking loss in SV fillets compared with M samples, which was over twice as much as noted in M samples (22.2% vs. 9.2%, respectively). Cooking losses are a direct result of the contraction of meat fibres in response to heating, which forces fluid (water with water-soluble ingredients) to be expelled from the muscle tissue [17]. Although the final temperature obtained in M samples was higher than in SV (83 °C vs. 65 °C, respectively), the time it affected muscle

tissue was much shorter, which affected cooking loss. The results could also indirectly indicate that that degree of muscle fibre shrinkage in M samples was lower than in SV.

In the present study, significant differences in the colour between raw and cooked fillets were noted. The increase in lightness as a result of muscle tissue cooking results from protein precipitation and solubility reduction [18]. The colour of raw and cooked fish muscle tissue results from myoglobin content and its forms [19] as well. Thus, colour changes during cooking are also caused by myoglobin denaturation and oxidation [20,21], which occurs more easily in samples cooked under atmospheric conditions [22]. In this study, a reduction in redness was noted in both M and SV treatments as compared with raw fillets, and there was a trend towards lower a* values in M samples ($p > 0.05$) cooked under atmospheric conditions in a microwave oven. Changes in the redness between raw and cooked fillets as a result of cooking may also be partially explained by cooking loss (leakage), which carried away some of the myoglobin and haemoglobin from the muscle tissue [21].

The cooking method did not affect sensory quality of the wild pikeperch fillets, which might be explained by a relatively high temperature used in both treatments, which caused changes in muscle tissue proteins, including a shrinkage of protein structure. At temperatures over 60 °C, which were used in this study in both M and SV treatments, shrinkage occurs both in diameter and in the longitudinal axis of sarcomeres [17]. Although significant differences in cooking loss were noted, suggesting a higher shrinkage of muscle fibres in SV samples, no negative effect on the texture was noted and the M and SV samples were similarly scored. As in the present study, a good sensory quality of SV-cooked (65 °C for 46 min.) seabream was reported by Espinosa et al. [23]. Results obtained thus suggest that both thermal treatments with the parameters proposed in this study could be used for preparing pikeperch without any adverse effect on the sensory quality.

It was proved that microwave cooking was more effective than sous-vide cooking in reducing microbial load and decreased the TVC by 5 to 6 folds, while in the case of sous-vide, it was a 4-fold reduction. This resulted from the different temperature obtained in the centre of the products, which was much higher in M samples (83 °C vs. 65 °C in M and SV samples, respectively), although the time in which the process was conducted was much shorter (3 min. vs. 40 min., respectively). The increase in microbial reduction as a result of increased temperature and time of heat treatment was also noted by González-Fandos et al. [24] in sous-vide rainbow trout.

Microwave cooking and sous-vide were effective in reducing *Staphylococcus* spp. and total *Enterobacteriaceae* below the detection level (100 CFU/g). The number of *Enterococcus* sp. and *Listeria monocytogenes* in the raw pikeperch muscle tissue was below the detection level, and the bacteria were detected in neither M nor SV samples. A similar result in terms of TVC reduction to that obtained in the present study for SV samples was reported by Cai et al. [25] in Russian sturgeon sous-vide cooked at 60 °C for 10 min. In their study, as a result of heating, the number of bacteria decreased from 4 log CFU/g to 2 log CFU/g, and this treatment turned out to be the most effective compared to those carried out at lower temperatures (40 °C and 50 °C). The use of sous-vide at 60 °C for 10 min. enabled to preserve fish products—after 9 days of storage under refrigerated conditions (4 °C), the TVC were below a spoilage limit of 7 log CFU/g [25,26]. Díaz et al. [27] used a higher temperature and a longer time (80 °C for 45 min) than was used in the present study and by Cai et al. [25] for heating salmon fillets and no growth of aerobic and anaerobic psychrotrophs, lactic acid bacteria, and total *Enterobacteriaceae* was noted during 10-week storage. Therefore, it might be concluded that pikeperch products obtained in the present study using the sous-vide technique, after their immediate cooling upon termination of heating, would be suitable for storing for a similar time under similar conditions without the risk of spoilage caused by mesophilic bacteria. Since microwave cooking was carried out without a hermetic packaging of the fillets, no such shelf-life could be expected.

Fatty acid composition (proportions and contents) was determined in raw, microwave-cooked, and sous-vide samples of wild pikeperch fillets. The results of the present study

resembled those by Orlando et al. [28], who studied changes in fatty acid composition of salmon after sous-vide treatment performed under similar conditions (65 °C, 20 min.) to those used in this study and cooked the fish in steam and convection ovens (65 °C for 20 min and 180 °C for 20 min, respectively). They reported that changes in fatty acid composition were marginal, and n-3 fatty acids were well preserved in the cooked fish. The n-3 fatty acids might also be well preserved in salmon even if a higher temperature of sous-vide treatment is used (90 °C for 10 min) [29]. This indicates that both of the cooking methods used in the present study were mild and did not degrade fish fatty acids.

5. Conclusions

Microwave- and sous-vide-cooked pikeperch fillets were similar in chemical composition, except for a higher fat content in sous-vide samples, sensory quality, and fatty acid composition. Microwave cooking was more effective in the reduction of microbiota; however, both treatments produced safe products from a microbial point of view. Both cooking methods preserved polyunsaturated fatty acids well, including n-3, which are precious from a nutritional perspective. Therefore, both of them can be recommended as methods for preparing pikeperch fillets for consumption.

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