Impact of spawning season on fillet quality of wild pikeperch (*Sander lucioperca*)

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Abstract

Pikeperch (*Sander lucioperca*) is a freshwater fish that has become increasingly popular as a food fish. Within this study, the influence of the spawning process on meat quality was investigated. For this purpose, adult pikeperch was examined directly before and after spawning, and compared regarding physical meat parameters and lipid composition. The results indicate that after spawning, the values of the pH, the electrical conductivity and the yellowness value of fillet were significantly higher than those of the animals sampled before spawning. Analysis of the sum of the total lipid content indicates no differences before and after closed season, but differences in the fatty acid profile were present. Despite significant lower MUFA concentrations, the EPA and DHA showed unaffected high contents. Therefore, the fish muscle indicated an equivalent meat quality. Nevertheless, the significant changes of some physical meat quality parameters after spawning season could have a particular impact on the shelf life and storage of the pikeperch fillet, highlighting the need for further research.

Keywords Pikeperch · Texture · Fatty acid composition · Muscle tissue · Quality

Introduction

Pikeperch (*Sander lucioperca*), a species of the family Percidae, has its habitat in fresh and brackish waters in Eurasia. Pikeperch is one of the most popular freshwater fish due to its white, tasty and low-fat, tender meat with few intermuscular bones, that it is also well received even by those who are otherwise less fond of fish.

This popularity is at the same time a reason for the expansion of pikeperch aquaculture [1]. However, compared to other percids like the Eurasian perch (*Perca fluviatilis*), pikeperch is harder to keep in aquaculture because it has a lower tolerance range for many abiotic and biotic factors [2]. However, as this species exhibits a lifelong growth, with a weight of 2–5 kg at a length of 50–70 cm, and even some

specimens have been reported weighing 12–18 kg with a body length of 130 cm [3], the effort could be worthwhile.

In central European aquaculture import quotas rose as the demand increased because the supply could not be covered from domestic waters and breeding facilities [1, 4]. Pikeperch cultivation in aquaculture is still challenging, as aspects like stagnation of gonad development [1] and cannibalism in early larval stages [5] remain problematic. For that reason, pikeperch production for restocking natural populations or directly for selling at the food markets relies on breeders, which are taken from the wild shortly before the spawning season or which are reared in ponds during winter and early spring already.

This reliance on natural populations is not sustainable as the catches of pikeperch are strongly fluctuating and have a declining tendency in the last decades [6]. Reasons for catch rate fluctuations are attributed to insufficient prey fish and absence of brood [7]. Furthermore, the denaturalisation of water plays an important role in the decline of pikeperch stock, as the observed nutrient decline in lakes and rivers has a limiting effect of pikeperch spawning and growth [7].

Animal reproduction is linked to high energetic cost, which often lead to increased mortality or at least reduced somatic growth [8]. Hereby, the amount of energy expenditure is species-specific and depends as well on behavioural

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aspects. In pikeperch, the energetic costs are caused by defence of breeding sites, courtship, mate guarding, mating and shedding of gametes, and parental care during the embryonic stage [7]. Depending on the water temperature and photoperiod, the spawning season mainly takes place between April and May, but can start as early as February or last until July [9]. The temperature has to reach 10–14 °C before spawning starts. In the wild, pikeperch prefers rather cloudy waters with hard bottom [9]. The males establish a territory by digging shallow depressions of about 50 cm in diameter and 5–10 cm deep in sand or gravel, where the female sanders spawn [9]. Each female spawns only once a year and lays all her eggs at once, which are then inseminated by the male. In pikeperch, sexual maturity starts commonly after 4 years, but can begin already at three or even as late as 10 years.

Pikeperch is one of the most expensive fish in Europe used for human consumption. Numerous methods have been proposed to determine various aspects of fish quality, which can be divided into subjective criteria of the consumers and objectively measurable values. These can be represented by sensory analyses (subjective criteria) or physical, chemical and microbiological analyses (objective criteria) [10]. However, there are only few studies available with single aspects of its meat quality [11–14]. For the first time, Komolka et al. (2020) examined pikeperch obtained from aquaculture in terms of physical meat parameters and compared them with two salmonids and the European perch [15]. This study showed that the pikeperch grows well in aquaculture, but the physical meat quality could be improved [15]. Pikeperch, a lean fish with a low lipid content of about 0.5%, is recommended as an important polyunsaturated fatty acid (PUFA) source due to its comparatively high n-3 PUFA concentrations. Studies on the fatty acid composition are commonly combined with food composition and its implications on the specimens' growth as done for fingerlings by Schulz et al.

(2008) [16] and Nyina-wamwiza et al. (2005) [17] and for adults by Celik et al. (2005) [18]. For adults of the closely related walleye (*Sander vitreus*), the variability of the fatty acid content of the fillet was additionally evaluated regarding water eutrophication levels, season and body length [19].

Since no in-depth investigations on the meat quality of wild pikeperch have been performed previously, this study will provide information on the physical and nutritional parameter in the fillet of wild *Sander lucioperca* from a natural population and compare these results with previously obtained data on pikeperch from aquaculture. Furthermore, this study will include pre-spawning and post-spawning surveys on physical and nutritional quality of pikeperch fillet to account for any seasonal changes in the nutritional parameters (Fig. 1).

Materials and methods

Animals

Mature *Sander lucioperca* (total $n=23$) were obtained from a fishery at the Hohen Sprenz Lake in Mecklenburg-Western Pomerania, Germany. Spawners were caught during late winter times and were kept in net cages ($4.0 \times 3.2 \times 3.0$ m) in the lake in a group of 20 animals. Spawning occurred naturally on coco mats without addition of hormones. Animals were fed with fresh fish from the lake as natural food source. Due to legal regulations of the fish closed season (spawning season), specimen were collected in the week before and directly the week after the fish closed season within 2 years. Animals that had not spawned were excluded from the study. Due to colder temperatures in the second year, fish closed season was extended as spawning took place on average 2 weeks later. Before spawning season in mid-March, 13 animals were taken (8 females and 5 males) and after

Fig. 1 Graphical summary of the study. To understand the influence of spawning time on fillet quality, the physical parameter and lipid composition were examined on pikeperch fillet before and after spawning season

spawning (end of May 2020 and mid-June 2021), 10 animals were taken (4 females and 6 males), each number distributed over the 2 years. All fish were transported alive from the Hohen Spreng Lake to the Research Institute for Farm Animal Biology (FBN) in Dummerstorf, Germany, using a transport tank with additional oxygen supply. For animal welfare reason and to reduce stress, the animals were transported in groups of no more than five specimen. Sampling and processing of each sampling group took place within 1–2 days.

Sampling and physical meat quality

Following the Directive 2010/63/EU and the German Animal Welfare Act (§ 4(3) TierSchG), fish were stunned with a beat to the head and killed by a stab through the heart and by severing the spinal cord behind the head. Total length, total weight, circumference and carcass weight (without head and internal organs) were measured.

Analyses of physical meat quality were performed as described in Komolka et al. (2020), [15]. To examine the current quality directly after slaughter and the *post-mortem* process, the pH value, electrical conductivity and impulse impedance were measured 5 min and 1 h after death for each fillet. The electrical conductivity is expressed in millisiemens per centimetre (mS/cm) and is a measure for the cell membrane destruction. High conductivity indicates more free cell fluid. The impulse impedance is similar to the conductivity, but works with an array of frequencies to detect cell membrane degradation much more accurately. The impulse impedance is expressed by the non-dimensional Py value due to the array principle. Comparing these parameters allows an insight into the degradation process and spoilage of the fish [20, 21]. Detection of pH values were performed with a pH-Star (Matthäus, Germany), electrical conductivity using the LF-Star (Matthäus, Germany) and impulse impedance was measured with the Meat Check 150 (sigma electronic, Germany), respectively.

The maximum shear force of the fillet was examined 30 min *post-mortem* via Texture Analyser TA.XTplus (Winopal, Germany) with a Warner–Bratzler blade to describe the tenderness of the fillet. For the shear force, the mean $\pm$ SEM of three cuts were performed on the right fillet having a size of 4 $\times$ 8 cm. Sections were made crosswise to the muscle fiber orientation and parallel to the horizontal septum at room temperature. The water holding capacity (WHC) was determined with the Hypress filter-press method [22]. For each specimen, three portions of the fresh fillet weighting 0.3 $\pm$ 0.05 g were placed on a 6 $\times$ 6 cm filter paper, which exhibited a varnish circle of 4 cm in diameter to ensure the complete removal of the pressed meat before weighing. The samples on the filter paper were constantly pressed with a force of 35 kg for 5 min in the Hypress device. Afterwards,

the meat was removed from the filter paper and the filter was weighed again to calculate the weight difference. WHC is expressed in percent of the initial weight of the sample [15]. Analysis of water and ash content was carried out according to standard procedures [23].

The colour was analysed according to the L*a*b* CIELab system, in which the L*-value describes the brightness between 0 (black) and 100 (white), the a*-value the red–green range and the b*-value the blue–yellow range. The colour (mean $\pm$ SEM) was measured at three positions each on the dorsal and ventral fillet along the horizontal septum using a Portable Spectrophotometer CM-600d (Konica Minolta, Germany) 10 min *post-mortem*. The measurement geometry was 8 mm (MAV) using D65 light with an observation angle of 2°.

Lipid extraction and fatty acid ester preparation

Immediately after sampling, the pikeperch fillet samples were cut into small pieces, frozen in liquid nitrogen and homogenised under liquid nitrogen using a stainless steel grinding mill (mill M20, IKA, Staufen, Germany). After homogenisation, the muscle samples were stored at -80°C until total lipid extraction. For lipid extraction, approx. 1 g of frozen fillet was weighed into a tube. Each tube contained 20 pieces of 2.8 mm bulk beads and 2 pieces of 5 mm bulk beads (Zirconium oxide beads, Bertin Technologies, Precellys). All solvents contained 0.005% (w/v) of t-butylhydroxytoluene (BHT) to prevent PUFA oxidation. After addition of 3 mL methanol and nonadecanoic acid (C19:0) as an internal standard, the extracts (in duplicate) were homogenised 3 times at 25 s intervals at 4°C at 6500 rpm using a homogeniser (Precellys Evolution, Bertin Technologies). The homogenates were vortexed and transferred to Pyrex-Tubes (Pyrex England) containing 8 mL of chloroform. The Precellys Tubes were washed two times with 1 mL methanol and added to the Pyrex Tubes. After filtration, the lipid extracts were stored at 5°C for 18 h in the dark and subsequently washed with 0.02% CaCl_2 solution. The organic phase was separated and dried with a mixture of Na_2SO_4 and K_2CO_3 (10:1, w/w), and the solvent was subsequently removed using vacuum centrifuge ScanSpeed 40 (Labo-Gene, Allerød, Denmark) at 2000 rpm/min, 30°C , 30 min. The lipid extracts were re-dissolved in 300 μL of toluene, and a 25 mg aliquot was used for methyl ester preparation [24]. Briefly, for transmethylation, 2 mL of 0.5 M sodium methoxide in methanol was added to the lipid extracts, which were shaken in a 60°C water bath for 10 min. Subsequently, 1 mL of 14% boron trifluoride in methanol was added to the mixture, which was then shaken for an additional 10 min at 60°C . The fatty acid methyl esters (FAMES) were extracted

twice with 2 mL of *n*-hexane and stored at $-18\text{ }^{\circ}\text{C}$ until use for high-resolution gas chromatography (HR-GC) analysis.

Fatty acid analysis

The fatty acid analysis was achieved using HR-GC with a CP-Sil 88 CB column ($100\text{ m}\times 0.25\text{ mm}$, Agilent, Santa Clara, CA, United States) that was installed in a PerkinElmer gas chromatograph CLARUS 680 with a flame ionisation detector and split injection (PerkinElmer Instruments, Waltham, Massachusetts, U.S.A.). The details of fatty acid analysis were recently described by Kalbe et al. (2019) [25]. Briefly, the oven temperature program was $150\text{ }^{\circ}\text{C}-5\text{ min}-2^{\circ}/\text{min}-200\text{ }^{\circ}\text{C}-10\text{ min}-1^{\circ}/\text{min}-225\text{ }^{\circ}\text{C}-20\text{ min}$. Hydrogen was used as the carrier gas at a flow rate of 1 mL min^{-1} . The split ratio was 1:20, and the injector and detector were set at 260 and $280\text{ }^{\circ}\text{C}$, respectively. The quantification of fatty acids was performed using C19:0 as the internal standard. For the calibration procedure, the reference standard mixture “Sigma FAME” (Sigma-Aldrich, Deisenhofen, Germany), the methyl ester of C18:1*cis*-11, C22:5*n*-3, and C18:2*cis*-9,*trans*-11 (Matreya, State College, PA, USA), C22:4*n*-6 (Sigma-Aldrich, Deisenhofen, Germany), and C18:4*n*-3 (Larodan, Limhamn, Sweden) were used. The five-point calibration of single fatty acids ranged between 16 and $415\text{ }\mu\text{g/mL}$ and was assessed after GC analysis of five samples. Fatty acid concentrations are displayed as $\text{mg}/100\text{ g}$ pikeperch fillet.

Statistics

Statistical analysis was carried out using SAS software version 9.4 (Statistical Analysis institute Inc., USA). The proofs of sex effects and spawning effects were carried out by two-way ANOVA. The data of the physical meat quality and lipid analysis were analysed based on the mean $\pm$ SEM (standard error of means) and Student’s *t* test variance. For comparison of the two time points of pH, EC, and impulse impedance, paired *t* test procedure was applied. Results are displayed in means $\pm$ SEM with a significance level of $p < 0.05$. Graphs were created with Graphpad Prism 8 (Graphpad Software, USA).

Results

There were no significant differences between the genders in the examinations. For this reason, the results have been combined for both genders in the following analyses.

Animals

The animals showed no significant differences in their morphometric parameters before and after spawning season. Before spawning season, animals had a total length of $45.25 \pm 0.57\text{ cm}$ and a circumference of $22.66 \pm 0.40\text{ cm}$ and after spawning $46.79 \pm 1.52\text{ cm}$ (total length) and $23.08 \pm 0.61\text{ cm}$ (circumference). Additionally, no significant differences in weight were recorded ($p = 0.438$), but the total weight of the animals was around 54 g higher in the group “after spawning” with $808.90 \pm 65.64\text{ g}$ compared to the group before spawning with $755.08 \pm 32.25\text{ g}$. Consequently, no significant differences ($p = 0.152$) were found in carcass weight, which was $440.75 \pm 25.37\text{ g}$ before spawning and $515.30 \pm 45.81\text{ g}$ after spawning.

Physical meat quality

Most of the physical parameters did not reveal a significant change from before to after spawning season (Fig. 2). At both time points, the water holding capacity was around 20% (Fig. 2a) and the shear force at around 81 N (Fig. 2b). In terms of body composition, the water content was $78.66 \pm 0.20\%$ before and $78.59 \pm 0.35\%$ after spawning as well as the ash content of about 1.2% showed no significant changes in either sample groups (Fig. 2c).

Significant changes were present in the pH, electrical conductivity and the impulse impedance. Measuring these parameters 5 min and 1 h *post-mortem*, it is evident that the pH value within the fillet decreased much faster before than after the spawning period. Thus, before spawning period, the pH value exhibited values of 7.20 ± 0.06 immediately after slaughter and 6.69 ± 0.03 one hour later. After spawning, the pH of the fillet was already lower 5 min *post-mortem* with 7.06 ± 0.05 and decrease significantly, but less compared to the sample group before spawning. In the after spawning group, the pH values of the fillet had been 6.85 ± 0.03 after 1 h *post-mortem* (Fig. 2d). For that reason, besides the significant change of the two measuring time points in both experimental groups, the pH value after 1 h remains on a significant higher level after spawning compared to the fillet taken from pikeperch before spawning. Furthermore, the electrical conductivity increased significantly after one hour (Fig. 2e) in both groups. Again, this increase was significantly stronger in the fillets sampled after spawning. Analysis of the impulse impedance did not detect any significant differences between the experimental groups. The values were similar between the groups both after 5 min and after 1 h, with the expected significant reduction (Fig. 2f). Analysis of the meat colour revealed a significant difference in yellowness. Before spawning season, the fillet had values of 4.24 ± 0.32 and after the spawning season the values

Fig. 2 Overview of fish meat quality parameter. Box–whisker plot of water holding capacity (A), maximal shear force (B), water and ash content (w-water, a-ash, C), pH value (D), electrical conductivity (E) and impulse impedance (F) are illustrated for pikeperch before (white boxes, $n=13$) and after (grey boxes, $n=10$) spawning season. PH value (D), electrical conductivity (E), and impulse impedance (F) were measured five minutes and one hour after slaughter. Significant differences are shown as $*p<0.05$ (Student's t test, SAS 9.4)

Table 1 Overview of colour parameters. Mean and SEM of lightness, redness, and yellowness for the fillets of *Sander lucioperca* before and after spawning season

	Before spawning ($n=13$)		After spawning ($n=10$)		p value
	Mean	$\pm$ SEM	Mean	$\pm$ SEM	
Lightness	51.25	1.14	50.63	1.23	0.716
Redness	0.11	0.11	-0.23	0.18	0.112
yellowness	4.24	0.32	1.96	0.32	$* < .0001$

Significant differences are shown as $*p<0.05$ (Student's t test, SAS 9.4)

decreased to 1.92 ± 0.32 (Table 1). The redness and the lightness were similar at both sampling periods.

Fatty acid composition

Before spawning season, animals had a total lipid content of $0.51 \pm 0.02\%$ and after spawning $0.47 \pm 0.02\%$ without significant differences. Overall, the evaluations exhibited similar amounts of the fatty acid content before and after the spawning season with exception of the monounsaturated

Fig. 3 Overview of the sum fatty acid concentrations in muscle of *Sander lucioperca*. Box–whisker plot of sum fatty acid concentrations (SFA—saturated fatty acids, MUFA—monounsaturated fatty acids, PUFA—polyunsaturated fatty acids, $n-3$ PUFA, $n-6$ PUFA) of pikeperch before (white boxes, $n=13$) and after (grey boxes, $n=10$) spawning season. Significant differences are shown as $*p<0.05$ (Student's t test, SAS 9.4)

fatty acids (MUFA). The total amount of MUFA in pikeperch fillet decreased significantly during spawning season from 133.45 ± 9.43 mg to 101.48 ± 7.80 mg per 100 g muscle (Fig. 3, Table 1). The lowest concentrations were measured

for *n*-6 PUFAs followed by MUFA and saturated fatty acids (SFA). The *n*-3 PUFAs exhibited the highest values (Fig. 3) and therefore, the sum of all PUFAs displayed the highest amounts in both examined time points. The detection of the single fatty acids indicated significant lower values of C20:0 and C21:0 in contrast to a higher C18:0 content in the SFA class after spawning. Furthermore, significant lower amounts of fatty acids in 100 g muscle tissue after spawning were detected in C17:1*cis*-9, C18:1*cis*-9, C18:1*cis*-11, C20:1*cis*-11, and C22:1*cis*-13 (MUFA group). The same statement applies to the fatty acids C18:3*n*-3 and C18:4*n*-3 of the *n*-3 PUFA as well C18:3*n*-6 and C20:3*n*-6 of the *n*-6 PUFA (Table 2).

Although some individual fatty acids contents were significantly altered, the sum concentrations of SFA, *n*-3 PUFA, *n*-6 PUFA and total PUFA remained unchanged with respect to spawning season (Fig. 3).

Discussion

In this study, wild pikeperch were examined before and after the spawning period in regard to their physical meat quality and lipid composition. The aim was to determine the influence of the spawning period on meat quality and to compare the parameters with pikeperch from aquaculture systems. The results gained from the wild pikeperch indicated an overall good fillet quality at both times of sampling. Furthermore, the physical meat quality was better in wild pikeperch than in the aquaculture pikeperch, which was examined in a former project [15]. However, differences between pre- and post-spawning pikeperch muscle quality were evident. The pH had an initial value of just over seven and dropped about 7%, respectively, 3% within the first hour. The initial values are typical for fish muscle and comparable to the values received from aquaculture pikeperch in a former study [15]. However, there is a great variation in glycogen levels between different fish species, which are still not fully described [26]. High glycogen levels are prerequisite for high amounts of lactate in the *post-mortem* process, which lead therefore to a faster decrease of the pH in fish meat [27, 28]. The significant differences between the measured pH values show a more intense dropdown before the spawning period, which could be explained by a higher glycogen loss during spawning. As rested, fish contains more glycogen than exhausted or stressed fish, like e.g. after spawning, the lower pH for the meat could be expected in the pre-spawning fish [10]. Additionally, as the slaughter procedure was the same in all animals, the difference in the decreases of the pH values in time can be explained by the stress of spawning. In comparison to the described prolonged stress, acute stress increases muscle actions and activates anaerobic glycolysis, which would result in a much lower initial pH value [29].

Table 2 Single fatty acid concentrations (mg/100 g muscle tissue) before and after spawning

Fatty acid in mg/100 g fish	Before spawning (<i>n</i> = 13)		After spawning (<i>n</i> = 10)		<i>p</i> value
	Mean	± SE	Mean	± SE	
C8:0	0.89	0.024	0.87	0.032	0.511
C10:0	0.67	0.085	0.57	0.075	0.406
C12:0	0.36	0.028	0.30	0.025	0.138
C13:0	0.04	0.011	0.04	0.012	0.789
C14:0	5.24	0.477	4.78	0.371	0.472
C15:0	1.53	0.093	1.35	0.062	0.150
C16:0	109.8	4.503	111.99	5.093	0.753
C17:0	1.89	0.096	1.97	0.124	0.587
C18:0	27.78	0.778	33.40	2.895	*0.048
C20:0	1.15	0.045	0.98	0.054	*0.020
C21:0	0.30	0.010	0.26	0.012	*0.009
C22:0	0.48	0.025	0.42	0.020	0.097
C23:0	0.55	0.120	0.27	0.027	0.053
C24:0	1.08	0.138	0.85	0.035	0.165
C26:0	1.63	0.600	0.97	0.053	0.343
SFA total	153.45	5.406	159.01	8.100	0.560
C14:1 <i>cis</i> -9	0.12	0.032	0.15	0.029	0.623
C16:1 <i>cis</i> -9	21.10	2.246	19.61	2.185	0.649
C17:1 <i>cis</i> -9	2.96	0.259	1.71	0.259	*0.003
C18:1 <i>trans</i> -9	0.38	0.035	0.34	0.033	0.526
C18:1 <i>trans</i> -11	0.16	0.042	0.13	0.045	0.637
C18:1 <i>cis</i> -9	84.22	8.740	59.80	6.551	*0.046
C18:1 <i>cis</i> -11	17.10	0.693	14.92	0.620	*0.034
C20:1 <i>cis</i> -11	5.91	0.703	3.51	0.505	*0.016
C22:1 <i>cis</i> -13	0.51	0.042	0.36	0.044	*0.023
C24:1 <i>cis</i> -15	1.00	0.064	0.94	0.084	0.602
MUFA total	133.45	9.426	101.48	7.997	*0.021
C18:2 <i>cis</i> -9, <i>trans</i> -11 (CLA)	0.16	0.026	0.18	0.033	0.710
C18:3 <i>n</i> -3 (ALA)	10.68	0.874	6.55	0.466	*0.001
C18:4 <i>n</i> -3 (SA)	1.70	0.167	1.06	0.082	*0.005
C20:3 <i>n</i> -3 (ETA)	1.66	0.111	1.40	0.081	0.086
C22:5 <i>n</i> -3 (DPA)	16.60	1.101	13.96	0.405	0.056
C22:6 <i>n</i> -3 (DHA)	158.42	8.362	146.36	7.748	0.315
C20:5 <i>n</i> -3 (EPA)	33.15	2.789	35.47	1.498	0.509
<i>n</i> -3 PUFA total	222.21	10.636	204.79	8.689	0.238
C18:2 <i>n</i> -6 (LA)	46.87	8.232	29.92	5.718	0.127
C18:3 <i>n</i> -6	0.89	0.059	0.59	0.062	*0.002
C20:2 <i>n</i> -6	2.21	0.228	1.61	0.176	0.062
C20:3 <i>n</i> -6	2.86	0.295	1.98	0.187	*0.030
C20:4 <i>n</i> -6	29.50	2.835	32.67	2.793	0.443
C22:2 <i>n</i> -6	0.48	0.131	0.23	0.040	0.125
C22:4 <i>n</i> -6	3.22	0.275	2.98	0.200	0.500
C22:5 <i>n</i> -6	12.64	0.974	11.28	0.930	0.334
<i>n</i> -6 PUFA total	98.68	6.628	81.26	4.583	0.055
C20:3 <i>n</i> -9	0.24	0.032	0.27	0.023	0.483
PUFA total	321.29	15.031	286.50	12.852	0.105

Results are displayed as mean and standard error (SE) with statistical level **p* < 0.05 (Student's *t* test, SAS 9.4)

Therefore, *rigor mortis* develops much faster in stressed fishes [30]. On the other hand, during prolonged stress, lactic acid production is stopped and energy reserves are used. In this case, no changes in pH value over a longer period would be evident [28]. Similar to the pH, the electrical conductivity exhibited an intense change after one hour, caused also by the change in intra- and extracellular electrolyte balance. Impulse impedance decreases and electrical conductivity increases as cell membranes collapse and intracellular ions are released [31]. So far, the reason of the more pronounced process in the post-spawning period cannot be answered, since no stronger and significantly different changes were measured in the impulse impedance. Research should be continued on this point.

Besides these parameters, water holding capacity and shear force can influence meat quality during the spawning period. Additional, these parameters are the most important factors influencing the acceptance of meat purchases in fish [32]. In the present study, there were no differences of water binding capacity, which is responsible for retaining of water around the muscle proteins as a hydrate shell. Consequently, the amount of water leaking out during the cooking process is not influenced by the spawning season. In addition, the shear force, which reflects the tenderness of the meat, indicates no change in the meat quality due to the spawning process. Meat firmness is an important quality parameter, as a decline in the firmness is generally perceived less appealing by consumers [33]. A comparison with pikeperch fillet from aquaculture revealed strong differences [15]. Fillets from pikeperch of aquaculture systems were very soft with just around 16 N and a WHC of more than 50%. Correspondingly, it could be shown that wild sea bass (*Dicentrarchus labrax*) revealed a firmer fillet, which was attributed to a higher level of activity [33].

While analysing the ash content, various previous studies supported it to be independent of dietary formulation. For example, Schulz et al. (2008) examined pikeperch fingerlings from aquaculture with different feeding compositions [16]. In this study, the crude ash content of the whole fish ranged between 3.3 and 3.5%. These ash contents were similar to those measured by Kowalska et al. (2012) in 6-month old pikeperch [34]. In adult pikeperch, Payuta and Flerova (2019) measured ash content values of 1.02–1.36% in muscle tissue, which is consistent with our measurements of around 1.2% [11].

In terms of moisture, the pikeperch examined in this study also showed comparable values to other studies [11]. In these analyses, no difference was evident between the two sampling time points or to the values we received from adult aquaculture pikeperch [12]. In pikeperch of the present study, the moisture content was $78.62 \pm 0.27\%$ and the ash content $1.17 \pm 0.01\%$.

The fact that the fatty acid composition can be modified by the feed has already been proven for pikeperch [e.g. 34] as well as for many other fish species. However, it has also been shown for other fish species that spawning time has an effect on lipids (e.g. Japanese catfish [35], Pacific herring [36], Atlantic herring [37]). These studies also showed that after spawning, a significant decrease of total lipids was present. An explanation for this effect can be found in the seasonal rhythm. Fish are subject to a seasonal lipid content cycle, which is highest during the summer months with active feeding and correspondingly lowest after the winter fasting period [e.g. 37, 38]. Additionally, during wintertime, lipids mobilised from the muscles to the gonads for development and maturation for the upcoming spawning season. In the muscle tissue, lipid content decreases and is at its lowest point immediately after the spawning season [38].

Since pikeperch follows this seasonal rhythm of spring spawning as well, it would be worthwhile to examine the fatty acid contents during summer, fall, and winter. Özparlak (2013) described a large seasonal difference in the individual fatty acid classes depending on the fish species [13].

Pikeperch is rich regarding to PUFA and here especially in DHA and EPA [37]. These results match with our data of the present study. The most abundant PUFAs have been DHA with 146–158 mg/100 g muscle, followed by linoleic acid (LA) with 30–47 mg/100 g muscle and EPA with around 34 mg/100 g muscle before and after spawning season and were not affected by spawning period (March vs. May/June). Several studies reported that DHA is the major PUFA in *S. lucioperca* [14, 39].

In addition, it is generally considered, that a decrease of water temperature results in an increase of EPA and DHA in polar lipids (phospholipids) to provide optimal cell membrane fluidity [40]. Recent results showed that the response of *n*-3 long-chain PUFA concentrations in fish tissue to temperature variations might be species-specific [41]. In the present study, the different water temperature (March vs. end of May/beginning of June) did not affect the fatty acid concentrations in pikeperch muscle except the single and sum of MUFA concentration, which were significantly reduced after the spawning period. Because oleic acid (C18:1*cis*-9) is the main component in the feed lipids, these differences could be explained by slight variations in the feed.

Comparing the fatty acid content of muscle from aquaculture pikeperch, no seasonal variation are present as abiotic factors are regulated and are constant over the year. Resulting, the fatty acid content is thus mainly dependent on the diet. For example, low content of EPA in the fillets results mainly from the vegetable source of fat in the fish diet [42, 43] and high content of LA (C18:3*n*-3) in the diets can result in the higher *n*3/*n*6 PUFA content in the fillets.

Conclusion

Wild freshwater pikeperch was analysed concerning the influence of the spawning process on the physical meat quality and lipid composition. The pikeperch was therefore caught directly before and after the close season. The results show a minor influence of the spawning period on the physical meat quality, which could have an impact on storage procedure. Furthermore, also the total MUFA content and some essential fatty acids were reduced. To what extent and when these changes, caused by the energetically high spawning process, readjust during the course of the year, must be further investigated.

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Data availability All relevant data are within the manuscript.

Declarations

Conflict of interest The authors have no competing interest to declare that are relevant to the content of this article.

Compliance with Ethics Requirements This study does not contain any animal experiments. Fishes used in this study were euthanized according to the animal welfare law Directive 2010/63/EU and TierSchG § 4(3) before slaughtering.

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