

Article

The Effect of Sumac (*Rhus coriaria* L.) Application on Oxidation Status, Sensory Attributes, Physicochemical and Microbiological Parameters of Carp (*Cyprinus carpio*) Fish during Chilled Storage

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Abstract: The aim of this study was to evaluate the impact of sumac on the oxidation status, sensory properties, and physicochemical and microbiological parameters of common carp (*Cyprinus carpio*) fish during chilled storage. Fillets of carp were treated with ground sumac at percentages of 0% (T0), 0.5% (T1), 1.5% (T2) and 2.5% (T3) and analysed after 24 and 72 h of chilled storage. The fat content, oxidation parameters (thiobarbituric acid reactive substances, TBARS), antioxidant capacity, total volatile basic nitrogen (TVB-N), free fatty acids (FFA), sensory properties, colour indicators (lightness L*, redness a*, yellowness b*), water activity, pH value, aerobic plate count (APC), psychrotrophic microorganism count (PMC), and coliform bacteria count were determined. The TBARS values of T1, T2, and T3 decreased significantly ($p < 0.05$) after 24 h of chilled storage. The antioxidant capacity increased in a dose-dependent and time-dependent manner. As regards organoleptic properties, sumac was able to reduce the natural fishy odour, increase the sour odour and flavour, and mask the fish odour and flavour significantly. A significant effect of sumac on the redness (a*) values of muscles was observed, which increased with elevation of the sumac ratio. A decrease in fillet pH and lower APC and PMC were observed. No effect was found on water activity or the growth of coliform bacteria. The study found that sumac plays a role in the oxidation status, pH value and organoleptic properties of fish fillets, which could be beneficial for the fish and fishery products industry.

Keywords: fish fillets; ground sumac; TBARS; DPPH; organoleptic properties; pH value



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1. Introduction

Carp fish is consumed traditionally in Central European countries [1], with the largest amount consumed in December at Christmas [2]. The Czech Republic is one of the largest producers of carp fish in the European Union. Total fishery products in the Czech Republic in 2019 amounted to around 21,000 tons, the vast majority of which was the common carp (*Cyprinus carpio*) [3]. The production ratio of carp fish in 2015 from the Czech Republic along with Poland and Hungary was 67.7% of EU-28 (the 28 countries of the European Union) production [4]. According to fish classification, based on the fat ratio content, the carp is a fatty to medium-fatty fish (7–15%) [5,6]. The fat level in the fish muscles depends on several factors, such as fish species, feeding, climate, fish source (wild or aquaculture), and the location of the muscles in the fish carcass [7,8]. The shelf life of fish meat is limited due to enzymatic and microbial activity and its oxidation susceptibility, which is attributed to its high content of unsaturated fatty acids [9,10]. The oxidation process of polyunsaturated fatty acids is catalysed by heat, light, and enzymes, leading to the formation of peroxides, aldehydes, ketones, and free radicals [2].

In recent years, consumer aspirations for healthier foods have been the reason for greater use of natural antioxidants such as plant and spice extracts, which have become

essential in food industries [11]. Sumac has been observed to have a role in food preservation and shelf-life prolongation. The food-preservative role of sumac is attributed to its natural antioxidant properties and antimicrobial effect [12,13]. Sumac grows as a wild plant in a large geographical area, including the Mediterranean, the Middle East and the south-eastern Anatolia region (Turkey) [14]. The fruits and leaves of sumac are extremely rich in flavones, hydrolysable tannins, anthocyanins, phenolic acids and organic acids. Sumac has a number of applications in different countries [12,13]. Ground sumac is traditionally used as a table condiment and sprinkled over grilled meats, kebobs, some salads and soups [14]. Gulmez et al. [14] found that a water extract of sumac extends the refrigerated shelf life and improves the sensory properties of chicken wings due to its antimicrobial effect. Fadiloğlu and Çoban [12] indicated that sumac (with edible chitosan coatings) has a positive impact on the microbiological, chemical and sensory properties of rainbow trout fillets during chilled storage (12 days). The treatment given (sumac + chitosan) delayed lipid oxidation and inhibited the growth of bacteria on rainbow trout fillets. The purpose of this study was to evaluate the impact of sumac (*Rhus coriaria* L.) and the refrigerated storage period (24, 72 h) on the oxidation status, sensory attributes, and physicochemical and microbiological parameters (in a raw state and after heat treatment) of carp (*Cyprinus carpio*) fish fillets.

2. Materials and Methods

2.1. Sample Preparation

A total of 35 common carp (*Cyprinus carpio*) fish (live weight 2.12 ± 0.13 kg) were used in this study. The origin of the fish was Rybníkářství Pohořelice a.s. (Pohořelice, Czech Republic), Novoveský CZ 62029582 fish pond, cadastral territory of the municipality of Vlasatice, date of catch 16 June 2020. The last place of fish holding was Velký Dvůr, CZ62029672 (purification centre, Rybníkářství Pohořelice a.s., Pohořelice, Czech Republic). Seventy common carp fillets (average weight 461.97 ± 43.06 g) with skin with the supporting bones cut through were obtained from a fish-processing plant Mušov Rybníkářství Pohořelice a.s. (Pohořelice, Czech Republic, Pasohlávky 216, CZ 43) in fresh condition, vacuum-packed. The preparation of the experiment was performed at the authors' workplace at the University of Veterinary Sciences Brno (VETUNI, Brno, Czech Republic). In sum, 24 fillets were used as control samples and 46 fillets were used for the application of sumac (Table 1). Each fillet was divided into 3 parts: cranial, middle, and caudal parts (average weight 142.13 ± 14.39 , 172.07 ± 19.09 and 145.56 ± 18.89 g, respectively). Sumac was applied on the muscle side of these three parts of the fillets at 0.5% (T1), 1.5% (T2), and 2.5% (T3), respectively. The sumac used in the study was in the form of ground seeds (food-grade). The percentage of sumac was estimated according to the weight of the parts of fillets and then spread evenly on the surface of the samples through a sieve. The samples were stored after being covered by polyolefin film stretched over the tray in a dark chilling chamber at a temperature of 2 ± 2 °C. Half of the samples were analysed after 24 h and the other half after 72 h of chilled storage (Table 1). The cold storage period imitates the expected marinating time of the fish before gastronomic heat treatment. The ground sumac (*Rhus coriaria* L.) seeds used in this study were produced by Jelínek & syn, s.r.o. (Havířov–Prostřední Suchá, Czech Republic). The country of origin of the sumac was Turkey.

Table 1. Numerical explanation of the use of carp fillets in the study.

	Oxidation Status and Colour Estimation		Evaluation of Sensory Attributes		Physicochemical and Microbiological Parameters	
storage period (hours)	24	72	24	72	24	72
control samples	5	5	2	2	5	5
samples with sumac treatment	10	10	3	3	10	10

2.2. Estimation of Fat Content and Oxidation Parameters

The experimental samples—control samples (fish only) and fish with sumac (fish with applied sumac and released juice)—were homogenised. For the control samples used for determination of oxidation status and colour, the cranial parts of fillets were analysed at initial sampling (0 h), while the middle and caudal parts were analysed after 24 and 72 h of chilled storage, respectively. The purpose of using the same part of fillet at each sampling point (initial and 24 and 72 h) was to avoid the possibility of an impact of location on the values of the monitored parameters.

2.2.1. Fat Content

The fat content was determined using a Soxtec 2055 (FOSS Analytical AB, Höganäs, Sweden) using petrol ether (40–65 °C, 1 L = 0.65 kg) as the extraction agent [15].

2.2.2. Thiobarbituric Acid Reactive Substance Content (TBARS)

TBARS values were estimated by the distillation method. First, 10 g of a sample was homogenised with 95.7 mL of distilled water and 2.5 mL of 4 N HCl for 2 min. The mixture was distilled, then 5 mL of distillate with 5 mL of reagent (15% trichloroacetic acid 99% p.a., 1 L = 105 g and 0.375% thiobarbituric acid 0.02 mol/L) was heated (boiled) in a water bath for 35 min. After cooling, the absorbance of the samples was measured by a GENESYS™ 6 spectrophotometer (Thermo Electron Corporation, Beverly, MA, USA) at 532 nm against an appropriate blank. The optical density was multiplied by 7.8 to obtain the TBARS value. Oxidation products were quantified as malondialdehyde equivalents (MDA) [16].

2.2.3. Antioxidant Capacity

Antioxidant capacity was determined according to the DPPH (2,2-diphenyl-1-picrylhydrazyl) method [17]. An extract of a sample was prepared according to Jung et al. [18] using a homogenisation sample (3 g) with 5% trichloroacetic acid (15 mL), after which chloroform (10 mL) was added. DPPH crystalline powder (Sigma-Aldrich Product, Steinheim, Germany) was dissolved in methanol (at a ratio of 0.025 g·L⁻¹) for the preparation of fresh DPPH solution (radical stock). The absorbance value of the DPPH solution was measured using the GENESYS™ 6 spectrophotometer (Thermo Electron Corporation, Beverly, MA, USA) as A_0 against a blank at 515 nm. The mixture was measured by a spectrophotometer (515 nm) after 10 min of sample extract (0.2 mL) reaction with DPPH solution (3.8 mL), and the absorbance was recorded as A_{10} . The inhibition percentage (%) of the DPPH radical was calculated according to the formula $(A_0 - A_{10} / A_0) \times 100$, where A_0 was the absorbance of the control at time = 0 min and A_{10} was the absorbance of the antioxidant at time = 10 min.

2.2.4. Total Volatile Basic Nitrogen (TVB-N)

TVB-N was estimated by distillation and titration of the sample (deproteinised with 7.5% trichloroacetic acid) according to regulation (EU) 2019/627, Annex VI, Chapter II, 3(c) [19] using a Kjeltac 2300 analyser (FOSS Analytical AB, Höganäs, Sweden).

2.2.5. Free Fatty Acid (FFA)

Free fatty acids were determined by the titration method. First, 50 mL of ethanol (96%):diethyl ether (at a proportion of 1:1) with 5 drops of phenolphthalein (1 g of phenolphthalein indicator with 99 mL ethanol) was added to 5 g of sample. This was then heated (20 °C) in a water bath and then titrated with an alcoholic solution of potassium hydroxide 0.1 mol/L (0.1 N) until red coloration. Free fatty acid is the amount (mg) of potassium hydroxide needed to neutralise the free fatty acids in 1 g of sample [20]. The free fatty acids were represented by the percentage of total fat as oleic acid. Five samples were analysed twice for each of the aforementioned analysed parameters for a total of ten values that were used for statistical analysis.

2.3. Evaluation of Sensory Attributes

Consumer panellists (10 trained persons) for the sensory assessment of samples were recruited from the Department of Animal Origin Food & Gastronomic Sciences (VETUNI, Brno, Czech Republic). Four of the persons on the panel are holders of the Sensory Attest Certificate (Czech Agriculture and Food Inspection Authority, organisational directive no. 026/2003), while the other six evaluators are trained in sensory analysis and have been previously acquainted with the protocols of sensory evaluation. Samples were evaluated raw and after heat treatment (baked in a round disposable aluminium foil bowl covered with aluminium foil at 100 ± 1 °C/30 min) in an oven (Garbin 23 GM UMI, GARBIN INDUSTRIES SRL, Monteviale, Italy). For evaluation of the sensory attributes of samples in a raw state, the panellists were asked about their overall acceptability, colour acceptability, natural fishy odour, sour odour, masking of fishy odour, the degree of muscle juice release and the degree of tenderness. The following sensory attributes were evaluated in the case of heat-treated samples: overall acceptability, odour acceptability, natural fishy odour, flavour acceptability, sour flavour, masking of fishy odour and flavour, the degree of muscle juice release, and the degree of tenderness. A non-structured 100 mm hedonic scale was used for testing.

2.4. Determination of Physicochemical and Microbiological Parameters

2.4.1. Colour Analysis

Colour indicators—lightness L^* , redness a^* , yellowness b^* —were measured on the raw surfaces of carp fillets (the muscle side, not the skin side) [21]. Measurement was performed according to the CIE $L^* a^* b^*$ system using a CM-5 spectrophotometer (Konica Minolta Sensing, Inc., Tokyo, Japan). The mean $\pm$ standard deviation (SD) of five measurements for each sample was recorded. SpectraMagic NX colour data software (v.CM-S100w 2.03.0006, 2003–2010) was used for the calculation of the parameters.

2.4.2. Water Activity and pH Value

Immediately after the microbiological examination, pH value and water activity were determined. A microprocessor pH meter 211 (Hanna Instruments, Smithfield, RI, USA) was used to determine the pH value. The pH value was measured from an aqueous leachate (10 g of sample + 100 mL of deionised water, for 15 min at the laboratory temperature) at 25 ± 1 °C. Water activity was determined using a LabMaster aw-meter (Novasina AG, Lachen, Switzerland) at a temperature of 25 ± 1 °C.

2.4.3. Microorganism Count

The aerobic plate count (APC), the psychrotrophic microorganism count (PMC) and coliform bacteria count (CBC) were determined according to the procedures described in the relevant ISO standards [22–24]. Basic processing of the collected samples was carried out in accordance with ČSN EN ISO 6887-1/2018 using sterile saline enriched with peptone (0.85% NaCl + 0.1% peptone, pH 7) as a dilution medium [25].

2.5. Statistical Analysis

The statistical analysis of the data was conducted using Microsoft Office Excel 2016. Significant differences ($p < 0.05$) between the investigated groups of samples (percentage of sumac treatment T0, T1, T2, and T3 and storage time 0, 24, and 72 h) were confirmed by analysis of variance (ANOVA) with a post hoc Tukey test using the statistical software SPSS 20 (IBM Corporation, Armonk, NY, USA). The letters A and a superscript refer to higher values; the letters C and c superscript refer to lower values.

3. Results and Discussion

3.1. Oxidation Status

Fat content and oxidation status parameters are shown in Table 2. Fat content was not affected significantly ($p > 0.05$) by either the sumac treatment or the storage time.

Lipid oxidation of fish and fish products can lead to changes in their sensory properties (off-flavour and colour change) and texture deterioration. The TBARS value is widely used as an indicator for the evaluation of the level of lipid oxidation [26]. The limit value of TBA for fish is 1–2 mg MDA kg^{−1}, and exceeding this limit usually leads to development of an objectionable odour in fish [27]. The TBARS values of samples treated with sumac (T1, T2 and T3) decreased significantly ($p < 0.05$) after 24 h of chilled storage and remained constant until 72 h of the storage period. Mardoukhi et al. [28] also found on the first day of storage a significant impact of sumac on the TBARS values of silver carp fillets treated with sumac extract (1%, 2.5% and 5%). This impact may be attributed to the presence of flavonoid in the sumac, which has an antioxidant effect. The role played by sumac in delaying the lipid oxidation of trout fillets was also reported by Fadiloğlu and Çoban [12]. These authors found that using a combination of chitosan with 2% sumac reduced lipid oxidation significantly during the storage period. It has been demonstrated that sumac extract has the ability to reduce TBARS levels due to its radical-scavenging activities [29]. Our results showed that gradual elevation of the percentage of sumac (T1, T2 and T3) applied did not significantly affect the TBARS values of carp samples. In contrast, Langroodi et al. [29] found that increasing the concentration of sumac extract led to a decrease in the TBARS values of beef meat in a concentration-dependent manner during 20 days of refrigerated storage. Similarly, Mardoukhi et al. [28] observed that increasing sumac percentage (1%, 2.5% and 5%) led to a slow elevation in TBARS values of silver carp fillets during 18 days of storage. However, the length of the chilled storage period may be sufficient to demonstrate the effect of sumac on secondary oxidation.

Table 2. Fat content and parameters of oxidation status (mean $\pm$ SD) of raw carp fillets with sumac treatment during chilled storage.

Storage Hours	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
Fat content (%)				
0 *	8.50 $\pm$ 2.98	8.28 $\pm$ 2.94	8.11 $\pm$ 1.24	8.39 $\pm$ 2.97
24	6.97 $\pm$ 3.04	7.79 $\pm$ 2.76	6.11 $\pm$ 1.71	8.36 $\pm$ 2.60
72	8.82 $\pm$ 3.75	6.61 $\pm$ 1.88	8.23 $\pm$ 3.71	7.88 $\pm$ 2.48
TBARS (mg MDA kg ^{−1})				
0 *	1.63 $\pm$ 0.31	1.62 $\pm$ 0.31 ^A	1.67 $\pm$ 0.30 ^A	1.66 $\pm$ 0.30 ^A
24	1.24 $\pm$ 0.28	0.77 $\pm$ 0.33 ^B	0.90 $\pm$ 0.10 ^B	1.09 $\pm$ 0.37 ^B
72	1.73 $\pm$ 1.35	0.70 $\pm$ 0.10 ^B	0.90 $\pm$ 0.27 ^B	1.02 $\pm$ 0.32 ^B
Antioxidant capacity (DPPH % inhibition)				
0 *	32.70 $\pm$ 1.51	32.82 $\pm$ 1.49	32.64 $\pm$ 1.49 ^C	32.48 $\pm$ 1.43 ^B
24	31.11 $\pm$ 2.39 ^c	32.67 $\pm$ 2.83 ^{cb}	34.81 $\pm$ 1.85 ^{Bb}	35.96 $\pm$ 2.88 ^{Aab}
72	31.02 $\pm$ 1.64 ^c	32.95 $\pm$ 1.04 ^b	37.23 $\pm$ 1.43 ^{Aa}	37.93 $\pm$ 1.69 ^{Aa}
TVB-N (mg N/100 g)				
0 *	15.46 $\pm$ 0.75 ^B	15.45 $\pm$ 0.80 ^{AB}	15.48 $\pm$ 0.79 ^B	15.47 $\pm$ 0.80 ^{AB}
24	16.95 $\pm$ 0.73 ^A	16.15 $\pm$ 0.78 ^A	16.57 $\pm$ 1.33 ^A	15.93 $\pm$ 0.88 ^A
72	15.34 $\pm$ 0.55 ^B	14.75 $\pm$ 0.38 ^B	15.19 $\pm$ 0.81 ^B	15.11 $\pm$ 0.24 ^B
Free fatty acids (% total fat as oleic acid)				
0 *	0.45 $\pm$ 0.07 ^A	0.45 $\pm$ 0.08 ^A	0.45 $\pm$ 0.08	0.44 $\pm$ 0.07
24	0.28 $\pm$ 0.05 ^{Cc}	0.36 $\pm$ 0.06 ^{Bcb}	0.42 $\pm$ 0.08 ^b	0.48 $\pm$ 0.08 ^{ab}
72	0.37 $\pm$ 0.08 ^B	0.43 $\pm$ 0.08 ^{AB}	0.39 $\pm$ 0.13	0.40 $\pm$ 0.09

^{a-c} Values in the same row are significantly ($p < 0.05$) different between sumac concentrations; ^{A-C} values in the same column are significantly ($p < 0.05$) different between storage hours; * control samples (without sumac application).

Antioxidant capacity has been widely evaluated recently using many determination methods. DPPH (2,2-diphenyl-1-picrylhydrazyl) is a stable free radical and becomes a stable diamagnetic molecule by accepting an electron or hydrogen radical. Determination of the radical-scavenging activity of the DPPH radical is performed by reduction in absorbance at 515 nm that is induced by antioxidants. The antioxidant capacity of the investigated samples at 24 and 72 h of storage increased with sumac application (T1) and with elevation in sumac treatment ratio (T1, T2 and T3). The antioxidant capacity of T2 and T3 increased gradually during the storage period. Al-Muwaly et al. [30] indicated that sumac seed extract is a potential source of natural antioxidant. They found that sumac seed extract contained large amounts of phenolic and flavonoid compounds and was a good scavenger of reactive oxygen species (ROS). The strong antioxidant activity of sumac is attributed to its high content of anthocyanins and hydrolysable tannins [30].

TVB-N is generally accepted as an indicator of fish spoilage that is elevated by the effect of spoilage bacteria and endogenous enzyme activity. TVB-N includes nitrogenous compounds such as ammonia, dimethylamine (DMA), trimethylamine (TMA), and others [31]. The TVB-N of the analysed samples increased slightly within 24 h, and then a significant decrease in values was observed in all study groups. It can be hypothesised that the activity of endogenous autolytic enzyme activity in muscles was maintained at a low level during storage due to low storage temperature [32]. The protective effect of sumac was not observed in our experiment. The potential difference between control and treated samples was not observed, maybe due to the short storage period, where TVB-N production usually requires more storage days. Fadiloğlu and Çoban [31] found that the TVB-N of rainbow trout (*Oncorhynchus mykiss*) fillets during frozen storage was reduced by the effect of sumac extract. They suggested that this sumac extract inhibited the decomposition of macromolecular components that occur via spoilage bacteria and endogenous enzymes. The results of this study show that elevation of the percentage of sumac treatment had no significant effect on the TVB-N values in carp fillets. Contrary to our results in this regard, Langroodi et al. [29] found that the level of TVN formation in beef meat reduced with an increasing concentration of sumac extract through the refrigerated storage period by reducing the primary counts of the common spoilage bacteria.

Free fatty acids are produced as a result of the enzymatic hydrolysis process of esterified lipids. A pro-oxidant effect of free fatty acids on lipid matter is possible through the catalytic impact of the carboxyl group on the formation of free radicals during the process of decomposition of hydroperoxides [33,34]. Free fatty acids in the investigated samples at 24 h of storage increased with sumac application, significantly ($p < 0.05$) in T2 and T3. Free fatty acids in T2 and T3 were not affected by the time factor during the storage period, as opposed to T0 and T1, which were significantly ($p < 0.05$) reduced. The increase in free fatty acid formation is attributed to hydrolysis of phospholipids and triglycerides resulting from lipase and phospholipase processes [35]. In contrast to the finding of Fadiloğlu and Çoban [31], our results (T1, T2 and T3 on day 1 of storage) indicated that the elevation in sumac percentages accelerated lipid hydrolysis and thereby free fatty acid accumulation. However, the lipolysis effect of sumac was attributed to its containing lipases that are capable of hydrolysing the fat in meat [36].

3.2. Sensory Attributes

The results of the organoleptic tests are shown in Tables 3 and 4. Generally, a significant ($p < 0.05$) influence of sumac on the sensory properties was observed after treatment of fish samples with sumac at a ratio of 1.5% (T2). Organoleptic evaluation after 24 h of chilled storage revealed a significant reduction ($p < 0.05$) in the natural fishy odour of T2 and T3 compared with T0 in a raw state and after heat treatment, whereas sour odour (in a raw state) and flavour (after heat treatment) were increased significantly ($p < 0.05$) after sumac treatment at the T2 level (1.5%) (Table 3). The reason for such acidic odour and flavour may be attributed to the fact that sumac contains some volatile substances with a distinct flavour and desired sour taste [37]. Sumac was able to mask fish odour and flavour significantly

($p < 0.05$) at ratios of 0.5–1.5% (T1–T2) in raw and heat-treated samples (Table 3). This property of sumac could be beneficial for masking or reducing the muddy and/or musty off-flavours that represent a post-harvest problem in some freshwater fish. It has been found that acidification treatment of the off-flavour compounds using acetic and citric acids significantly decreased the concentrations of geosmin and 2-methylisoborneol (MIB) in investigated samples [38]. Brown et al. [39] indicated that the pH-shift method may be utilised to reduce off-flavours and thereby increase the acceptability of processed products of catfish.

Table 3. Sensory evaluation (mean $\pm$ SD) of carp fillets following sumac treatment in the raw state and after heat treatment (100 °C/30 min) after 24 h of chilled storage.

Parameters	Sumac Concentration			
In Raw State	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
overall acceptability	76.29 $\pm$ 27.13	76.43 $\pm$ 21.90	63.00 $\pm$ 34.39	43.43 $\pm$ 32.45
colour acceptability	79.86 $\pm$ 25.02	79.43 $\pm$ 16.04	57.29 $\pm$ 34.54	42.43 $\pm$ 31.94
natural fishy odour	88.57 $\pm$ 13.85 ^a	74.86 $\pm$ 18.69 ^{ab}	45.57 $\pm$ 29.52 ^b	34.71 $\pm$ 14.34 ^{cb}
sour odour	10.43 $\pm$ 13.18 ^b	23.14 $\pm$ 18.97 ^b	54.43 $\pm$ 30.86 ^a	62.57 $\pm$ 13.91 ^a
masking of fish odour	1.29 $\pm$ 1.60 ^b	46.50 $\pm$ 25.32 ^a	62.86 $\pm$ 28.9 ^a	69.14 $\pm$ 19.10 ^a
degree of muscle juice release	4.14 $\pm$ 8.01	6.86 $\pm$ 10.54	31.86 $\pm$ 34.14	29.29 $\pm$ 23.34
degree of tenderness	21.14 $\pm$ 29.14	22.00 $\pm$ 29.33	31.86 $\pm$ 32.53	45.29 $\pm$ 30.12
overall acceptability	76.29 $\pm$ 27.13	76.43 $\pm$ 21.90	63.00 $\pm$ 34.39	43.43 $\pm$ 32.45
After Heat Treatment				
overall acceptability	70.86 $\pm$ 26.00	67.14 $\pm$ 27.89	64.29 $\pm$ 27.66	56.43 $\pm$ 31.30
colour acceptability	63.00 $\pm$ 31.43	68.47 $\pm$ 31.47	55.43 $\pm$ 24.25	51.14 $\pm$ 27.78
natural fishy odour	86.00 $\pm$ 17.66 ^a	80.43 $\pm$ 17.28 ^a	43.71 $\pm$ 27.00 ^b	36.86 $\pm$ 24.45 ^b
masking of fish odour	16.57 $\pm$ 17.07 ^b	38.00 $\pm$ 37.34 ^{ab}	74.43 $\pm$ 22.85 ^a	73.43 $\pm$ 28.08 ^a
flavour acceptability	85.57 $\pm$ 20.49	85.86 $\pm$ 13.53	65.43 $\pm$ 26.26	69.29 $\pm$ 17.90
sour flavour	4.14 $\pm$ 3.24 ^b	14.71 $\pm$ 10.47 ^b	47.00 $\pm$ 23.90 ^a	60.14 $\pm$ 19.13 ^a
masking of fish flavour	16.43 $\pm$ 23.14 ^b	14.57 $\pm$ 15.15 ^b	76.43 $\pm$ 20.84 ^a	65.71 $\pm$ 29.02 ^a
degree of muscle juice release	38.14 $\pm$ 30.16	68.57 $\pm$ 28.34	63.29 $\pm$ 28.31	64.71 $\pm$ 16.92
degree of tenderness	42.29 $\pm$ 41.64	26.86 $\pm$ 34.29	28.29 $\pm$ 24.33	25.00 $\pm$ 27.08

^{a–c} Values in the same row are significantly ($p < 0.05$) different between sumac concentrations, $p < 0.05$.

The results of organoleptic evaluation after 72 h of chilled storage are stated in Table 4. The panellists reported a significant reduction in overall acceptability and colour acceptability for T2 and T3 in a raw state. In contrast, a good colour for chicken wings treated with a water extract of sumac was reported by Gulmez et al. [14], and a significant increase in the grades awarded by the panellists for the colour characteristics of beef samples treated with sumac was confirmed by Mohsen et al. [37]. Such a positive effect of sumac on the colour of meat could be attributed to the use of a water extract of sumac by these researchers, whereas we seasoned the fish fillets directly with ground sumac. The significant ($p < 0.05$) increase in juiciness for T3 samples in a raw state in comparison with T0 is in agreement with Mohsen et al. [37], confirming that sumac contains some softening agent such as citric acid that increases the tenderness and juiciness of the treated meat. The natural fishy odour, sour odour and flavour, and masking of fish odour and flavour (in a raw state and after heat treatment) of the investigated samples are in line with organoleptic evaluation after one day of chilled storage (Tables 3 and 4). A positive effect of sumac on the sensory properties of meat during chilled storage has been reported by several authors [12,14,29,37,40]. The fact that such a clear role of sumac was not observed in our study could be due to the treatment of samples with ground sumac instead of a water extract of sumac, as well as the fact that sumac is not a substance that is usual for consumers (panellists) in our region.

Table 4. Sensory evaluation (mean $\pm$ SD) of carp fillets with sumac treatment in the raw state and after heat treatment (100 °C/30 min) after 72 h of chilled storage.

Parameters	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
In Raw State				
overall acceptability	82.43 $\pm$ 24.10 ^a	75.43 $\pm$ 25.96 ^{ab}	40.86 $\pm$ 29.34 ^b	27.57 $\pm$ 25.32 ^{bc}
colour acceptability	85.00 $\pm$ 13.99 ^a	67.43 $\pm$ 22.69 ^{ab}	45.14 $\pm$ 26.30 ^b	26.29 $\pm$ 26.22 ^{bc}
natural fishy odour	91.43 $\pm$ 13.16 ^a	75.57 $\pm$ 27.48 ^{ab}	57.71 $\pm$ 26.57 ^b	42.29 $\pm$ 21.37 ^b
sour odour	6.86 $\pm$ 8.95 ^c	17.71 $\pm$ 20.48 ^{cb}	46.14 $\pm$ 28.21 ^b	55.86 $\pm$ 21.59 ^{ab}
masking of fish odour	3.14 $\pm$ 7.08 ^b	27.00 $\pm$ 33.28 ^{ab}	57.29 $\pm$ 35.30 ^a	62.00 $\pm$ 31.19 ^a
degree of muscle juice release	3.14 $\pm$ 5.11 ^b	7.86 $\pm$ 9.62 ^b	22.14 $\pm$ 28.01 ^{ab}	42.43 $\pm$ 31.88 ^a
degree of tenderness	24.86 $\pm$ 31.88	24.86 $\pm$ 29.69	53.71 $\pm$ 24.74	57.00 $\pm$ 27.82
overall acceptability	82.43 $\pm$ 24.10 ^a	75.43 $\pm$ 25.96 ^{ab}	40.86 $\pm$ 29.34 ^b	27.57 $\pm$ 25.32 ^{bc}
After Heat Treatment				
overall acceptability	78.43 $\pm$ 26.41	74.14 $\pm$ 25.21	49.71 $\pm$ 14.23	45.29 $\pm$ 24.92
colour acceptability	75.71 $\pm$ 31.65	71.57 $\pm$ 31.65	49.71 $\pm$ 17.09	46.14 $\pm$ 28.48
natural fishy odour	88.71 $\pm$ 13.50 ^a	75.00 $\pm$ 25.19 ^a	41.71 $\pm$ 18.64 ^b	30.29 $\pm$ 13.94 ^b
masking of fish odour	9.14 $\pm$ 11.85 ^b	30.29 $\pm$ 27.88 ^b	72.14 $\pm$ 14.53 ^a	77.00 $\pm$ 21.71 ^a
flavour acceptability	83.29 $\pm$ 25.57	78.29 $\pm$ 25.82	51.43 $\pm$ 18.63	58.00 $\pm$ 29.19
sour flavour	12.43 $\pm$ 18.27 ^c	24.57 $\pm$ 24.09 ^{cb}	57.43 $\pm$ 20.78 ^b	65.29 $\pm$ 26.44 ^{ab}
masking of fish flavour	7.14 $\pm$ 10.14 ^b	32.14 $\pm$ 28.93 ^{ab}	60.57 $\pm$ 27.83 ^a	55.00 $\pm$ 37.25 ^a
degree of muscle juice release	43.43 $\pm$ 32.34	63.86 $\pm$ 31.93	73.29 $\pm$ 16.97	77.14 $\pm$ 18.28
degree of tenderness	30.71 $\pm$ 31.65	27.43 $\pm$ 31.49	39.86 $\pm$ 26.13	42.43 $\pm$ 29.27

^{a–c} Values in the same row are significantly ($p < 0.05$) different between sumac concentrations, $p < 0.05$.

3.3. Physicochemical and Microbiological Parameters

The colour of fresh meat and meat products is one of the most important quality properties affecting consumer choice, for which reason the colour stability of such products during storage and retail display is crucial for meat manufacturers and retailers [41]. The evaluation of colour indicators is explained in Table 5. The L* values (indicating lightness) of samples with sumac treatment (T1, T2 and T3) were significantly lower ($p < 0.05$) in comparison with control samples. Lightness reduction was correlated with the increasing percentage of sumac treatment. Sumac had a significant ($p < 0.05$) effect on the redness (a*) values of carp muscle. The redness values of T1, T2 and T3 increased with the elevation in the sumac ratio. No significant differences were observed in redness indicators between samples at 24 h and 72 h. The red-like pigmentation of sumac was attributed to anthocyanins, which are the main phenolic compound in sumac. Hydroxyphenyl-pyranoanthocyanins are found in sumac and wine and are responsible for their pigmentation capacity [42]. The contribution of the main pigment in sumac (anthocyanins) to the red coloration of the product seems to be complex in nature because it is affected by the pigment's heat stability, the temperature regime, the concentration and pH [43]. Sumac did not influence yellowish values (b*) except in T3, in which the b* values increased significantly ($p < 0.05$) after 24 h of storage. Caliskan and Dirim [44] indicated that sumac may be exposed to some browning coloration reaction due to the effect of air temperatures.

Table 5. Colour indicators (mean $\pm$ SD) of raw carp fillets with sumac treatment during chilled storage.

Storage Hours	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
	L*			
0 *	56.13 $\pm$ 1.52	56.39 $\pm$ 1.41 ^A	56.55 $\pm$ 1.21 ^A	56.09 $\pm$ 1.52 ^A
24	56.58 $\pm$ 2.03 ^a	50.88 $\pm$ 1.46 ^{Bb}	46.36 $\pm$ 3.91 ^{Bc}	45.35 $\pm$ 2.43 ^{Bc}
72	55.17 $\pm$ 1.41 ^a	49.49 $\pm$ 1.57 ^{Bb}	48.23 $\pm$ 2.09 ^{Bbc}	46.16 $\pm$ 1.98 ^{Bc}

Table 5. Cont.

Storage Hours	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
a*				
0 *	-0.24 ± 0.73^B	-0.32 ± 0.70^B	-0.51 ± 0.39^B	-0.18 ± 0.71^B
24	0.68 ± 0.85^{ABc}	3.73 ± 0.72^{Ab}	5.66 ± 1.50^{Aa}	6.25 ± 0.86^{Aa}
72	1.59 ± 1.02^{Ab}	4.09 ± 1.50^{Aa}	4.93 ± 1.29^{Aa}	5.95 ± 0.55^{Aa}
b*				
0 *	8.13 ± 0.50	8.14 ± 0.50	8.04 ± 0.45	8.05 ± 0.74^B
24	8.49 ± 1.19	9.05 ± 0.57	8.77 ± 1.12	9.03 ± 0.41^A
72	8.33 ± 0.84	9.61 ± 1.24	9.21 ± 1.21	9.69 ± 0.64^A

a–c Values in the same row are significantly ($p < 0.05$) different between sumac concentrations; ^{A,B} values in the same column are significantly ($p < 0.05$) different between storage hours; * control samples (without sumac application).

The results of water activity, pH value and microorganism count are shown in Table 6. Regarding water activity, we did not find any statistically significant differences ($p > 0.05$) between the measured values as a function of the concentration of sumac product or as a function of the storage time of the samples. We can therefore conclude that in terms of this parameter and its importance on the growth and multiplication of contaminating microorganisms, the conditions were practically the same in all fillet samples.

A different situation was found for the pH values. Given the pH value of the aqueous sumac spice leachate used in this experiment of 2.85, there was a statistically significant ($p < 0.05$) acidification of the fillets at the highest concentration of sumac spice used (T3) at both 24 and 72 h after application. A similar trend of decrease in pH value at 24 h after application was also observed for the 1.5% concentration (T2); however, after 72 h of storage the pH value of this sample was higher than 6.00. The pH value of fillets with 0.5% addition of sumac spices (T1) was practically the same during the experiment. For the control samples, the value of this parameter decreased statistically significantly ($p < 0.05$) after 72 h of storage, but did not fall below 6.00. Similar results to the increase in pH values after their initial decrease have been presented by other authors [45]. This is because after fish killing, changes in pH values also occur as a result of biochemical post-mortem processes due to the breakdown of glycogen to lactic acid, as observed in the control samples. These changes are more pronounced in aquacultured fish, which have a higher supply of energy-rich compounds compared to wild fish. Therefore, it can be concluded that in our experiment, the decreasing trend in pH values during fillet storage was probably amplified with increasing concentrations of sumac preparation. This can be concluded from the results of the existence of statistically significant differences ($p < 0.05$) between the pH values depending on the increasing concentrations of sumac spices applied to the surface of the fillets, where differences were found after 24 h between the control samples or samples with 0.5% sumac (T1) and samples with the application of sumac with a concentration of 1.5% and 2.5% (T2 and T3) of the product, respectively. The increase in the pH values during the experiment could be related to the development of bacteria with proteolytic enzymes involved in the degradation of proteins and the formation of total volatile nitrogen bases (TVB-N), which are alkaline in nature [46].

The fillets with cut muscle bones are specially prepared on machines equipped with circular knives placed at a distance of approximately 2–3 mm from each other in order to cut the muscle of the fillet down to the skin, breaking these bones and thus minimising the risk of injury to the mucous membranes of the digestive tract of the consumers. However, a significant increase in the surface area of the fillets entails the possibility of spreading surface contamination of the fillet into the cut muscle, where microorganisms find optimal conditions for growth and multiplication due to the appropriate composition of the internal tissue environment. There is no mandatory limit for APC for fresh freshwater fish that should not be exceeded; however, for freshwater fish, some sources indicate a maximum of

up to 7 log CFU·g⁻¹ [47]. Considering the expected higher APC values in the input samples that we demonstrated in our experiment, the application of seasonings with antimicrobial and antioxidant effects seems to be highly desirable [48]. This is because by cutting the fillet, the fats present inside the muscle are exposed directly to the oxygen present in the air. Unfortunately, a disadvantage of using dry natural seasonings may be the potential presence of contaminating microorganisms, which may be activated in an environment with appropriate water activity and pH values and secondarily increase the contamination of the tissues to which they have been applied [49].

The decrease in pH values 24 h after application of 1.5% and 2.5% (T2 and T3) sumac spices to carp fillets was probably the reason for the statistically significantly ($p < 0.05$) lower APC values found. However, after 72 h, APC values increased significantly and no statistically significant differences were found between the contamination intensity of control and experimental fillets with different sumac concentrations. The trend of contamination of fillets spiked with 0.5% (T1) sumac was practically the same as that of the control samples, with a slight statistically insignificant ($p > 0.05$) decrease in APC values after 24 h. Pajohi-Alamoti et al. [50] studied the antimicrobial properties of sumac at 4 °C and found that the extract reduced bacterial growth. Also, Ahmadi et al. [51] evaluated the antimicrobial effect of this plant and concluded that the aqueous extract of sumac (*Rhus coriaria*) could be used as a natural antibacterial agent.

For samples stored at low refrigeration temperatures, psychrotrophic microorganisms adapted to low environmental temperature conditions can be expected to account for the majority of the total contamination. The dynamics of their changes closely followed the pattern of changes in APC values, including the existence of statistically significant differences between the values or inconclusive findings. It is possible that after 24 h of storage, the psychrotrophic microorganisms adapted to a more acidic environment and their growth intensity increased.

There were no statistically significant differences in the number of coliform bacteria (CB) in the samples based on the concentration of sumac preparation throughout the experiment. Significant differences were found in all samples between day 0 and after 24 and 72 h of cold storage, respectively, during which time there was a statistically significant ($p < 0.05$) increase in CB counts.

Table 6. Water activity, pH value and microorganism count (mean $\pm$ SD) of raw carp fillets with sumac treatment during chilled storage.

Storage Hours	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
Water activity				
0 *	0.979 $\pm$ 0.002	0.979 $\pm$ 0.002	0.979 $\pm$ 0.002	0.979 $\pm$ 0.002
24	0.974 $\pm$ 0.005	0.977 $\pm$ 0.004	0.975 $\pm$ 0.003	0.978 $\pm$ 0.003
72	0.971 $\pm$ 0.007	0.976 $\pm$ 0.004	0.978 $\pm$ 0.004	0.976 $\pm$ 0.005
pH value				
0 *	6.41 $\pm$ 0.11 ^A	6.41 $\pm$ 0.11	6.41 $\pm$ 0.11 ^A	6.41 $\pm$ 0.11 ^A
24	6.30 $\pm$ 0.09 ^{aAB}	6.21 $\pm$ 0.21 ^{ba}	5.90 $\pm$ 0.20 ^{cbB}	5.61 $\pm$ 0.18 ^{cB}
72	6.19 $\pm$ 0.10 ^{aB}	6.35 $\pm$ 0.17 ^a	6.04 $\pm$ 0.39 ^{abAB}	5.53 $\pm$ 0.40 ^{bB}
Aerobic plate count (log CFU·g ⁻¹)				
0 *	5.50 $\pm$ 0.17	5.50 $\pm$ 0.17	5.50 $\pm$ 0.17 ^A	5.50 $\pm$ 0.17 ^A
24	5.48 $\pm$ 0.16 ^a	5.32 $\pm$ 0.04 ^a	5.09 $\pm$ 0.10 ^{bB}	5.09 $\pm$ 0.08 ^{bB}
72	5.55 $\pm$ 0.13	5.45 $\pm$ 0.20	5.33 $\pm$ 0.16 ^A	5.64 $\pm$ 0.50 ^A

Table 6. Cont.

Storage Hours	Sumac Concentration			
	0% (T0)	0.5% (T1)	1.5% (T2)	2.5% (T3)
Psychrotrophic microorganism count (log CFU·g ^{−1})				
0 *	5.00 ± 0.12	5.00 ± 0.12 ^A	5.00 ± 0.12 ^A	5.00 ± 0.12
24	4.86 ± 0.20 ^a	4.85 ± 0.12 ^{aA}	4.49 ± 0.16 ^{bB}	4.64 ± 0.08 ^b
72	4.96 ± 0.17	4.49 ± 0.25 ^B	4.67 ± 0.08 ^B	5.06 ± 0.63
Coliform bacteria count (log CFU·g ^{−1})				
0 *	2.30 ± 0.23 ^B	2.30 ± 0.23 ^B	2.30 ± 0.23 ^B	2.30 ± 0.23 ^B
24	3.14 ± 0.25 ^A	3.33 ± 0.17 ^A	3.35 ± 0.12 ^A	3.29 ± 0.19 ^A
72	3.54 ± 0.39 ^A	3.65 ± 0.27 ^A	3.70 ± 0.37 ^A	3.52 ± 0.93 ^A

^{a-c} Values in the same row are significantly ($p < 0.05$) different between sumac concentrations; ^{A,B} values in the same column are significantly ($p < 0.05$) different between storage hours; * control samples (without sumac application).

4. Conclusions

Fish meat is susceptible to oxidation processes that greatly influence its sensory and quality properties. In the Czech Republic, muddy off-flavours are a post-harvest problem in common carp bred and harvested from pond aquacultures. This work is an attempt to study the impact of sumac on the oxidation status and sensory properties of fillets of carp fish. The TBARS values (after 24 h and 72 h of chilled storage) in samples that were treated with sumac were lower than those in initial samples. The antioxidant capacity elevation in fish muscle correlated with the increase in sumac percentage. A longer storage period (72 h) may be required to study the connection between sumac and TVB-N and FFA and to obtain unambiguous results. The sensory properties of meat from carp fish were influenced by the sumac treatment. Sumac aroma and its sour odour and flavour were able to mask or reduce the natural fish odour and flavour. These characteristics of sumac could be beneficial for consumers that are disturbed by the smell and taste of fish, and can also be useful in reducing muddy off-flavours in some freshwater fish. However, high variation among panellist's opinions was observed in several descriptors of sensorial attributes, which is reflected in the standard deviation values. The use of a water extract of sumac instead of ground sumac for the treatment of the meat of carp fish might be more acceptable by panellists due to appearance and technical reasons. The decrease in pH of fillets due to application of 1.5% and 2.5% sumac correlated with a decrease in aerobic plate count after 24 h of cold storage and also with lower growth of psychrotrophic microorganisms. After 72 h of sumac application, microorganism counts were higher than after 24 h. Thus, sumac promoted the suppression of microorganism growth for a short period of time after application, but itself may be a source of contamination. In a further experiment, it would be advisable to test the level of sumac contamination. Sumac is exotic and unusual in our region, for which reason its role in the oxidation state and sensory properties of meat from carp fish may be beneficial for the fish industry. The potential limitations in this study are represented by short refrigeration period (72 h) resulting from the experimental setup. In further studying the effect of sumac, it would be advisable to extend the storage period to assess the effect of sumac throughout the shelf life.

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Institutional Review Board Statement: In this research, the raw material used (fillets of fish) were bought from the fish-processing plant. We did not deal with live fish or any process before or during processing of common carp.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in this article.

Conflicts of Interest: The authors declare no conflicts of interest.

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