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# Low-Pressure Application Improved the Physicochemical and Microbiological Properties of Fresh and Stored Pikeperch (*Sander lucioperca*)

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***ABSTRACT***

In this study, low-pressure treatment was applied to pike-perch and the changes in quality criteria during the storage process were examined. L*, a*, and b* values in samples treated with low pressure were significantly different compared to the control. It was observed that the process had an improving effect on the textural properties of the fish. While the $a_w$ value decreased to 0.822, the pH value decreased to 6.47. While TBARS values of the samples ranged between 0.014 and 0.031 mg MA / kg, TVB-N values ranged between 7.69 and 24.06 mg / 100 g. Total aerobic mesophilic bacteria, yeast/mold, total coliform group bacteria, and total aerobic psychrophilic bacteria counts of all samples exposed to low-pressure treatment were lower than the control during storage. As a result, the treatment positively affected the quality of pikeperch meat during the storage period.

**Keywords:** Pike-perch, low-pressure, quality, texture

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## Düşük Basınç Uygulaması Taze ve Depolanmış Sudak Balığının (*Sander lucioperca*) Fizikokimyasal ve Mikrobiyolojik Özelliklerini Geliştirdi

**Öz: :** Bu çalışmada sudak balığına düşük basınç işlemi uygulanmış ve depolama sürecindeki kalite kriterlerindeki değişimler incelenmiştir. Düşük basınç işlemi uygulanmış örneklerde L*, a* ve b* değerleri kontrole kıyasla belirgin bir şekilde farklı çıkmıştır. İşlemin balığın tekstürel özellikleri üzerinde iyileştirici etkisi olduğu görülmüştür. $a_w$ değeri 0,822 değerine kadar düşerken, pH değeri 6,47 değerine kadar düşmüştür. Numunelerin TBARS değerleri 0,014 – 0,031 mg MA/kg aralığında değişirken, TVB-N değerleri 7,69 – 24,06 mg/100 g aralığında değişmiştir. Düşük basınç işlemine maruz kalmış bütün örneklerin toplam aerobik mezofilik bakteri, maya/küf, toplam koliform grubu bakteri, toplam aerobik psikrofilik bakteri sayımları depolama süresince kontrole kıyasla daha düşük çıkmıştır. Sonuç olarak yapılan işlem depolama sürecinde sudak balığı etinin kalitesi üzerinde olumlu etki göstermiştir.

**Anahtar kelimeler:** Sudak, düşük basınç, kalite, tekstür

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## Introduction

Manufacturers encounter several significant challenges while producing food products. One of the priorities is to provide affordable, high-nutrition, and reliable food that can meet the needs of the ever-growing population. Producers are developing new techniques to meet the increasing demand for minimally processed, perishable foods. Therefore, producers are developing different techniques to cope with these problems and trying to apply them commercially (Corradini 2018). Another problem with food products is that they are often transported and consumed outside their production location and timeframe. Since many food products are consumed in different places and over extended periods, storage becomes critical (Gökoğlu 2020).

Spoilage of food means that the product becomes unconsumable, and if consumed, it causes serious health problems. Especially products such as fresh fish meat, which have a high water activity value, are rich in nutrients, have weak connective tissue and pH values close to neutral, are considered easily

perishable foodstuff (Gökoğlu 2019). The main factors affecting spoilage in fish are biochemical reactions such as hydrolysis and oxidation of polyunsaturated fatty acids catalyzed by endogenous proteases (Zeng et al. 2023). To ensure the delivery of high-quality fish meat to consumers, it is crucial to preserve and process fish under appropriate conditions.

Today, consumers pay considerable attention to the quality and freshness of food products, as well as their minimal processing. Thermal treatment traditionally applied in food production causes a loss of quality and a decrease in the nutritional value of raw materials. Therefore, using new non-thermal technologies is very advantageous to reduce the heat-related loss of nutritional value and deterioration in sensory quality that occurs in traditional production methods (Chen et al. 2020). Foods with higher nutritional value, longer shelf life, and higher product safety can be produced with these technologies. Therefore, the demand for minimal and non-heat-treated food products has increased significantly in recent years. Because of this, as with other foods, research on the application of non-thermal methods for the preservation of fish has become very popular (Rathod et al. 2021).

The pikeperch (*Sander lucioperca*) is a freshwater fish that belongs to the family Percidae and is native to Asia and Europe. The pikeperch stands out with its meat being soft, white, delicious, and low in fat. It is appreciated and preferred by consumers as it is also one of the most popular freshwater fish due to its small number of intermuscular bones (Tönißen et al. 2022). Within the scope of our research, pikeperch was preferred because it is abundant in the inland waters of our country, is a fish species preferred by consumers, and its meat is suitable for use in the study. Upon reviewing the available literature, it has come to our attention that there are no existing studies on the utilization of low pressure in pikeperch fish. As such, our study marks a pioneering effort in this particular field.

## Materials and Methods

### Materials

The pikeperch (*S. lucioperca* (L.,1758)) used in the research was caught from Lake Eğirdir in May 2023. The average weight of the caught fish was 432.53 ± 101.24 grams and their length varied between 36.42 ± 3.72 cm. The fish were brought to the laboratory on the same day in ice-filled foam boxes. After use, they were promptly cleaned and stored in a freezer at a temperature of -20 ℃ until they were ready to be analyzed again.

### Methods

#### *Application of low-pressure treatment*

A specially designed cabin was used for the low-pressure process applied to fish samples. The samples were subjected to two different low-pressure and time applications separately. The applications determined cabin interior conditions as pressure: -250/-500 mbar, temperature: 4 °C, humidity: 55.7 %, oxygen concentration: 0.06 %, carbon dioxide: 0.13 ppm.

#### *Physicochemical analysis of samples*

#### *pH and $a_w$ values*

pH values of pikeperch samples were measured with a calibrated pH meter (Ohaus, starter 3100) (AOAC 2016). Water activity values of the samples were determined according to AOAC (2016) with the help of a water activity tester (Novasina Lab Touch-$a_w$ Lachen, Switzerland).

#### *Thiobarbituric acid (TBA) and total volatile basic nitrogen (TVB-N) values*

TBA values of pikeperch samples during storage were determined by Tarladgis et al. (1960), while TVB-N values were determined according to the method specified in İnal (1992).

#### *Color values*

Color analysis of the samples was carried out using a Konica Minolta (Chroma meter CR-400) device. Color measurements were determined separately by making three parallel measurements on the interior section (flesh) and exterior (skin) surfaces.

#### *Texture profile analysis (TPA) values*

TPA values of fish samples were determined at room temperature using a 5 kg load cell texture analyzer (TA-XT2i; Stable Microsystems Ltd. Surrey, UK). Measurements were performed using a cylindrical aluminum probe (P/50, 50 mm diameter Stable Micro Systems LTD, Godalming, UK). Pre-test, test, and post-test speeds were set to 5, 1, and 5 mm/s, respectively. The type of deformation applied to the samples during the analysis was selected as strain and set as 50%. Measurements were made in triplicate to determine the TPA profile of each sample (Eroğlu et al. 2015).

#### *Microbiological analysis*

Microbiological analysis of the samples was performed according to the spread plate technique. For microbiological analysis, 10 g of sample was taken, and 90 mL of sterile Ringer's solution (Merck, 11525, Germany) was added and homogenized in a Stomacher (Lab Stomacher Blender 400-BA 7021, Seward Medical). Appropriate dilutions were prepared by taking 1 mL of this homogenate. In the research, all sowings were carried out in two parallel ways, and the results were given as log cfu/g (Sekin and Karagözlü 2004).

Total aerobic mesophilic bacteria (TAMB) and total aerobic psychrophilic bacteria (TAPB) counts were determined using plate count agar (PCA) (Merck 1.05463, Germany). The cultivated Petri dishes were incubated under aerobic conditions for 48-72 hours at 30°C for TAMB count and 5-7 days at 0-4°C for TAPB count (ISO 2008; ISO 2013a). For the total count of yeast/molds, rose bengal chloramphenicol agar (Merck 1.00467, Germany) (RBC) was used, and the cultivated Petri dishes were incubated at 22°C for 5-7 days under aerobic conditions (ISO 2013b). For total coliform group bacteria (TCGB) count, violet red bile agar (Merck 1.01406, Germany) was used, and Petri dishes were incubated under aerobic conditions at 30°C for 24-48 hours (ISO 1991).

***Experimental design and statistical analysis***

The experimental design was random with a factorial structure (3 x 6). Factors are storage time (days 1, 5, and 7) and fish samples (control, -250 mbar for 60 minutes, -250 mbar for 120 minutes, -500 mbar for 60 minutes, and -500 mbar for 120 minutes low-pressure treated samples). Two-way analysis of variance was used to determine differences ($P < 0.05$) between samples across sample type and storage time. The analysis results were subjected to the ANOVA procedure followed by Duncan's multiple range tests (SPSS, version 23). The design was completely randomized with replications.

## Results

### Color values

The color values determined by measuring

**Table 1.** Color values of pikeperch samples subjected to low-pressure treatment

| | | Sample | Storage Time | | |
|---|---|---|---|---|---|
| | | | 1st Day | 5th Day | 7th Day |
| L* | Interior | Control | 43.89±0.65$^{Ac}$ | 40.83±0.69$^{Bc}$ | 35.62±1.20$^{Cc}$ |
| | | -250 mbar 60 min | 45.01±0.19$^{Ac}$ | 43.90±0.25$^{Bb}$ | 40.61±0.36$^{Cab}$ |
| | | -250 mbar 120 min | 47.09±0.72$^{Ab}$ | 42.19±0.50$^{Bbc}$ | 39.44±1.82$^{Bbc}$ |
| | | -500 mbar 60 min | 46.67±0.49$^{Ab}$ | 43.61±1.57$^{ABb}$ | 39.89±2.23$^{Bbc}$ |
| | | -500 mbar 120 min | 49.09±0.56$^{Aa}$ | 47.72±0.99$^{ABa}$ | 44.37±1.28$^{Ba}$ |
| | Exterior | Control | 39.90±0.31$^{Ab}$ | 36.47±1.34$^{Ab}$ | 31.27±1.62$^{Bb}$ |
| | | -250 mbar 60 min | 41.91±1.05$^{Ab}$ | 39.69±0.63$^{Aa}$ | 34.29±1.65$^{Bab}$ |
| | | -250 mbar 120 min | 43.99±0.38$^{Aa}$ | 40.79±0.45$^{Aa}$ | 35.54±1.84$^{Bab}$ |
| | | -500 mbar 60 min | 44.76±0.78$^{Aa}$ | 40.40±1.48$^{ABa}$ | 35.95±1.83$^{Bab}$ |
| | | -500 mbar 120 min | 45.75±0.69$^{Aa}$ | 41.43±1.37$^{ABa}$ | 38.69±2.04$^{Ba}$ |
| a* | Interior | Control | 4.60±0.03$^{Ca}$ | 6.74±0.11$^{Ba}$ | 8.99±0.06$^{Aa}$ |
| | | -250 mbar 60 min | 4.28±0.07$^{Cb}$ | 5.24±0.12$^{Bb}$ | 7.01±0.25$^{Ab}$ |
| | | -250 mbar 120 min | 4.22±0.0.04$^{Cb}$ | 5.22±0.18$^{Bb}$ | 6.79±0.20$^{Ab}$ |
| | | -500 mbar 60 min | 4.16±0.07$^{Bb}$ | 4.71±0.39$^{ABbc}$ | 5.33±0.28$^{Ac}$ |
| | | -500 mbar 120 min | 4.11±0.11$^{Ab}$ | 4.17±0.15$^{Ac}$ | 4.42±0.08$^{Ad}$ |
| | Exterior | Control | 2.93±0.77$^{Aa}$ | 2.26±0.78$^{Ba}$ | 2.04±0.18$^{Ba}$ |
| | | -250 mbar 60 min | 2.49±0.78$^{Ab}$ | 2.25±0.28$^{Aa}$ | 1.82±0.23$^{Aa}$ |
| | | -250 mbar 120 min | 2.28±0.08$^{Ab}$ | 1.95±0.13$^{Ba}$ | 1.88±0.07$^{Ba}$ |
| | | -500 mbar 60 min | 2.26±0.21$^{Ab}$ | 2.12±0.16$^{Aa}$ | 2.07±0.08$^{Aa}$ |
| | | -500 mbar 120 min | 1.73±0.19$^{Ac}$ | 1.50±0.06$^{Ab}$ | 1.38±0.04$^{Ab}$ |
| b* | Interior | Control | 3.20±0.15$^{Ba}$ | 3.24±0.17$^{Ba}$ | 4.47±0.11$^{Aa}$ |
| | | -250 mbar 60 min | 2.08±0.30$^{Ab}$ | 2.49±0.06$^{Ab}$ | 2.88±0.33$^{Ab}$ |
| | | -250 mbar 120 min | 1.10±0.05$^{Cc}$ | 1.97±0.26$^{Bc}$ | 2.56±0.17$^{Abc}$ |
| | | -500 mbar 60 min | 1.91±0.17$^{Bb}$ | 2.18±0.21$^{Bbc}$ | 2.76±0.07$^{Abc}$ |
| | | -500 mbar 120 min | 1.07±0.33$^{Bc}$ | 1.98±0.21$^{Ac}$ | 2.34±0.13$^{Ac}$ |
| | Exterior | Control | -3.22±0.13$^{Aa}$ | -3.43±0.13$^{Aa}$ | -3.96±0.11$^{Bd}$ |
| | | -250 mbar 60 min | -3.86±0.07$^{Bb}$ | -3.29±0.25$^{Aba}$ | -3.08±0.21$^{Ac}$ |
| | | -250 mbar 120 min | -4.36±0.47$^{Bbc}$ | -3.49±0.18$^{Ba}$ | -2.05±0.31$^{Ab}$ |
| | | -500 mbar 60 min | -4.18±0.10$^{Bbc}$ | -3.08±0.31$^{Aba}$ | -2.54±0.52$^{Abc}$ |
| | | -500 mbar 120 min | -4.71±0.18$^{Cc}$ | -2.75±0.42$^{Ba}$ | -0.92±0.27$^{Aa}$ |

±: Represents standard deviations. A - C (→): Values with the different capital letters in the same line for each analysis differ significantly ($P < 0.05$). a - d (↓): Values with the different small letters in the same column for each analysis differ significantly ($P < 0.05$).

the interior and exterior of the samples are given in Table 1.

When the storage time was examined, it was observed that there was a time-dependent decrease in the L* value of each sample. Regarding the applied process parameters, the increase in pressure and time also caused an increase in the L* value. The highest L* (interior) and L* (exterior) values were detected in the first day sample (49.09 and 45.75) with -500 mbar pressure for 120 min treatment, while the lowest L* (interior) and L* (exterior) values were detected in the control sample on the seventh day (35.62 and 31.27).

While there was a time-dependent increase in a* interior values of all samples according to the storage time, there was a decrease in a* exterior values. The increase in pressure and time caused an increase in a* (interior) value and a decrease in a* (exterior) value. While the highest a* (interior) value was detected in the control sample on the seventh day (8.99), the lowest a* (interior) value was detected in the first-day sample (4.11) with -500 mbar pressure for 120 min treatment. While the highest a* (exterior) value was detected in the control sample on the first day (2.93), the lowest a* (exterior) value was detected in the seventh-day sample (1.38) with -500 mbar pressure for 120 min treatment.

There was a time-dependent increase in all samples' b* (interior) values according to the storage time. There was a general increase in the b* (exterior) values, except for the control sample. Parallel to the increase in pressure and time, there was an increase in b* (interior) values. When b* (exterior) values are examined, while there was a decrease in the control sample, there was an increase in all treated samples. While the highest b* (interior) value was detected in the control sample on the seventh day (4.47), the lowest b* (interior) value was detected in the first-day sample (1.07) with -500 mbar pressure for 120 min treatment. The highest b* (exterior) value was detected in the seventh-day sample (-0.92), where -500 mbar pressure for 120 min of treatment was applied.In contrast, the lowest b* (exterior) value was detected in the seventh-day sample (4.71), where -500 mbar pressure for 120 min of treatment was applied.

**Textural values**

Textural values of the samples are given in Table 2.

**Table 2.** Textural values of pikeperch samples subjected to low-pressure treatment

| | Sample | Storage Time 1st Day | 5th Day | 7th Day |
|---|---|---|---|---|
| **Hardness** | **Control** | 730.69±6.33$^{Ba}$ | 1227.44±22.38$^{Aa}$ | 1261.63±45.85$^{Aa}$ |
| | **-250 mbar 60 min** | 225.75±9.06$^{Cb}$ | 512.32±14.97$^{Bc}$ | 581.87±22.10$^{Ac}$ |
| | **-250 mbar 120 min** | 118.60±8.66$^{Cd}$ | 554.61±9.00$^{Bb}$ | 634.28±16.65$^{Abc}$ |
| | **-500 mbar 60 min** | 141.39±11.24$^{Cc}$ | 587.37±14.32$^{Bb}$ | 664.04±22.35$^{Ab}$ |
| | **-500 mbar 120 min** | 117.86±3.38$^{Ce}$ | 362.91±10.82$^{Bd}$ | 511.61±14.96$^{Ad}$ |
| **Adhesiveness** | **Control** | -5.59±0.65$^{Aa}$ | -7.02±0.16$^{Ba}$ | -9.78±0.33$^{Ca}$ |
| | **-250 mbar 60 min** | -20.49±0.79$^{Ad}$ | -25.07±1.90$^{Bc}$ | -25.09±1.37$^{Bb}$ |
| | **-250 mbar 120 min** | -18.44±1.69$^{Acd}$ | -19.09±2.10$^{Ab}$ | -31.28±0.88$^{Bc}$ |
| | **-500 mbar 60 min** | -16.25±0.55$^{Abc}$ | -19.48±0.09$^{Bb}$ | -26.22±1.23$^{Cb}$ |
| | **-500 mbar 120 min** | -14.59±0.78$^{Ab}$ | -16.33±0.08$^{Ab}$ | -32.81±1.86$^{Bc}$ |
| **Springiness** | **Control** | 0.908±0.01$^{Aa}$ | 0.817±0.02$^{Ba}$ | 0.694±0.02$^{Ca}$ |
| | **-250 mbar 60 min** | 0.676±0.03$^{Ab}$ | 0.598±0.02$^{Bb}$ | 0.519±0.02$^{Cb}$ |
| | **-250 mbar 120 min** | 0.609±0.01$^{Ac}$ | 0.557±0.01$^{Bc}$ | 0.447±0.02$^{Cc}$ |
| | **-500 mbar 60 min** | 0.589±0.01$^{Ac}$ | 0.560±0.01$^{Ac}$ | 0.427±0.02$^{Bcd}$ |
| | **-500 mbar 120 min** | 0.538±0.02$^{Ad}$ | 0.498±0.01$^{Ad}$ | 0.395±0.01$^{Bd}$ |
| **Cohesiveness** | **Control** | 0.676±0.02$^{Aa}$ | 0.638±0.02$^{ABa}$ | 0.623±0.01$^{Ba}$ |
| | **-250 mbar 60 min** | 0.592±0.02$^{Ab}$ | 0.579±0.01$^{Ab}$ | 0.496±0.01$^{Bb}$ |
| | **-250 mbar 120 min** | 0.557±0.01$^{Ac}$ | 0.517±0.02$^{Ac}$ | 0.456±0.01$^{Bc}$ |

| | | | | |
|---|---|---|---|---|
| (table continues) | **-500 mbar 60 min** | 0.554±0.01$^{Ac}$ | 0.527±0.02$^{Ac}$ | 0.445±0.01$^{Bc}$ |
| | **-500 mbar 120 min** | 0.536±0.01$^{Ac}$ | 0.500±0.01$^{Bc}$ | 0.432±0.01$^{Cc}$ |
| **Gumminess** | **Control** | 494.01±17.71$^{Ba}$ | 783.60±1.27$^{Aa}$ | 785.73±14.29$^{Aa}$ |
| | **-250 mbar 60 min** | 133.74±9.83$^{Bb}$ | 296.92±10.48$^{Ab}$ | 288.52±7.41$^{Ab}$ |
| | **-250 mbar 120 min** | 66.09±5.83$^{Bc}$ | 286.82±15.43$^{Ab}$ | 289.29±12.07$^{Ab}$ |
| | **-500 mbar 60 min** | 78.37±7.22$^{Bc}$ | 310.03±22.92$^{Ab}$ | 295.94±16.06$^{Ab}$ |
| | **-500 mbar 120 min** | 63.23±1.56$^{Cc}$ | 181.52±10.03$^{Bc}$ | 221.12±13.70$^{Ac}$ |
| **Chewiness** | **Control** | 448.63±20.27$^{Ca}$ | 640.58±13.91$^{Aa}$ | 545.57±2.85$^{Ba}$ |
| | **-250 mbar 60 min** | 90.54±10.24$^{Cb}$ | 177.63±10.89$^{Ab}$ | 149.68±1.77$^{Bb}$ |
| | **-250 mbar 120 min** | 40.24±3.17$^{Cc}$ | 159.96±10.94$^{Ab}$ | 129.58±11.33$^{Bb}$ |
| | **-500 mbar 60 min** | 46.25±5.31$^{Cc}$ | 173.59±12.39$^{Ab}$ | 126.67±12.93$^{Bb}$ |
| | **-500 mbar 120 min** | 34.04±2.36$^{Bc}$ | 90.56±7.69$^{Ac}$ | 87.54±8.39$^{Ac}$ |
| **Resilience** | **Control** | 0.386±0.01$^{Ca}$ | 0.467±0.01$^{Ba}$ | 0.513±0.01$^{Aa}$ |
| | **-250 mbar 60 min** | 0.359±0.01$^{Bb}$ | 0.441±0.01$^{Aa}$ | 0.478±0.01$^{Ab}$ |
| | **-250 mbar 120 min** | 0.339±0.01$^{Ccd}$ | 0.399±0.01$^{Bb}$ | 0.478±0.01$^{Ab}$ |
| | **-500 mbar 60 min** | 0.355±0.01$^{Cb}$ | 0.407±0.01$^{Bb}$ | 0.463±0.01$^{Abc}$ |
| | **-500 mbar 120 min** | 0.328±0.01$^{Cc}$ | 0.381±0.01$^{Bb}$ | 0.448±0.01$^{Ac}$ |

±: Represents standard deviations. A - C (→): Values with the different capital letters in the same line for each analysis differ significantly ($P < 0.05$). a - e (↓): Values with the different small letters in the same column for each analysis differ significantly ($P < 0.05$).

The low-pressure process was effective on all texture values. The highest hardness value was detected in the control sample on the seventh day (1261.63), while the lowest hardness value was detected in the first-day sample (117.86) with -500 mbar pressure for 120 min treatment. The highest adhesiveness value was determined in the control sample on the first day (-5.59), and the lowest adhesiveness value was determined in the seventh day sample (-32.81), which was applied at -500 mbar pressure for 120 min of treatment. The lowest springiness value was found in the seventh-day sample (0.395) with -500 mbar pressure for 120 min treatment, while the highest springiness value was found in the first-day control sample (0.908). Similarly, the lowest cohesiveness value was determined in the seventh-day sample (0.432), where -500 mbar pressure for 120 min treatment was applied, and the highest cohesiveness value was determined in the first-day control sample (0.676). When the gumminess value was examined, the lowest value was detected in the first-day sample (63.23) with -500 mbar pressure for 120 min treatment, and the highest value was found in the control sample on the seventh day (785.73). When looking at the chewiness values, the highest value was found in the control sample on the fifth day (640.58), and the lowest value was found in the first-day sample (34.04) with -500 mbar pressure for 120 min of treatment. Regarding resilience value, the highest value was determined in the control sample on the seventh day (0.513), and the lowest value was determined in the first-day sample (0.328) with -500 mbar pressure for 120 min treatment.

**$a_w$, pH, TBARS and TVB-N values**

$a_w$, pH, TBARS and TVB-N values of the samples are given in Table 3.

In general, $a_w$ values tended to decrease according to the storage time of the samples and the applied process parameters. While the highest $a_w$ value was determined in the control sample on the first day (0.900), the lowest $a_w$ value was determined in the seventh-day sample (0.822), which was applied at -500 mbar pressure for 120 min of treatment. Considering the pH values, the low-pressure treatment did not cause much change in the samples; only an increase was observed in the control sample over time.

**Table 3.** $a_w$, pH, TBARS and TVB-N values of pikeperch samples subjected to low-pressure treatment

| | Sample | Storage Time 1st Day | 5th Day | 7th Day |
|---|---|---|---|---|
| $a_w$ | **Control** | 0.900±0.03$^{Aa}$ | 0.883±0.02$^{Ba}$ | 0.872±0.03$^{Ca}$ |
| | **-250 mbar 60 min** | 0.876±0.01$^{Ab}$ | 0.859±0.01$^{Bc}$ | 0.850±0.01$^{Bb}$ |
| | **-250 mbar 120 min** | 0.868±0.03$^{Abc}$ | 0.844±0.03$^{Bd}$ | 0.826±0.02$^{Cc}$ |
| | **-500 mbar 60 min** | 0.877±0.03$^{Ab}$ | 0.865±0.01$^{Bb}$ | 0.853±0.02$^{Cb}$ |
| | **-500 mbar 120 min** | 0.864±0.01$^{Ac}$ | 0.843±0.01$^{Bd}$ | 0.822±0.01$^{Cc}$ |
| pH | **Control** | 6.65±0.01$^{Ca}$ | 6.81±0.03$^{Ba}$ | 7.03±0.02$^{Aa}$ |
| | **-250 mbar 60 min** | 6.61±0.01$^{Bb}$ | 6.65±0.01$^{ABb}$ | 6.70±0.03$^{Ab}$ |
| | **-250 mbar 120 min** | 6.57±0.01$^{Ac}$ | 6.54±0.01$^{Ac}$ | 6.58±0.02$^{Ac}$ |
| | **-500 mbar 60 min** | 6.55±0.01$^{Ac}$ | 6.50±0.01$^{Bcd}$ | 6.53±0.01A$^{Bcd}$ |
| | **-500 mbar 120 min** | 6.51±0.01$^{Ad}$ | 6.47±0.02$^{Ad}$ | 6.52±0.02$^{Ad}$ |
| TBARS (mg MA/kg) | **Control** | 0.026±0.002$^{Ca}$ | 0.029±0.001$^{Ba}$ | 0.031±0.002$^{Aa}$ |
| | **-250 mbar 60 min** | 0.024±0.001$^{Bb}$ | 0.024±0.001$^{Bb}$ | 0.026±0.001$^{Ab}$ |
| | **-250 mbar 120 min** | 0.019±0.001$^{Bc}$ | 0.019±0.001$^{Bc}$ | 0.021±0.001$^{Ac}$ |
| | **-500 mbar 60 min** | 0.023±0.001$^{Bb}$ | 0.023±0.001$^{Bb}$ | 0.025±0.001$^{Ab}$ |
| | **-500 mbar 120 min** | 0.014±0.001$^{Bd}$ | 0.015±0.001$^{Bd}$ | 0.018±0.001$^{Ad}$ |
| TVB-N (mg/100 g) | **Control** | 10.78±0.50$^{Ba}$ | 19.67±0.91$^{Aa}$ | 24.06±3.69$^{Aa}$ |
| | **-250 mbar 60 min** | 9.92±0.15$^{Ca}$ | 14.76±0.77$^{Bb}$ | 18.56±1.75$^{Aab}$ |
| | **-250 mbar 120 min** | 8.57±0.19$^{Cb}$ | 12.09±0.30$^{Bc}$ | 15.24±0.24$^{Abc}$ |
| | **-500 mbar 60 min** | 7.69±0.94$^{Cb}$ | 10.07±0.28$^{Bd}$ | 15.62±0.76$^{Abc}$ |
| | **-500 mbar 120 min** | 7.82±0.17$^{Bb}$ | 8.77±0.34$^{Bd}$ | 12.01±0.49$^{Ac}$ |

±: Represents standard deviations. A - C (→): Values with the different capital letters in the same line for each analysis differ significantly ($P < 0.05$). a - d (↓): Values with the different small letters in the same column for each analysis differ significantly ($P < 0.05$).

The highest pH value was detected in the control sample (7.03) on the seventh day, while the lowest was in the fifth-day sample (6.47) with -500 mbar pressure for 120 min treatment. When TBARS and TVB-N values are examined, the values detected in the low-pressure treated samples were detected in lower amounts than the control samples. The highest TBARS value was determined in the control sample on the seventh day (0.031 mg MA/kg), and the lowest TBARS value was determined in the first-day sample (0.014 mg MA/kg) with -500 mbar pressure for 120 min treatment. Similarly, the highest TVB-N value was found in the control sample on the seventh day (24.06 mg/100 g), and the lowest TVB-N value was found in the first-day sample (7.82 mg/100 g) with -500 mbar pressure for 120 min treatment.

**Microbiological analysis results**

Microbiological analysis results of the samples are given in Table 4. When the effect of low-pressure treatment on different groups of microorganisms was examined, it was seen that the counts in all treated samples were lower compared to the control samples. The total count of aerobic mesophilic bacteria was lowest in the fifth-day sample (3.67 log cfu/g) applied at -500 mbar pressure for 120 min treatment. The lowest value in terms of yeast/mold count was detected in the first-day sample (2.00 log cfu/g) at -500 mbar pressure for 120 min of treatment. When the total coliform group bacterial counts were examined, the lowest value was determined in the first-day sample (1.85 log cfu/g), where -500 mbar pressure for 120 min of treatment was applied. Finally, the lowest count of the total aerobic psychrophilic bacteria count was determined in the first-day sample (2.57 log cfu/g) at 500 mbar pressure for 120 min treatment.

## Discussion

The effect of low-pressure treatment on the color values of the samples was found to be statistically significant ($P < 0.05$). The increased applied treatment parameters also led to an increase in L* values. However, all samples observed a decrease in L* values over time. The increase in treatment parame ters led to a decrease in both a* (interior) and a* (exterior) values. Considering the duration of storage, an increase in a* (interior) value was observed, while a decrease in a* (exterior) value was

**Table 4**. Microbiological analysis results of pikeperch samples subjected to low-pressure treatment

| | Sample | Storage Time | | |
|---|---|---|---|---|
| | | 1st Day | 5th Day | 7th Day |
| Total Aerobic Mesophilic Bacteria Count (log cfu/g) | **Control** | 4.04±0.06$^{Ca}$ | 5.19±0.03$^{Ba}$ | 6.90±0.04$^{Aa}$ |
| | **-250 mbar 60 min** | 3.97±0.03$^{Bab}$ | 4.11±0.03$^{Bb}$ | 5.47±0.08$^{Ab}$ |
| | **-250 mbar 120 min** | 3.94±0.01$^{Bab}$ | 4.04±0.17$^{ABb}$ | 4.38±0.07$^{Ac}$ |
| | **-500 mbar 60 min** | 3.87±0.03$^{Bb}$ | 3.90±0.02$^{Bbc}$ | 5.24±0.12$^{Ab}$ |
| | **-500 mbar 120 min** | 3.75±0.06$^{Bc}$ | 3.67±0.08$^{Bc}$ | 4.15±0.07$^{Ac}$ |
| Yeast/Mold Count (log cfu/g) | **Control** | 2.76±0.04$^{Ca}$ | 4.21±0.17$^{Ba}$ | 5.93±0.03$^{Aa}$ |
| | **-250 mbar 60 min** | 2.61±0.03$^{Cb}$ | 3.00±0.01$^{Bb}$ | 4.61±0.06$^{Ab}$ |
| | **-250 mbar 120 min** | 2.41±0.02$^{Bd}$ | 2.59±0.07$^{Bd}$ | 4.30±0.09$^{Ac}$ |
| | **-500 mbar 60 min** | 2.52±0.01$^{Cc}$ | 2.67±0.05$^{Bc}$ | 4.46±0.04$^{Ac}$ |
| | **-500 mbar 120 min** | 2.00±0.05$^{Ce}$ | 2.42±0.04$^{Be}$ | 4.00±0.06$^{Ad}$ |
| Total Coliform Group Bacteria (log cfu/g) | **Control** | 2.94±0.04$^{Ca}$ | 4.96±0.03$^{Ba}$ | 5.34±0.05$^{Aa}$ |
| | **-250 mbar 60 min** | 2.67±0.05$^{Cb}$ | 3.69±0.05$^{Bb}$ | 4.09±0.06$^{Ab}$ |
| | **-250 mbar 120 min** | 2.15±0.03$^{Cc}$ | 3.29±0.04$^{Bc}$ | 3.77±0.09$^{Ac}$ |
| | **-500 mbar 60 min** | 2.23±0.03$^{Cc}$ | 3.38±0.03$^{Bc}$ | 3.86±0.05$^{Ac}$ |
| | **-500 mbar 120 min** | 1.85±0.12$^{Cd}$ | 2.41±0.11$^{Bd}$ | 2.77±0.02$^{Ad}$ |
| Total Aerobic Psychrophilic Bacteria (log cfu/g) | **Control** | 3.18±0.06$^{Ca}$ | 4.47±0.07$^{Ba}$ | 5.66±0.01$^{Aa}$ |
| | **-250 mbar 60 min** | 2.93±0.04$^{Cb}$ | 3.73±0.09$^{Bb}$ | 4.59±0.03$^{Ab}$ |
| | **-250 mbar 120 min** | 2.78±0.04$^{Cbc}$ | 3.53±0.01$^{Bc}$ | 4.44±0.02$^{Ad}$ |
| | **-500 mbar 60 min** | 2.76±0.09$^{Cc}$ | 3.73±0.03$^{Bb}$ | 4.51±0.01$^{Ac}$ |
| | **-500 mbar 120 min** | 2.57±0.04$^{Cd}$ | 3.13±0.02$^{Bd}$ | 3.99±0.02$^{Ae}$ |

±: Represents standard deviations. A - C (→): Values with the different capital letters in the same line for each analysis differ significantly ($P < 0.05$). a - e (↓): Values with the different small letters in the same column for each analysis differ significantly ($P < 0.05$).

observed.

When the effect of process parameters on b* values was examined, it resulted in a similar decrease in b* (interior) and b* (exterior) values. During the storage process, an increase was detected in all but a* (interior) values, while an increase was also detected in a* (exterior) values, except for control. When all color parameters were evaluated as a whole, it was seen that the low-pressure process had different effects on the flesh and skin of the pikeperch.

In a study (Bou et al. 2023), L*, a*, and b* values in vacuum-treated sea bream fillets were determined as 52, -4.6, and -0.8 on the first day, and 51, -4.6, and 0.3 on the fifth day, respectively. It is postulated that the dissimilarities in these estimations when compared to the outcomes of our research, are attributable to the variances in the species of fish utilized.

The low-pressure treatment applied to pikeperch was observed to have a significant effect, especially on texture values ($P < 0.05$). Hardness values in all treated samples decreased compared to the control. The increased applied pressure and time significantly caused a further decrease in hardness values. Depending on the storage process, hardness values also increased as the storage time increased. Adhesiveness values were also determined to be lower in treated samples compared to the control. A decrease in adhesiveness values was observed depending on the storage time. Notably, applying pressure at lower values caused lower adhesiveness values. In general, both the increase in the applied treatment parameters and the increase in storage time led to a decrease in springiness and cohesiveness values. As the applied pressure and time increased, both values decreased. Gumminess values in all treated samples were lower than the control. However, the change in treatment parameters had different effects on the samples. The gumminess values generally increased as the storage time increased depending on the process. Chewiness values of low-pressure treated samples decreased compared to the control. The increasedapplied pressure and time led to a general decreasing trend in chewiness values. During the storage process, chewiness values increased from the first day to the fifth day and decreased again on the seventh. Compared to the control, resilience values decreased due to increased treatment parameters. An increase in resilience values was observed as storage time in-

creased.

When all texture values are evaluated as a whole, it is worth noting that low-pressure treatment has been shown to have a positive contribution to the textural properties of fish. It was determined that our study results were different from the results of Bou et al. (2023). It is thought that the differences in textural values arise from the differences in the type of fish and treatment parameters.

The effect of low-pressure treatment and storage time on the $a_w$, pH, TBARS, and TVB-N values of the samples was found to be statistically significant ($P < 0.05$). $a_w$ values were determined to be lower in the treated samples compared to the control sample. A decrease in $a_w$ values was observed as storage time increased. It is thought that the water in the samples evaporates more quickly due to the decrease in external pressure with the low pressure applied. The pH values in samples treated with low pressure remained at lower levels compared to the control's. Especially, during the storage period, the pH value increased more in control samples. During the storage process, the formation of TMA and other volatile compounds due to the action and metabolism of endogenous and microbial enzymes causes the pH to increase (Olatunde and Benjakul 2018). The TBARS value, an indicator of lipid oxidation, was detected at lower levels in low-pressure treated samples than in the control. It can be said that the decrease in the amount of oxygen in the environment due to low-pressure treatment causes this value to be low. An increase in TBARS value was observed in all samples depending on the storage process. In a study (Muela et al. 2014), it was stated that the lipid oxidation value in terms of TBARS in *Thunnus obesus* increased in the presence of $O_2$, and it was stated that this was caused by oxygen causing the release of free radicals. TVB-N, a part of the non-protein nitrogen portion of fish muscle, has been reported in many studies as one of the indicator components in fish spoilage (Nikzade et al. 2019). A decrease in TVB-N values was detected in all samples treated with low pressure compared to the control. This decrease became greater as the applied pressure and treatment time increased. TVB-N values of all samples increased depending on the storage process. It has been reported that the activity of spoilage bacteria and internal enzymes causes the increase in TVB-N value (Nikzade et al. 2019). The increase in TVB-N values is thought to be due to the increase in microbial activity depending on the storage time.

The effect of low-pressure treatment and storage time on the microbial load of all samples was found to be statistically significant ($P < 0.05$). The microbial load of treated samples was lower than the control. While the count of microorganisms decreased with the increase in applied pressure and time, the count of microorganisms also increased as the storage time increased. At the end of the 7-day storage period, the total count of aerobic mesophilic bacteria in the control sample was determined to have the highest microbial count value with 6.90 log cfu/g. This value was within the range of 6 – 7 log cfu/g, considered the acceptability limit for freshwater and marine fish (Silbande et al. 2016). Microbial count values in all other samples remained below this value. The type and count of microorganisms that cause spoilage vary depending on storage conditions, especially temperature and atmospheric composition (Parlapani et al. 2014).

Following the exposure of pikeperch to low-pressure treatment, very significant differences were detected between the quality criteria in the storage process and the quality criteria in the storage process of control samples that were not exposed to any treatment. It was observed that color, texture, $a_w$, pH, TBARS, TVB-N, and microbial values were at superior levels in fish to which this process was applied. Notably, the changes in applied pressure and time played a decisive role in the quality characteristics of the fish. Upon evaluation of the study data as a whole, it can be concluded that fish stored using a low-pressure process is of superior quality. The results of this study will lead to similar applications in different aquatic food products.

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