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PO Yıldız, N Kızıloğlu

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Investigation of Microbiological, Chemical, Sensory and Nutritional Properties of Gravlax Prepared from Catfish

Pınar Oğuzhan Yıldız,[1*] Nilay Kiziloğlu[2]

[1,2]Faculty of Fisheries, Atatürk University, Erzurum, Turkey

ABSTRACT: Gravlax, a traditional Scandinavian dish made by curing fish with salt, sugar, and dill, was prepared using catfish (*Silurus glanis*) to evaluate its microbiological, chemical, sensory, and nutritional properties. The samples were divided into 3 groups: vacuum-packed fresh fish meat (A), standard gravlax applied (B), gravlax with different additives (additional coriander, celery, grated carrots, lemon and beetroot) (C). While the protein, lipid, ash, carbohydrate contents of gravlax-treated samples were found to be higher compared to fresh fish meat, decreases in moisture content were observed. The growth of bacterial was slower in gravlax samples. Increases in TBARS, TVB-N values were observed in parallel with storage, and the effect of storage time was also found to be significant ($p<0.01$). Group C was the most liked group in terms of all sensory parameters. All these analyzes concluded that the gravlax process had positive effects on the quality parameters of the samples and also increased the shelf life of the product.

Keyword: Catfish; Gravlax; Fermentation; Food preservation; Traditional fish products

Correspondence author:
Pınar Oğuzhan Yıldız,
Faculty of Fisheries, Atatürk University, 25240, Erzurum, Turkey
E-mail address: pinaroguzhan@atauni.edu.tr

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INTRODUCTION

Catfish belongs to the Siluridae family (*Silurus glanis* Linnaeus, 1758) and is the only species in this family that is fully produced and bred. Aquaculture has become an important segment of the aquaculture sector due to the high economic value of the species and the preference of consumers for its taste, high protein and low fat content. In recent years, catfish farming has shown a steady growth reflecting its importance in meeting the increasing demand for sustainable and nutritious fish products. It is a good fish species in pond farming rather than in single-farming, and its advantages due to its importance in aquaculture can be listed as follows; It is resistant to oxygen deficiency and their requirements are compatible with the maintenance conditions of carp fish. They develop rapidly at low temperatures and are quite resistant to parasites and diseases. It is a fish species with high commercial value, preferred in our country as in many other countries due to its boneless and delicious meat and marketability (Kamari, 2007; Saylar, 2009; Uysal et al., 2009; Çağıltay, 2011; Yüngül and Dörücü, 2023).

Fish meat is a foodstuff that is extremely sensitive to spoilage, and many processing methods have been used since ancient times to prevent spoilage and increase shelf life, and many new processing methods have also been brought about in parallel with developing technology. Seafood is offered to consumers in various forms as fresh, raw, minimally processed, ready-to-eat, and processed with traditional methods (salting, smoking, drying, marinating, canning) (Şengör et al., 2018; Çoban et al., 2020; Vurat, 2021). Minimally processed products play an important role in the diversity of foods obtained from fish. Nowadays, as consumers want a natural and reliable product, minimally processed fish are highly preferred. One of the most interesting examples of minimally processed fish products is gravlax. Gravlax is an alternative product that is prepared in a short time. During the production proses of the gravlax process, the product is ripened in a mixture of salt and sugar as a preservative (Rzepka et al., 2013). Unfortunately, there is not much information about the changes during the production and storage of gravlax prepared with rainbow trout in our country (Michalczyk and Surówka, 2007; Durmuş et al., 2017; Çoban et al., 2020; Özpolat, 2020).

Gravlax is a traditional dish made from fermented salmon in Scandinavian cuisine. Fermentation is an important method for producing traditional fish products globally, with significant cultural and nutritional roles in both Southeast Asia and Europe. While Southeast Asia has a rich history of fermented fish consumption, only a few traditional products remain in Northern Europe. Among them, "Gravlax" stands out as a key element of Scandinavian cuisine, particularly in Sweden, Norway, Finland, and Iceland. Traditionally made with salmon or other oily fish like herring or certain shark species, gravlax is prepared by fermenting the fish in soil, under birch bark and stones, or in barrels, and is consumed without further processing. Although gravlax is less familiar in some countries, it is highly regarded in others, and there is an increasing variety of quickly prepared alternatives to meet modern demands (Özpolat, 2020; Skåra et al., 2015). The main ingredients used in the gravlax method are salt, sugar, spices and today; in addition to being able to add different aromas to the final product, there are also gravlax products prepared by adding cress, carrots, coriander, dill and red beet due to the benefits they provide in human nutrition. This blend of natural preservatives and nutrient-rich ingredients not only preserves gravlax but also elevates its nutritional and functional value, making it a healthful and flavorful delicacy. Red beet, rich in flavonoids and polyphenols, provides vibrant color, antioxidant properties, and cancer-preventing effects, along with a high fiber content. Carrots are another valuable addition, supplying antioxidants, dietary fiber, and essential minerals (magnesium, potassium, calcium) and, which are particularly beneficial for bone health. They also contain higher levels of vitamin C than many other fruits and vegetables. Coriander is a nutrient-rich herb that is low in calories and saturated fat, while being an excellent source of vitamins A, C, E, and K, dietary fiber, as well as essential minerals (potassium, iron, magnesium, calcium). Dill contributes antifungal properties, while black pepper, with its phenolic acid amides, delivers potent antioxidant activity, surpassing even α-tocopherol. Finally, celery stalks act as powerful antioxidants and are rich in magnesium, potassium, folic acid, and dietary fiber, further enhancing the health benefits of gravlax (Rajeshwari and Andallu, 2011; Çoban et al., 2020; Çümen and Bostancı, 2021; Anonymous, 2023; Vurat and Kocatepe, 2023). In light of all this information, it is important to benefit from the nutritional content of gravlax with different additives (additional coriander; celery; grated, carrot, lemon and beet) in addition to the standard gravlax application during this application.

Although there are studies using different fish in the production of gravlax, no study on catfish has been found in the literature. In this research, it was aimed to investigate the quality parameters of gravlax prepared from catfish.

MATERIAL AND METHOD

Fish Material

The material of the study, 9 catfish (a total of 3 groups of 3 fish each) with an average length of 120.12±1.55 cm and a weight of 11.15±0.32 kg were purchased from a market in Ardahan and brought to the Processing Laboratory of Atatürk University Faculty of Fisheries in accordance with the cold chain rules.

Method

Gravlax Preparation

The gravlax process was carried out by making some changes to the method developed by Emir Çoban et al. (2020) and for this process, brown sugar-salt mixture, dill, black pepper, celery stalk, grated carrot, lemon and beet were spread on both sides of the catfish fillets. Approximately 350 g of mixture was used for 1 kg of fish fillet. The fish fillets were wrapped in stretch film, and placed in a container against the possibility of water leakage and left to ripen for 36 hours at 2°C. At the end of the ripening period, the mixture on the fillet was cleaned with a sterile brush (Figure 1). The gravlax were divided into 3 groups: vacuum-packed catfish sample (A), standard gravlax applied sample (B) and gravlax sample with different additives (additional coriander, celery, grated carrot, lemon and beetroot) (C). They were stored in the refrigerator temperature (4±1ºC) and were analyzed at 1, 4, 8, 12, 16, 20, 24, 28, 32, 36 and 40 days.

Microbiological Analysis

Approximately 10 g of the fillet was placed into sterile stomacher bags, followed by the addition of 90 mL of buffered peptone water, and homogenized for 2 minutes using a stomacher (BagMixer 400P Lab Blenders, Interscience USA). The total aerobic mesophilic bacteria (TAMB) and psychrotrophic bacteria were enumerated using Plate Count Agar (Chemsolute, Germany), incubated aerobically at 30°C for 48 hours and at 7°C for 10 days, respectively. Lactic acid bacteria (LAB) and Enterobacteriaceae were enumerated on de Man, Rogosa, and Sharpe Agar and Violet Red Bile Glucose Agar (VRBGA), respectively, with both incubated aerobically at 30°C for 48 hours. Last-

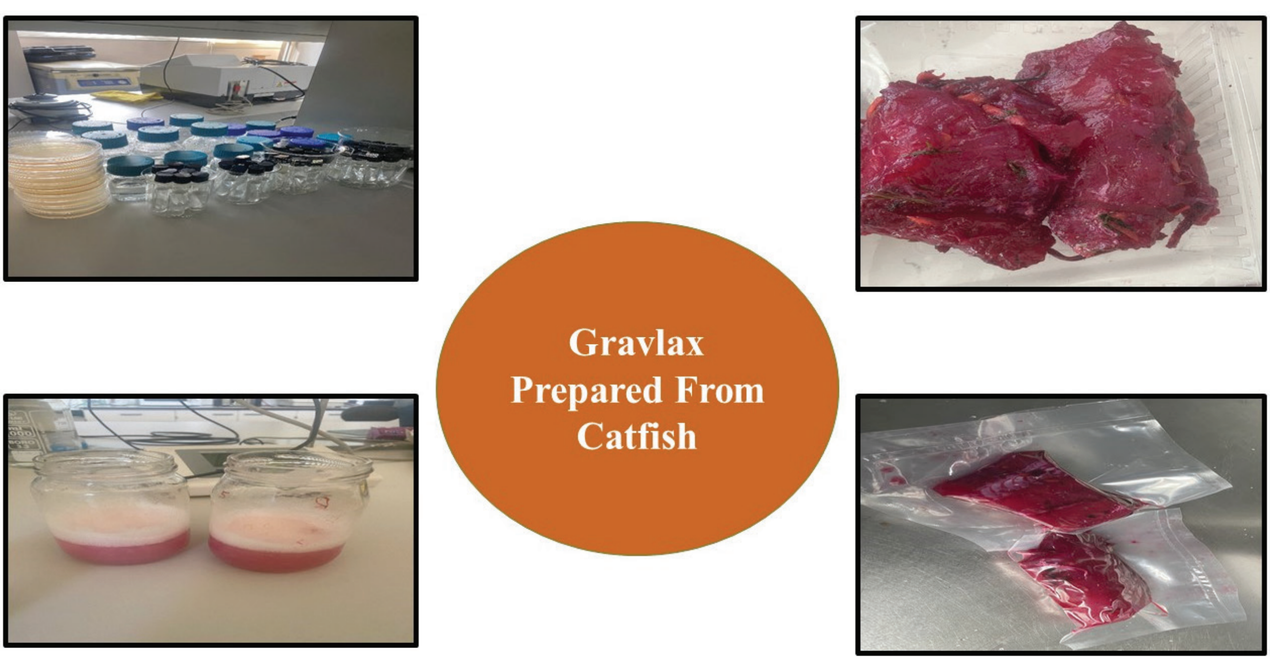

Figure 1. Gravlax Prepared from Catfish.

ly, yeast-mold were enumerated using Rose Bengal Chloramphenicol Agar (RBC) and incubated at 25°C for 5 days. The microbiological analysis results were reported as log10 CFU/g (Halkman, 2005).

Physio-chemical Analysis

Moisture, crude protein, lipid, carbohydrate, and ash contents (%) were determined following standard AOAC methods (AOAC, 2000). Moisture was measured by drying the samples at 105°C in a laboratory oven (Memmert UNB 400, Schwabach, Germany). Crude protein was measured by the Kjeldahl method using a nitrogen distillation unit (Gerhardt Vapodest 500, Königswinter, Germany). Lipid content was determined using a Soxhlet extraction unit (Wiggens SES630, Germany) with petroleum ether. Ash content was measured using a muffle furnace (Nabertherm P330, Lilienthal, Germany) at 550°C. Carbohydrate content was calculated by difference. Salt content (%) was measured via volumetric titration according to Keskin (1992).

Determination of pH Value

For pH measurement, 10 g of the fish sample was homogenized with 100 mL of distilled water using a homogenizer (IKA T25 digital Ultra-Turrax, Staufen, Germany) for 1 minute. The pH was then measured with a pH-meter Seven Compact (Mettler Toledo, USA), previously calibrated with standard buffer solutions (Gokalp et al., 2001).

Determination of Thiobarbituric Acid Reactive Substance (TBARS)

A 2 g sample was mixed with 12 mL of 7.5% trichloroacetic acid and homogenized. The mixture was then filtered (Whatman No. 1). Next, 3 mL of the filtrate was mixed with 3 mL of 0.02 M thiobarbituric acid. This solution was heated in a boiling water bath for 40 minutes and then cooled in cold water for 5 minutes. After centrifuging at 2000×g for 5 minutes (Beckman Coulter, ABD), the absorbance was measured at 530 nm using a spectrophotometer (Shimadzu, UVmini-1240, Japan). TBARS results were reported as mg of MDA per kg of sample (Kilic and Richards, 2003).

Determination of Total Volatile Basic Nitrogen (TVB-N)

For the analysis, 40 g of the sample was mixed with 80 mL of 7.5% trichloroacetic acid, homogenized, and centrifuged. The filtrate was passed through Whatman No. 3 filter paper. Then, 5 mL of NaOH was added, and the mixture was distilled. The resulting distillate was titrated with 0.1 N H_2SO_4 until a stable pink color appeared. The TVB-N content was calculated using the following formula (Malle and Tao, 1987).

TVB-N (mg/100g) = n x 16.8 mg nitrogen

Sensory Evaluation

Sensory evaluation was conducted according to the method suggested by Rzepka et al. (2013). The evaluation was performed by eight trained panelists, who received prior training on identifying and scoring sensory attributes of gravlax, including smell, taste, texture, and color. Each panelist participated in three repeated sessions, and the final scores were averaged. The sensory evaluation was based on a five-point hedonic scale (1=the worst, 5=the best).

Statistical Analysis

For the research trial, the data obtained in the factorial design of three applications and eleven storage days were analyzed by applying SPSS 26.0 package program. Statistical analysis was performed using a one-way analysis of variance (ANOVA) with a 95% confidence interval, and Duncan's Multiple Range Test was used to assess differences between the products.

RESULTS AND DISCUSSION

Microbial changes

Microbial results (log cfu/g) of gravlax prepared with catfish are given in Figure 2. The number of mesophilic aerobic bacteria is a frequently used criterion as an indicator in determining the microbiological quality of foods (Alakavuk, 2009; Yaz, 2013). Total aerobic mesophilic bacteria counts of vacuum-packaged catfish samples were determined as 3.01 log cfu/g at the beginning of storage. In fish meat treated with standard gravlax (B) and with different additives (C) were found 2.63 and 2.05 log cfu/g respectively. Total aerobic mesophilic bacteria counts increased during the storage and at the end of the 40-day storage period, bacterial counts in samples A, B and C were determined as 10.30, 8.39 and 6.70 log cfu/g, respectively. Higher bacterial counts were detected in fresh fish meat compared to samples treated with gravlax. Vacuum environments limit the growth of aerobic microorganisms by reducing oxygen levels. However, these conditions may promote the growth of facultative anaerobic or low oxygen demand microorganisms. This may have contributed to the high total aerobic count. In addition, additives such as salt, sugar and coriander have antimicrobi-

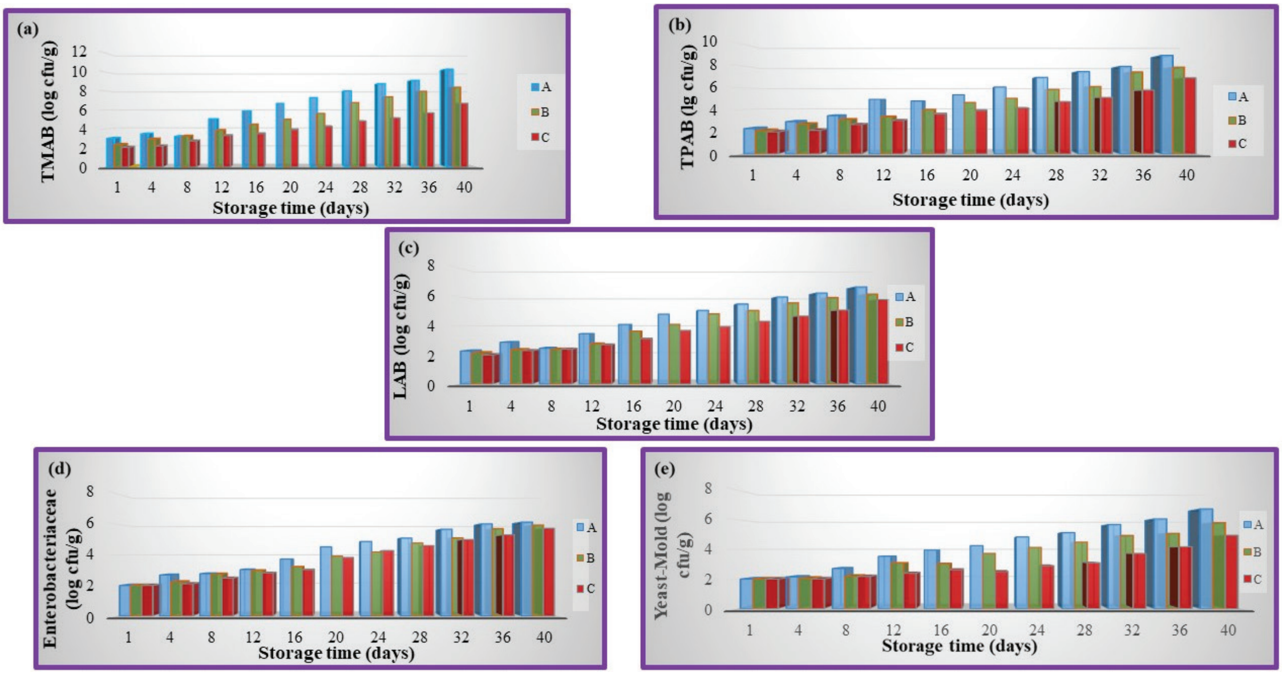

Figure 2. Microbial results of gravlax prepared with catfish. A: vacuum-packed fresh fish meat, B: standard gravlax applied group, C: gravlax group with different additives (additoonal coriander, celery, grated carrot, lemon and beetroot).

al properties that cause slower bacterial growth in gravlax-treated samples. Salt creates an unfavorable environment for bacterial growth by reducing water activity. It draws water from microbial cells through osmotic pressure, causing dehydration and inhibiting enzymatic activity necessary for survival. Salt disrupts their membranes, causing structural damage and dysfunction. Sugar balances the concentration of salt while binding free water molecules, further reducing water activity. This dual effect of salt and sugar synergistically reduces bacterial viability and slows down microbial proliferation.

Statistically significant differences between groups were observed during storage ($p<0.05$). Mesophilic bacteria grow at moderate temperatures and are less adapted to cold environments. The low storage temperatures used in the study probably inhibited their metabolic activities and delayed spoilage in gravlax-applied samples. Other researchers have emphasized that coriander has antimicrobial activity (Albayrak et al., 2012; Deniz et al., 2017). It has been determined that the additives used in the production of gravlax significantly slow down the growth of bacteria compared to fresh fish meat due to their antimicrobial and antibacterial activity. As stated in the studies, the antimicrobial properties of coriander can be attributed to its volatile oils, which are rich in bioactive compounds such as linalool and terpenes. These compounds disrupt bacterial cell walls, interfere with metabolic pathways and inhibit DNA synthesis, which explains the decrease in the number of bacteria in the samples applied with additives. Özpolat (2020) reported that the total mesophilic aerobic bacteria count of spiny eel gravlax exceeded the limit value on the 35th day. Another study reported that the total bacterial count of rainbow gravlax was 3.92 log cfu/g at the beginning of storage and increased to 10^6 cfu/g by the end of storage (Surowka et al., 2021).

Psychrotrophic bacteria play an important role in determining the quality of seafood stored under chilled conditions and cause spoilage under these conditions (Orhan, 2019). On day 1 of storage, the bacterial count ranged between 2.00 and 2.30 log cfu/g. By the end of storage (40th day), the bacterial count reached 8.93 log cfu/g in group A, while it was 7.87 log cfu/g in group B and 6.90 log cfu/g in group C. Statistically significant differences between groups were observed during storage ($p<0.05$). This is due to the presence of additives used in the production of gravlax, especially salt and sugar, which act as natural preservatives. It is thought that the salting process slows down the growth of psychrotrophic bacteria (which can grow at low temperatures) by reducing the water activity of the fish, and also prevents the development of psychrotrophic bacteria by reducing the oxygen transmission of the salt and sugar layer on the surface of the gravlax. Lyhs et al. (2001) reported that the psychrotrophic bacterial count in gravlax made from rainbow trout exceeded the limit of 10^6 cfu/g by the end of storage (20th day). Adetokunbo (2021), psychrotrophic bacterial counts of mackerel gravlax were found to be 2.79± 2.50 log cfu/g.

The yeast-mold numbers were determined as 2.00 log cfu/g in the groups on the 1st day of storage. Increases in yeast-mold counts were observed depending on storage, and on the 40th day of storage, it reached 6.72, 5.78 and 4.95 log cfu/g in samples A, B and C, respectively. Significant differences ($p<0.05$) were detected between the groups in terms of yeast-mold counts during storage. Yeast-mold counts were lower in fish gravlax than in fresh fish meat samples, and the positive effect of the gravlax treatment on yeast-mold growth was observed. Additives used in gravlax, such as coriander, have antifungal properties due to compounds such as linalool and terpenoids. These compounds disrupt fungal cell walls and inhibit enzymatic activity, contributing to lower yeast-mold counts in groups B and C compared to fresh fish. Similar results were reported by Vurat and Kocatepe (2023). Salt and sugar can prevent yeast and mold growth to a certain extent, especially in high concentrations, it slows down the growth of microorganisms such as yeast-mold (Leistner, 1995). It is thought that the gravlax process has an antimicrobial effect, and this is due to the salt and sugar used in gravlax preventing the growth of yeast and mold.

They emphasized that the reason why LAB numbers have low values is because these bacterial groups are especially important in semi-preserved seafood (Genç and Diler, 2019). In our study, the highest LAB count was determined as 6.67 log cfu/g of in A sample on the 40th day of storage. The lowest LAB number was found to be 2.00 log cfu/g in C samples on the 1st day of storage. Lower lactic acid bacteria growth was observed in catfish gravlax compared to the fresh catfish. Gravlax processing, which includes salt and sugar treatment, likely inhibits initial LAB growth due to reduced water activity and antimicrobial effects of additives. Cruz et al. (2008) reported that the LAB number of salmon gravlax was 10^4 cfu/g on the 1st day of storage and 10^7 cfu/g at the end of storage. In another study conducted with salmon gravlax, it was noted that LAB numbers reached 7.1±0.7 log cfu/g after 25 days of storage (Wiernasz et al., 2020). There is a relationship between the type of fish and the rate of deterioration, and the freshness of the fish, storage and transportation conditions also play an important role on the quality of the fish. Depending on all these, microbiological, chemical, sensory and physical changes occur in the quality of seafood (Özturan, 2009). Therefore, our study results are compatible with other studies.

It was emphasized that members of the Enterobacteriaceae family were present in the spoilage microflora of fresh chilled seafood (Genç and Diler, 2019). Enterobacteriaceae counts were observed as 2.00 log cfu/g at the beginning of storage in all groups, and an increase was observed during storage. At the end of storage, the highest bacterial count reached 6.14 log cfu/g in group A. It was found that storage time had a significant effect on the Enterobacteriaceae counts of the samples ($p<0.05$). The increase in Enterobacteriaceae counts observed during storage may also be due to their ability to grow in nutrient-rich environments with moderate oxygen levels, such as those found in refrigerated storage conditions. In addition, the composition of the seafood microbiota and the degradation of proteins and lipids over time likely provide an ideal substrate for Enterobacteriaceae growth. Wiersz et al. (2020) the initial number of Enterobacteriaceae of salmon gravlax was 4.0 log cfu/g, and it was determined that it reached 8.2±0.4 log cfu/g after 25 days of storage.

Chemical changes

Chemical results of gravlax prepared with catfish are given in Figure 3a-c. Seafood is high-value foods that deteriorate quickly and lose quality due to their biological structure, and the nitrogenous compounds that cause spoilage in fish meat are among protein and non-protein nitrogenous compounds. One of the most frequently used methods for determining freshness in seafood is the determination of volatile basic nitrogen compounds (TVB-N) value (Maghraby et al., 2013; Çakmak and Sancak, 2019; Arslan, 2020; Düzarduç, 2021). An increase were observed in TVB-N values in all groups during storage, but deterioration limits were not reached. The highest values in terms of TVB-N values during storage were determined in group A samples. The lower final TVB-N values in B and C samples compared

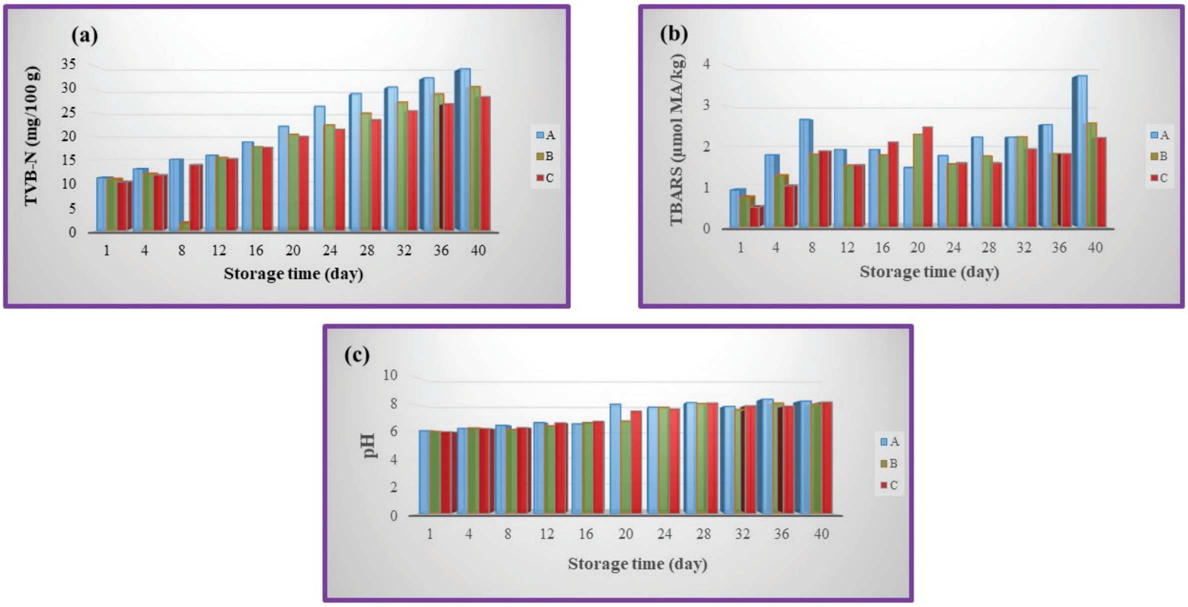

Figure 3. Chemical results of gravlax prepared with catfish. A: vacuum-packed fresh fish meat, B: standard gravlax applied group, C: gravlax group with different additives (additoonal coriander, celery, grated carrot, lemon and beetroot).

to A samples suggest that the additives (e.g., salt and sugar) effectively slowed the accumulation of nitrogenous compounds. Similarly, El-Lahamy et al. (2019) reported that the TVB-N value was 13.7 mg/100 g in their study with fresh catfish. Pankyamma et al. (2020) emphasized that TVB-N values of tilapia gravlax remained stable until the 16th day of storage, and reached 29.85 mg/100 g on the 41st day of storage. TVB-N value can be affected by many factor, such as species, nutritonal status, age and fishing area (Düzarduç, 2021).

Another important parameter in determining freshness and quality in seafood is the lipid oxidation (Çankırılıgil and Berik, 2017). Lipid oxidation causes deterioration in the quality of foods (Abeyrathne et al., 2021). Bitter taste and yellow color occur in oxidized products. TBARS are the commonly used method for detecting lipid peroxidation. TBARS value is an index that measures malondialdehyde (MDA) content, and many factors such as species, season, and oil amount are effective in changing the TBA value (Öksüztepe et al., 2010; Jardine et al., 2002; Abdeldaiem et al., 2017). On the first day of storage, TBARS values were found to be 0.92, 0.73 and 0.49 µmol MA/kg in A, B and C samples, respectively. TBARS value generally increased in parallel with storage and was found to be 3.75, 2.58 and 2.22 µmol MA/kg at the end of storage. The inclusion of coriander, celery, and beetroot in group C appeared to provide antioxidant protection, delaying oxidative spoilage. Salt and sugar slow down lipid oxidation. Salt also prevents the formation of free radicals, which are the precursors of oxidation. In addition, maintaining low temperatures throughout the gravlax process causes TBARS values to remain low. In many studies conducted with aquatic products, researchers have determined an increase in the TBARS value in parallel with the storage period (Chen et al., 2022; Li et al., 2022; Pachekrepapol et al., 2022; Mol et al., 2023; Öz and Uçak, 2023; Tunçelli and Özden, 2023; Villamarín et al., 2023). Rzepka et al. (2013) determined the TBARS value in fresh bonito fish as 0.9±0.02 mg MDA kg^{-1} and reported that it caused an increase in the TBARS value in fish treated with gravlax. Vurat and Kocatepe (2023) reported that the TBARS value of fresh bonito was 1.95 mg MDA/kg, that of bonito gravlax was 0.25 mg MDA/kg.

The pH value varies depending on the season and fish species, and the size can also play an important role. Researchers also found that the pH values of fish after rigor mortis are between 6.2-6.5. Although the consumable values for fresh fish are between 6.5-7.0, this value gradually increases slowly in parallel with the storage time and is not a definitive criterion (Çorapçı, 2018; Yeşilsu et al., 2023). The pH value of the samples varies between 6.03-8.41, the lowest was found in C group, and the highest was determined in A group. Lower pH values in Group C suggest that the additives used (e.g., salt, sugar, or natural antimicrobials) effectively suppressed microbial activity and slowed down protein degradation. In general, pH value was also affected depending on the progression storage time and increases in pH values were also detected due to the increase in microbial counts. It is thought that the antimicrobial properties of the additives used in the gravlax groups suppress microbial growth and the increase in pH value. The sugar applied during the curing process is a non-ionic substance, meaning it does not break down into ions. However, when it interacts with moisture, OH+ and H+ ions can be produced. The presence of OH+ ions is believed to contribute to a rise in pH levels. Moreover, research has indicated that the breakdown of nitrogen-based compounds in meat, occurring due to post-mortem biochemical reactions, also leads to an increase in pH (Vurat, 2021). Namiq and Milne (2017) found that the initial pH values of salmon gravlax were between 6.23-6.35 and decreased on the 2nd day of storage. While pH increases with spoilage, it is not a standalone indicator of quality. The combination of pH, microbial counts, and sensory properties provides a more reliable assessment of fish quality. The gravlax process mitigates rapid pH increases by inhibiting microbial growth, thereby extending shelf life and preserving quality. The interplay between pH, microbial activity, and storage conditions highlights the importance of processing and additives in gravlax production. Group C's lower pH values and slower spoilage progression underline the benefits of optimized preservation methods.

Salt

The salt content was determined as 0.35±0.07% in group A samples, 3.44±0.14% in group B and 4.02±0.08% in group C. Vurat (2021) reported that the salt content of gravlax is between 3-6%, and this results obtained in our study are similar. In another study, the salt levels were reported to be 11.41% and 6.85%, in salmon gravlax (1 and 2 cm thick), respectively (Namiq and Milne, 2017).

Nutritional composition results

Nutritional composition of gravlax prepared with catfish are given in Table 1. While the carbohydrate, crude oil, crude ash and crude protein contents of catfish gravlax samples were found to be higher compared to fresh catfish, decreases in moisture content were observed. The total weight of the fish decreases due to water loss, but solid contents such as protein, lipid and ash remain in the fish and increase. The salting process causes the water inside the fish to come out. The addition of salt and sugar draws water from the fish tissues through osmosis, causing the moisture content of the gravlax to decrease. Our findings are similar to the results determined by Çoban et al. (2020) and Özpolat (2020). The researchers explained this situation with the removal of water from the fish meat by the effect of the sugar and salt in gravlax process, and the reason for the decrease in the amount of moisture is the imbalance in osmatic pressure caused by the salt and sugar in the gravlax process. It has also been stated that the materials used in gravlax production cause an increase in ash content. Michalczyk and Surówka (2007) found that the protein content in fresh fish meat was 20.5±0.49%, fat content was 4.5±0.79%, ash content was 1.3±0.08% and water content was

Table 1. Nutritional composition of gravlax prepared with catfish (*S. glanis*)

	Day 1			Day 40		
	A	B	C	A	B	C
Moisture (%)	75.43±0.60	65.30±0.47	63.02±0.33	74.34±0.25	64.25±0.40	61.70±0.61
Ash (%)	1.65±0.12	4.09±0.08	4.53±0.29	3.94±0.07	6.06±0.02	6.05±0.18
Lipid (%)	2.25±0.24	4.00±0.10	4.56±0.16	1.35±0.09	3.00±0.10	3.87±0.18
Carbohydrate (%)	1.06±0.22	2.20±0.21	2.49±0.09[c]	2.44±0.16	4.02±0.12	4.57±0.29
Protein (%)	19.61±0.72	24.40±0.23	25.40±0.21	17.94±0.08	22.66±0.39	23.80±0.04
Energy (kcal/100 g)	102.93±4.14	142.44±2.76	152.60±1.01	93.65±1.20	133.78±2.05	148.33±2.64

Results are given as mean ± standard deviation.

73.4±2.24% and in trout gravlax it was 22.5±0.41%, 3.8±0.29%, 7.1±1.32% and 60.4±1.68%, respectively. In another study, the moisture content of carp gravlax decreased compared to fresh fish, while protein, fat and ash contents increased (Durmuş et al., 2017). This study is similar to our study.

Sensory evaluation results

One of the most frequently used methods since ancient times in determining the freshness and quality of seafood is the sensory analysis method. Sensory tests are based on the evaluation of seafood by a group of trained panelists in terms of characteristics such as texture, smell, appearance and taste (Ünlüsayın and Erdilal, 2007; Çetinkaya et al., 2014).

For the consumer, it is important that the product is of good quality and nutritious, as well as being sensory appealing. Color, smell, taste, appearance and texture are important criteria in meat and meat products (Peksezer, 2012). In the light of all this information, red beet was used in the production of gravlax in order to contribute positively to the color and make the product more attractive. The color scores of gravlax prepared with catfish are given in Figure 4a. It was highly appreciated by the panelists and the C samples received the highest scores during storage. While group B received the second scores, group A received the lowest scores. It was determined that red beet and other materials used had a positive sensory effect on the color parameters of the samples. Similarly, Çoban et al. (2020) emphasized in their study that the red beet used in gravlax production had a positive effect on color and caused it to receive a high score (4.91±0.11).

The odor scores of gravlax prepared with catfish are given in Figure 4b. The least liked group was group A, while the most liked was group C. It can be said that other additives, especially the spices used in the gravlax process, have positive effects. Durmuş et al. (2017) reported that fresh carp meat scored higher than the gravlax applied group in terms of odor parameters.

Taste scores of gravlax prepared with catfish are given in Figure 4c. The difference between the samples was found to be significant ($p<0.05$), and group C samples received the highest scores. It can be said that this situation is due to the positive effects of other additives, especially the spices used in the gravlax process. Vurat and Kocatepe (2023) stated that group B samples received the highest score in terms of flavor parameters of bonito gravlax, which they packaged with stretch film (A) and vacuum packaging (B).

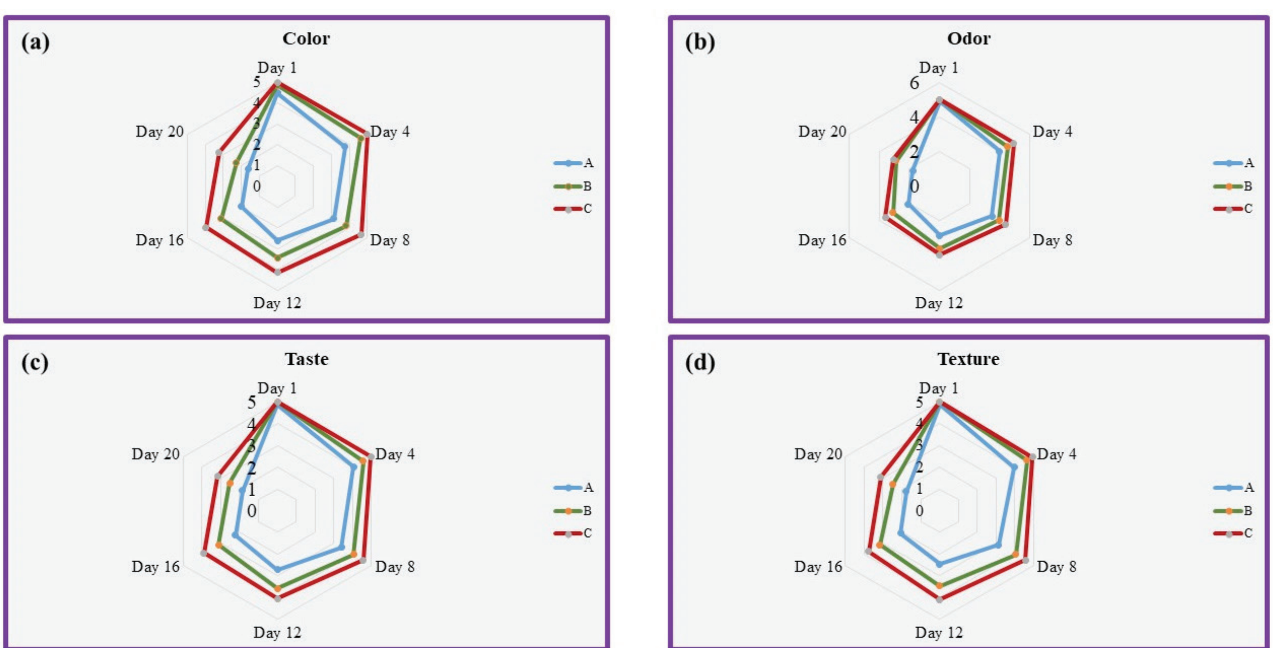

Figure 4. Sensory evaluation results of gravlax prepared with catfish. A: vacuum-packed fresh fish meat, B: standard gravlax applied group, C: gravlax group with different additives (additoonal coriander, celery, grated carrot, lemon and beetroot).

Texture scores of gravlax prepared with catfish are given in Figure 4d. With the effect of the salt used in the gravlax process, some water was removed from the sample, and as a result, the fish meat gained a firmer structure, and it was determined that group C received the highest scores in terms of texture scores. Altan et al. (2022) reported in their study with bonito gravlax that the samples prepared with dill received higher scores in terms of texture score than the group prepared with garden cress.

CONCLUSIONS

Although gravlax is not yet widely recognized in our country, it is a traditional and highly popular fish product in Scandinavian countries. With the growing consumer demand for nutritious, health-promoting, easy-to-prepare, and minimally processed foods, products like gravlax are expected to gain greater prominence in the food industry. In this study, it was determined that the gravlax processing technique, which differs from traditional methods, had positive effects on the sensory, chemical, and microbiological quality of catfish. In particular, shelf-life analyses revealed that Group A samples had a shelf life of 20 days, Group B 28 days, and Group C 40 days, clearly demonstrating the preservation potential of this technique. Based on these findings, it was concluded that gravlax processing not only enhances product quality but also significantly improves the marketability of catfish by extending its shelf life. This is especially important for freshwater fish, which are often limited in commercial use due to their short shelf lives. Considering the increasing consumer interest in minimally processed seafood products, gravlax represents a promising alternative to both diversify seafood consumption and reshape conventional dietary patterns. Furthermore, this study highlights that the integration of such innovative processing techniques into the seafood industry and ready-to-eat food technologies may contribute to both economic and technological advancements.

In conclusion, gravlax-style processed catfish emerges as a promising option in terms of food safety, product quality, shelf life, and consumer acceptability. Future studies applying similar techniques to other fish species and under different processing conditions are expected to enrich the scientific literature and support further development within the sector.

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CONFLICTING INTERESTS

The authors declare no conflicts of interest related to this article.

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