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EFFECT OF SALT CONCENTRATION ON MICROBIAL STABILITY AND QUALITY EVOLUTION OF CARP (*Cyprinus carpio*) ROE DURING MATURATION

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Abstract

Carp roe (Cyprinus carpio) is a rich, concentrated source of nutrients in the human diet, offering multiple health benefits. The maturation of Cyprinus carpio roe is a complex technological process characterized by a series of controlled biochemical transformations that contribute to the development of the final sensory profile. The aim of this study was to monitor the maturation process of Cyprinus carpio roe under controlled refrigeration conditions (0-4°C) for 20 days. Three experimental trials were conducted in which different amounts of NaCl (4%, 7%, and 9%) were added per 450 g of raw material. Controlling maturation parameters, including NaCl concentration, temperature, and duration of the process, is essential for obtaining a product with optimal consumer properties, quality, and safety. The experimental samples were tested microbiologically and physicochemically at 10 and 20 days to identify the optimal maturation time. According to the results, increasing the NaCl concentration led to a significant reduction (<0.005) in total microbial load and mold, with the effect being more pronounced at 9% NaCl. However, at 10 days of maturation, TVC values were slightly higher at 7% and 9% NaCl compared to 4%, suggesting a possible selection of halotolerant microbiota in the product. The physicochemical analyses were significantly influenced (<0.005) by both the salt concentration and the time period. Water activity is significantly influenced by time, salt concentration, and the interaction between time and salt concentration (<0.005). The L parameter is influenced by salt concentration (<0.005) and is not influenced by time. A maturation period of 20 days was identified as optimal for ensuring the safety and quality of the final product.*

Key words*: carp, roe, maturation, quality, safety*

INTRODUCTION

People consume fish roe products because of their pleasant aroma and taste, as well as their nutritional value. Value-added products made from fish roe are highly regarded and rank among the most widely consumed products worldwide. There are various methods for producing fish roe, depending on the fish species, which significantly influence their quality and marketability (Shirai et al., 2006).

In the current context of the food industry, there is growing interest in utilizing by-products and developing high-value-added products. The study conducted by Anchidin B. G. et al. (2024) highlights the potential for transforming secondary raw materials into functional foods, emphasizing the importance of qualitative characterization based on biological source and processing. Although fish roe is considered a high-value product, its integration into concepts of sustainable development and the efficient use of fishery resources aligns with modern trends in the food industry, as highlighted by recent studies (Gucianu I. et al., 2024).

The roe with the highest commercial value is caviar, which comes from the beluga sturgeon or the great sturgeon (*Huso huso*), but are also often harvested from other fish species such as cod (*Gadus morhua*), paddlefish (*Polyodon spathula*), lumpfish (*Cyclopterus lumpus*), carp (*Cyprinus carpio*), mullet (*Mugil cephalus*), etc. The roe from the fish species mentioned above can be considered substitutes for caviar at a much lower cost and are consumed as a spread (Křížek et al., 2011). Carp roe (*Cyprinus carpio*) is a rich source of nutrients, polyunsaturated fatty acids, essential amino acids, and various vitamins. However, its use is

currently limited to a few fish species, as most present various processing challenges (Binsi et al., 2019).

Roe is a product susceptible to oxidative processes, such that the concentration of NaCl significantly influences the microbiological stability and quality evolution of the roe during maturation. In the study by Mirsadeghi et al. (2022), the amount of salt influences the fatty acid composition during the production of salted rainbow trout roe. The results showed that, after salting, the fatty acid composition decreased in raw roe, but no changes were observed during storage. The impact of food additives on the structure and stability of food products depends on their nature and their interactions with the matrix components. The study conducted by Ciobotaru M.C. et al. (2024) highlights the fact that the use of alternative technologies, such as liquid smoke, can significantly influence the quality and sensory characteristics of food products. According to Flocea E.I. et al. (2024), these interactions can significantly influence physicochemical parameters, suggesting that the replacement of synthetic additives with natural alternatives must be analyzed in an integrated manner. The integration of plant-based functional ingredients, such as those rich in phenolic compounds and carotenoids, represents a promising direction, as demonstrated in studies by Anchidin B. G. et al. (2023), although further research is needed for their application in roe maturation. Improved product stability may be attributed to the presence of bioactive compounds in the plant-based ingredients used. In this regard, Manoliu Diana-Remina et al. (2024) highlight the role of fruit fibers in reducing lipid oxidation and improving the textural properties of food products. Sensory evaluation is an indispensable tool in assessing food quality, providing information that complements physicochemical analyses (Ciobanu M. M. et al., 2023). The sensory evaluation of matured roe is an essential parameter in determining product acceptability, as it is influenced by biochemical changes during maturation. Recent studies, such as the one conducted by Boișteanu P. C. et al. (2025), highlight the importance of detailed analysis of sensory attributes (color, aroma, texture, taste) in characterizing complex food products, emphasizing their role in consumer perception. The integration of plant-based bioingredients into fish-based products represents a promising strategy for the development of functional foods, as highlighted in recent literature (Flocea E. I. et al., 2025). The incorporation of smart packaging into products made from matured roe, combined with the use of natural bio-ingredients, represents an innovative approach to enhancing food safety and reducing post-processing losses (Davidescu et al., 2025).

The study aimed to monitor the maturation process of carp (*Cyprinus carpio*) roe under refrigerated conditions over 20 days. To this end, three salt concentrations were used: 4%, 7%, and 9% NaCl.

The samples underwent microbiological and physicochemical analyses (color, pH, and water activity) at 10- and 20-day intervals to determine the optimal maturation duration.

MATERIALS AND METHODS

The study began with the collection of carp roe from a local farm, followed by weighing the roe and subjecting it to a salting process using different salt concentrations (4%, 7%, and 9%) (Table 1). The samples were properly homogenized and then placed in the maturation chamber and stored at refrigeration temperatures (0-4°C). During maturation, the samples were protected from light to limit oxidative processes.

Table 1. Formulation of the experimental sample

	Sample Code	NaCl %	Raw Material (g)
1.	4SFR	4	450
2.	7SFR	7	459
3.	9SFR	9	453

Microbiological tests and physicochemical analyses were conducted under controlled conditions after 10 days and 20 days of maturation. Microbiological analyses were performed to evaluate the hygienic quality and safety of processed fish roe products (roe-based spreads), in accordance with internationally standardized methods. The following microbiological parameters were determined: total viable count (TVC), molds and yeasts, *Escherichia coli*, and coagulase-positive

staphylococci. For sample preparation, 10 g of product were aseptically weighed and homogenized with 90 mL of sterile peptone water (0.1%, w/v) using a stomacher (BagMixer, Interscience, France) to obtain the initial dilution (10^{-1}). Subsequent decimal dilutions were prepared in the same diluent as required. Appropriate aliquots were inoculated onto selective and non-selective culture media using standard pour-plate or surface-plating techniques. The total viable count (TVC) was determined on Plate Count Agar (PCA) following incubation at 30°C for 72 h, according to ISO 4833-1:2013. Molds and yeasts were enumerated on Dichloran Rose Bengal Chloramphenicol (DRBC) agar after incubation at 25°C for 3-5 days under aerobic conditions, in accordance with ISO 21527-1:2008. *Escherichia coli* was determined using Rapid *E. coli* agar after incubation at 37°C for 24 h, based on the principles described in ISO 16649-2:2001. Coagulase-positive staphylococci were enumerated using Rapid Staph agar following incubation at 37°C for 24–48 h, in agreement with ISO 6888-1:2021. Microbial counts were expressed as colony-forming units per gram (CFU/g). Results were log-transformed and reported as log CFU/g. Only plates containing 30-300 colonies were considered for enumeration. When counts were outside this range, results were reported as estimated values. All analyses were carried out in duplicate, and the mean values were used for statistical analysis (Lipșa et al., 2025; Anchidin et al., 2024). An integrated approach to food quality, which takes into account both physical and chemical parameters, is essential for evaluating complex products, as recent studies have shown (Manoliu Diana-Remina et al., 2023). The pH of the experimental batches was measured using the HI98163 pH meter, equipped with the FC2323 electrode, supplied by Hanna Instruments SRL (Gucianu et al., 2023; Ciobotaru et al., 2024). Colorimetric analyses were performed using a Konica Minolta CR-410 colorimeter (Konica Minolta, Inc.) to determine color parameters in the three-dimensional CIELAB color space (Manoliu et al., 2025). The moisture content of the samples was determined using a Humimeter RH2 (Schaller Messtechnik) in accordance with the manufacturer's instructions. Statistical analysis of the obtained data was performed in Microsoft Excel to verify the data's normality for two-way analysis of variance (ANOVA). The Chi-square (χ^2) test, with a significance level of $p < 0.001$, and PCA analysis were performed using the JASP software. These analyses were necessary to determine the influence of the NaCl percentage and the maturation time on the analyzed parameters.

RESULTS AND DISCUSSIONS

The microbiological parameters of the samples analyzed are presented in Table 2, showing the levels of the main groups of microorganisms monitored during the monitoring period. Increasing the NaCl concentration resulted in a significant reduction in total microbial load and mold populations, an effect attributed primarily to the decrease in water activity and the increase in osmotic pressure within the product matrix. These conditions become unfavorable for microbial growth, inhibiting metabolic processes and cell proliferation. The antimicrobial effect was more pronounced at a 9% NaCl concentration, suggesting a directly proportional relationship between salt concentration and the intensity of microbial inhibition, particularly in the case of filamentous fungi, which exhibit increased sensitivity to variations in water activity (Beuchat, 1981).

Table 2. Evolution of microbiological content in samples analyzed during the maturation process

Microorganism	Time (Days)	4SFR	7SFR	9SFR
E.coli	10	*nd*	*nd*	*nd*
	20	*nd*	*nd*	*nd*
S. aureus	10	*nd*	*nd*	*nd*
	20	*nd*	*nd*	*nd*
Molds*	10	2.6±0.00	2.48±0.03	2.18±0.00
	20	2.2±0.05	2±0.01	1.7±0.00
TVC*	10	3.65±0.00	3.86±0.05	3.84±0.15
	20	3.45±0.13	3.45±0.00	3.03±0.03

"*nd*" = not detected; *log CFU·g^{-1}; 4SFR- carp roe sample with 4% *NaCl*; 7SFR- carp roe sample with 7% NaCl; 9SFR-carp roe sample with 9% NaCl

Increasing the NaCl concentration resulted in a significant reduction in total microbial load and mold counts, with the effect being more pronounced at 9% NaCl. However, at 10 days of ripening, TVC values were slightly higher at 7% and 9% NaCl compared to 4%, suggesting a possible selection of halotolerant microbiota. According to Table 3, water activity is significantly influenced by time, the percentage of NaCl, and the interaction between NaCl and time in the carp roe samples studied. The significant effect of salt concentration on water activity can be attributed to NaCl's ability to bind free water through ionic interactions, thereby reducing water availability. Storage time also significantly influenced aw. Furthermore, the significant interaction between salt concentration and time indicates that the impact of NaCl on water activity is time-dependent, likely due to the gradual diffusion of salt and its progressive interaction with muscle proteins, which alters water-binding capacity over the course of storage (Tilapia et al., 2020; Shin & Rasco, 2007).

Table 3. Combined effect of salt concentration (S) and storage time (T) on physicochemical parameters of carp roe

Sample	T (days)	a_w	pH	L*(D65)	a*(D65)	b*(D65)
4SFR	10	0.99±0.00	5.86±0.02	33.98±1.29	1.59±0.04	7.01±0.45
	20	0.93±0.00	5.72±0.02	33.21±0.44	2.23±0.09	7.11±0.19
7SFR	10	0.96±0.00	5.85±0.01	34.29±1.24	2.31±0.08	7.40±0.46
	20	0.93±0.00	5.77±0.01	35.33±0.94	3.30±0.28	7.05±0.69
9SFR	10	0.96±0.00	6.41±1.35	37.34±2.18	2.29±0.35	8.31±0.92
	20	0.93±0.00	5.76±0.01	38.46±1.04	3.98±0.15	7.40±0.81
ANOVA-two-way-factor with replication (*p*-values)						
S		<0.005**	0.423^{ns}	<0.005**	<0.005**	<0.005**
T		<0.005**	0.162^{ns}	0.335^{ns}	<0.005**	<0.005**
S x T		<0.005**	0.448^{ns}	0.207^{ns}	<0.005**	0.019*

4SFR- carp roe sample with 4% NaCl; 7SFR- carp roe sample with 7% NaCl; 9SFR-carp roe sample with 9% NaCl

The influence of the higher salt concentration was observed in the experimental samples containing 7% NaCl and 9% NaCl. Therefore, time and salt concentration are key factors affecting the activity of water. In the case of pH, the p-values here are greater than 0.005, which means that pH is not influenced by the amount of salt or the maceration time. As can be seen during the maturation process, each sample showed a progressive decrease, which may contribute to the inhibition of pathogenic microorganisms, the development of the sensory profile, and increased product stability. With regard to color parameters, a significant influence of salt concentration on the lightness (L*) of the analyzed roe was observed. An increase in NaCl concentration can accelerate pigment oxidation processes, leading to an increase in L* values and, consequently, a reduction in color intensity. For the a* parameter, the results indicate that curing time has a more pronounced influence compared to salt concentration, although the latter also contributes to the observed variations. For the b* parameter, the results suggest a comparable influence of curing time and NaCl percentage on this chromatic component. The interaction between maturation time and salt concentration has a limited effect on color parameters, indicating a limited contribution of the combined effect of the two factors to the color variations in the roe.

Figure 2 shows a graphical representation of the main physicochemical parameters analyzed, namely water activity (aw), pH, and color parameters in the CIELAB system (L*, a*, b*), determined under D65 lighting conditions, highlighting their variations as a function of NaCl concentration and maturation period. (A) The evolution of water activity (a_w) shows a similar pattern during the first stage of ripening (after 10 days), indicating relatively uniform values regardless of the salt concentration used. After 20 days of maturation, a change in the slope of the curves is observed, a finding supported by the statistical significance of the differences (<0.005). In this context, salt concentrations ranging from 7-9% tend to stabilize water activity, reducing it and suggesting improved product stability from a food safety perspective. (B) pH values did not show significant variations under the influence of NaCl concentration, indicating relative stability of this parameter during maturation. (C) The lightness parameter (L*) showed an upward trend throughout the maturation

process, with higher values in the final stage, indicating an increase in the lightness of the samples. These results are consistent with the typical characteristics of carp roe. Salt concentration significantly influenced this parameter. (D) For the a* parameter (D65), the results show that an increase in salt concentration has a more pronounced effect on its dynamics, suggesting a gradual shift in the red-green chromatic component. (E) The values of the b* parameter also confirm the influence of salt concentration on the color characteristics of the analyzed roe.

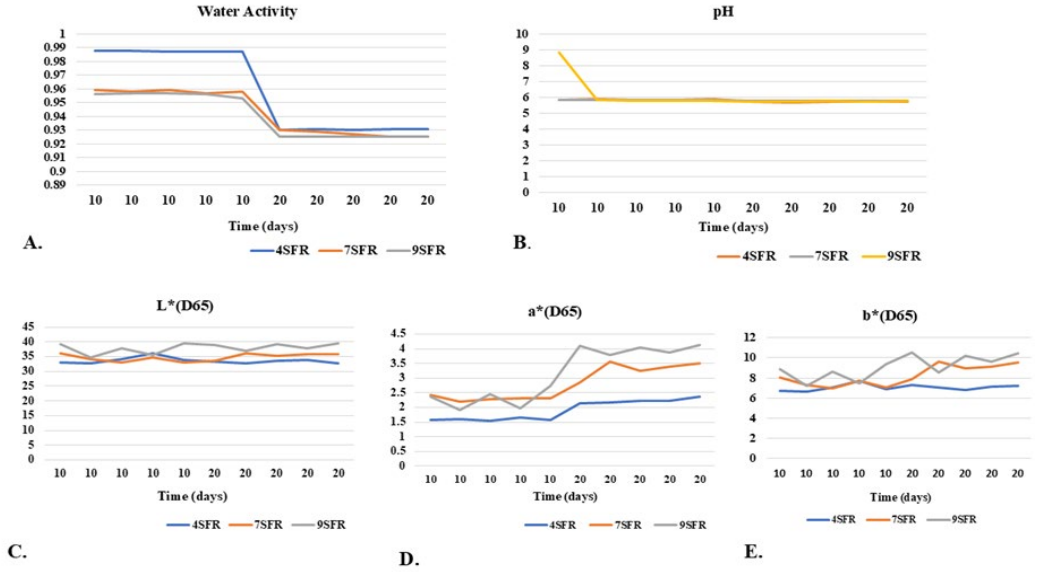

Figure 1. Graphical representation of the analyzed physicochemical parameters
[A. Water Activity; B. pH; C. L*(D65); D. a*(D65); E. b*(D65)]

According to Table 4, the results of the χ^2 (chi-squared) test showed a value of $p < 0.001$, indicating that both salt concentration and maturation time have a statistically significant effect on the parameters analyzed.

Table 4. Chi-square test of association between salt concentration, maceration time and analyzed parameters

Test	χ^2	Df	*p*-value
Chi-square test	31.486	1	< 0.001

The obtained *p*-value (< 0.001) demonstrates a highly significant statistical effect, indicating that the influence of salt concentration and maturation time on the analyzed parameters is not attributable to random variability, but reflects a real and consistent relationship within the studied system.

An interpretation of the loading coefficients (Table 5) reveals that RC1 is strongly correlated with color parameters (L*, a*, b*) and water activity (a_w), suggesting an interdependence between optical properties and product moisture content. In contrast, RC2 is dominated by pH, which exhibits a variation independent of the other parameters, a finding supported by the absence of significant correlations.

Table 5. Rotated component loadings obtained from Principal Component Analysis (PCA)

Variable	RC1	RC2
a*(D65)	0.975	
b*(D65)	0.951	
a_w	-0.781	
L*(D65)	0.775	0.476
pH		0.909

Principal component analysis (PCA) was applied to highlight the relationships among the analyzed physicochemical parameters. Based on the component characteristics (Table 6), two principal components were selected using the eigenvalue criterion (eigenvalue > 1), which explain a high cumulative percentage of the total variation in the data. After applying Varimax orthogonal rotation, the variance distribution was optimized, with component

RC1 explaining 61.5% of the variation and RC2 24.9%, indicating a good descriptive capacity of the analyzed system (Table 5).

Table 6. Total variance explained by principal components

Component	Eigenvalue	Variance	Cumulative
PC1	3.077	0.615	0.615
PC2	1.247	0.249	0.865

The graphical representation of the PCA scores (Figure 2) confirms these observations, highlighting a clear separation of the samples based on the parameters associated with each component. Thus, the samples are distributed along the RC1 axis based on color characteristics and water activity, while variations along the RC2 axis primarily reflect changes in pH. This distribution suggests that color parameters and water activity are the main factors differentiating the samples, while pH contributes secondarily to the system's variability.

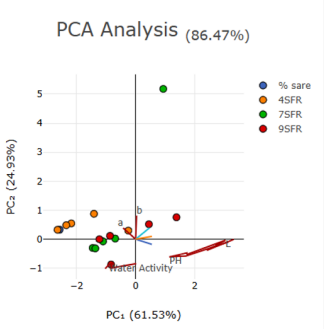

Figure 2. Principal component analysis (PCA), illustrating the distribution of the samples based on the analyzed physicochemical parameters

As for future research, although the present study did not focus on chemical contaminants, the literature highlights the importance of monitoring them in animal-derived products, including in the context of the safety of susceptible raw materials such as carp roe (Matei M. și Pop I. M., 2023; Matei M. et al., 2024).

CONCLUSIONS

The results highlight that NaCl plays a decisive role in both the microbiological stability and the physicochemical properties of the product. Although increasing the salt concentration effectively reduces the microbial load, high levels may likely favor the selection of halotolerant microorganisms during ripening; however, further studies are needed. The range of 7-9% NaCl, particularly at 20 days, appears optimal, ensuring a reduction in water activity and, consequently, improved stability from a food safety perspective, given that the ripening time did not have a statistically significant effect. At the same time, salt concentration significantly influences color parameters (L, a, b*), confirming its impact on the product's visual characteristics. Overall, the differentiation of samples is primarily determined by color parameters and water activity, while pH contributes secondarily to the system's variability.

USE OF GENERATIVE ARTIFICIAL INTELLIGENCE (GenAI)

The authors state that ChatGPT was used exclusively for linguistic review and refinement of the text in the "Introduction" and "Conclusions" sections of this paper. All scientific content, data processing, analyses, and interpretations were developed independently and critically reviewed by the authors.

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