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STUDY ON THE EFFECT OF OPTIMIZING SODIUM SUBSTITUTION FORMULA ON THE STORAGE QUALITY AND SHELF LIFE OF *ONCORHYNCHUS MASOU* CAVIAR

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I. INTRODUCTION

Caviar, a valued delicacy, faces quality maintenance challenges during storage and transport. Oncorhynchus masou caviar is a new market addition requiring rigorous quality control. Traditional sodium chloride (NaCl) salting effectively inhibits microbes but results in high sodium content, counter to global health initiatives[1, 2]. Sodium substitutes offer a way to reduce sodium while maintaining or enhancing preservation and extending shelf life. Microbial growth is the primary spoilage factor for ready-to-eat caviar like this. Predicting shelf life via accelerated shelf-life testing (ASLT) is crucial for market introduction and managing economic risk [3][4].

This study investigates the impact of an optimized sodium salt complex replacement formulation compared to traditional NaCl salting on the storage quality of Oncorhynchus masou caviar. Physicochemical (color, pH, TVB-N, Aw, LF-NMR) and microbiological indicators (TPC, OD600nm) were evaluated at various temperatures. ASLT was used to monitor total plate count (TPC) changes at 20℃, 27℃, and 34℃, determine shelf life at these temperatures (using an endpoint of 6.00 log CFU/g TPC), and predict shelf life at 0℃ and 4℃ using the Q7 model. The goal is to provide scientific support for advanced fish roe processing and salt reduction technologies.

II. MATERIALS AND METHODS

2.1 Sample preparation

Oncorhynchus masou roe was processed using two methods:

Experimental Group: Optimized sodium salt complex formulation (17.64% potassium lactate, 14.61% potassium chloride, 34.36% magnesium chloride, 33.39% sodium chloride).

Control Group: Traditional sodium chloride salting. Salting involved a 1:1 water to roe ratio, 10 min salting, and 5 min washing. Samples were stored at 20℃, 27℃, and 34℃ for ASLT..

2.2 Microbiological analysis

Total Plate Count (TPC) was determined by plating serial dilutions on Plate Count Agar and incubating at 37±1℃ for 24 hours. Results were expressed as log CFU/g. Bacterial density was also assessed by measuring absorbance at OD600nm.

2.3 Chemical analysis

pH: Measured using a pH-meter at room temperature.

Color: Measured using a colorimeter (L*, a*, b* values).

Total volatile basic nitrogen (TVB-N): Determined by micro-titration with a Kjeldahl apparatus, expressed as mg TVB-N per 100g.

Aw: Water activity was measured using an intelligent water activity meter at 20℃, 27℃, and 34℃.

Low field NMR analysis (LF NMR): Used to analyze moisture distribution (bound, immobilized, free water) based on T2 relaxation times.

2.4 Shelf-life prediction model（ALST）

TPC was measured at specified intervals for both groups stored at 20℃, 27℃, and 34℃. Based on national and international standards, a TPC of 6.00 log CFU/g was set as the shelf-life endpoint. The Q7 model was applied using the shelf life observed at the experimental temperatures to predict the shelf life at 0℃ and 4℃.

2.5 Statistical analysis

SPSS 13.0 was used for ANOVA and Pearson correlation analysis. Significance was set at $p < 0.05$.

III. RESULTS AND DISCUSSION

3.1 Chemical analysis

pH: The experimental group showed a slower fluctuation trend in pH compared to the control group, indicating a lower degree of spoilage, particularly at 20℃ and 27℃.

OD600 nm: The increase in OD600nm values (reflecting bacterial growth) was slower in the experimental group across all temperatures (20℃, 27℃, 34℃). The experimental group reached the logarithmic growth phase later than the control group. This confirmed the inhibitory effect of the sodium salt substitute formulation, with the best effect observed at 20℃. The presence of Mg^{2+} and K^{+}, lower pH, and reduced water activity likely contribute to this effect.

Color (Lab):* L* (lightness) and b* (yellowness) generally increased during storage in most groups, consistent with moisture changes and potential oxidation. The experimental group often showed higher L* values. a* (redness) initially increased then decreased. These changes are external manifestations of biochemical and microbial spoilage.
Total volatile basic nitrogen (TVB-N): TVB-N values increased in both groups, indicating declining freshness. However, the experimental group consistently exhibited lower TVB-N values and a slower increase rate, especially after 6h of storage, demonstrating the superior freshness preservation and spoilage inhibition provided by the sodium salt substitute formulation.
Aw: Water activity in both groups remained above 0.90, showing fluctuations during storage but little significant overall change in the closed storage environment.
Low field NMR analysis (LF NMR): Analysis of water distribution showed significant differences. The experimental group had a higher percentage of immobilized water (T_{22}) at 20℃ and 27℃ compared to the control, suggesting enhanced water retention capacity. This is attributed to the hydration and structural influence of ions like Mg^{2+} and K^{+}, and the Laguerre effect from higher ionic concentration and osmotic pressure. However, at 34℃, this protective effect was somewhat weakened, with a slight increase in free water (T_{23}).

3.2 Microbiological analysis and Shelf-life prediction model（ALST）

TPC increased with storage time and temperature in both groups. The experimental group showed a significantly slower rate of TPC increase and longer time to reach the 6.00 log CFU/g endpoint compared to the control group at all tested temperatures (20℃, 27℃, 34℃). This indicates a strong bacteriostatic effect of the sodium salt substitute.
Using the ASLT Q7 model:
The predicted shelf life for the control group was 45.27 h at 0° C and 33.09 h at 4° C.
The predicted shelf life for the experimental group was 128.51 h at 0° C and 83.28 h at 4° C.
The experimental group exhibited a significantly extended predicted shelf life at refrigeration temperatures (0℃ and 4℃) compared to the control group..

3.3 Correlations analysis

Pearson's correlation analysis revealed strong positive correlations between microbial indicators (lg CFU/g, OD600) and spoilage marker (TVB-N). Strong negative correlations were observed between OD600 and Aw, and moderate negative correlation between TVB-N and Aw, highlighting the link between microbial growth, spoilage, and water activity. Correlations involving water distribution (PT23, PT21) and microbial/Aw parameters further supported the role of water migration and activity in controlling microbial spoilage. These correlations collectively underscore the effectiveness of the optimized formulation in managing spoilage through microbial and water activity control.

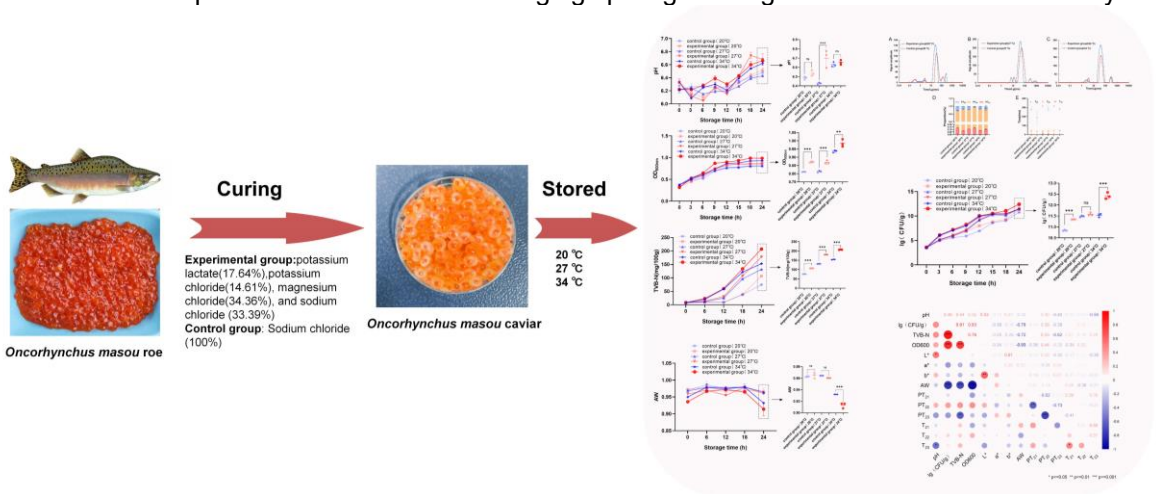


Figure 1. Experimental design and quality evaluation of Oncorhynchus masou caviar cured with sodium substitution formula versus traditional NaCl.

IV. CONCLUSION

The composite sodium-substitution formula significantly inhibits microbial proliferation and protein degradation compared with traditional NaCl salting.
Enhanced bound-water retention and slightly reduced water activity contribute to improved textural and sensory stability.
Shelf-life prediction models indicate a 2−3-fold extension under both ambient and chilled conditions.
The findings support healthier, low-sodium processing for caviar and offer a practical approach for industry innovation.

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