Multivariate Statistical Analysis of Shelf-Life Indicators (TVB-N, pH, and Lipid Oxidation) in Fish and Fishery Products

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Lipid oxidation, enzymatic degradation, and microbial growth make fish and fisheries products extremely perishable. Determining shelf life is crucial for ensuring food safety, quality control, and consumer acceptance—especially in the international seafood trade. Conventional freshness assessment techniques depend on individual factors like pH, lipid oxidation indices like Peroxide Value (PV) and Thiobarbituric Acid Reactive Substances (TBARS), and Total Volatile Basic Nitrogen (TVB-N). However, species variation, packaging systems, storage temperature, and inherent biochemical factors all affect and are influenced by these indicators. Through relationship identification, dimensionality reduction, and predictive model development, multivariate statistical analysis (MSA) provides an integrated framework for interpreting complex spoilage datasets. This review addresses the use of Principal Component Analysis (PCA), Cluster Analysis (CA), Multiple Regression Analysis (MRA), and Partial Least Squares Regression (PLSR) in fish quality modelling, as well as the critical evaluation of the roles of TVB-N, pH, and lipid oxidation in shelf-life assessment. There is also discussion of methodological issues, research gaps, and next steps, including the incorporation of machine learning.

Keywords: TVB-N; fish spoilage; pH; lipid oxidation; PCA, PLSR, multivariate analysis, Predicting shelf life.

Introduction

Fish is a very nutrient-dense food that is high in vitamins, minerals, polyunsaturated fatty acids, and essential amino acids. Because of its high moisture content, pH that is almost neutral, and the presence of autolytic enzymes, fish muscle degrades quickly after harvest, despite its nutritional advantages. Microbial growth, enzymatic autolysis, and oxidative reactions are all components of the complex process of spoilage. Conventional univariate analysis assesses each spoilage parameter separately, but it might miss the interactive character of biochemical alterations. The integration of chemometrics and multivariate statistical tools for more accurate shelf-life prediction is emphasised by recent research trends.

Mechanisms of Fish Spoilage

Lipid oxidation, enzymatic breakdown, and microbial growth are the three main processes that cause fish to spoil. TVB-N accumulation is facilitated by volatile amines produced by microbial metabolism. Proteins and nucleotides are broken down by endogenous enzymes, changing texture and pH. Peroxides and secondary aldehydes, which cause rancidity, are produced as a result of lipid oxidation.

Shelf-Life Indicators

Total Volatile Basic Nitrogen (TVB-N)
TVB-N measures the amounts of ammonia, trimethylamine, and dimethylamine produced when proteins break down. Depending on the species, values usually rise during chilled storage and surpass permissible limits (25–35 mg/100 g). Microbial load and storage time are highly correlated with TVB-N.

pH
The pH of fresh fish muscle is typically between 6.0 and 6.5. Lactic acid production may cause an initial drop, which is followed by an increase brought on by the buildup of alkaline metabolites. Enzyme kinetics and microbial activity are influenced by pH.

Lipid Oxidation
Lipid oxidation significantly affects fatty fish species. Primary oxidation products are measured by Peroxide Value (PV), while secondary products such as malondialdehyde are quantified using TBARS. Oxidation rate depends on oxygen exposure, temperature, and fatty acid composition.

Statistical Approaches in Shelf-Life Modeling

Principal Component Analysis (PCA)
PCA is used to reduce the multidimensional data to principal components that explain the maximum variance. PCA is commonly used for pattern recognition and classification of storage stages.

Cluster Analysis (CA)
Cluster analysis is used to group samples according to similarity measures, which helps to classify treated and untreated samples.

Multiple Regression Analysis (MRA)
MRA is used to establish predictive relationships between shelf life and spoilage indicators like TVB-N, pH, and TBARS.

Partial Least Squares Regression (PLSR)
PLSR is able to deal with multicollinearity when there are correlations between variables.

Comparative Evaluation of Multivariate Techniques
PCA is useful for graphical representation but not for prediction. MRA can be used for prediction but may be affected by multicollinearity. PLSR is able to deal with correlated variables but needs careful validation

Research Gaps
The challenge of limited integration of microbial, chemical, and sensory data still exists. Very few studies have validated predictive models under industrial settings. There is a lack of species-specific predictive models, and the problem of overfitting still exists in small datasets

Future Perspectives
The future of research should focus on the integration of spectroscopy techniques with chemometrics and machine learning models like artificial neural networks and random forest models. The development of real-time smart packaging sensors along with multivariate models can be a revolutionary step in the monitoring of seafood quality.

Conclusion
TVB-N, pH, and lipid oxidation are basic parameters of fish freshness. Multivariate statistical analysis offers a holistic approach to understanding the dynamics of spoilage and shelf life. Modern modeling techniques may improve scientific validity and practical utility in fish quality management.

References
1. Erkan, N., & Özden, Ö. (2021). Chemometric evaluation of quality changes in chilled fish using multivariate analysis. Food Chemistry, 344, 128619.

2. Li, T., et al. (2022). Multivariate analysis of freshness indicators in refrigerated aquatic products. LWT – Food Science and Technology, 154, 112739.
3. Zhang, Y., et al. (2023). Application of chemometrics in seafood quality evaluation under cold storage. Foods, 12(4), 812.
4. Wang, X., et al. (2022). Prediction of fish freshness using PLS regression models based on chemical spoilage indices. Journal of Food Engineering, 314, 110768.
5. Gao, F., et al. (2024). Multivariate modeling for shelf-life prediction of chilled aquatic products. Food Control, 156, 110116.
6. He, H., et al. (2021). NIR spectroscopy combined with PCA and PLSR for rapid evaluation of fish freshness. Talanta, 223, 121737.
7. Sun, J., et al. (2023). Hyperspectral imaging coupled with multivariate analysis for monitoring quality of chilled fish. Food Chemistry, 404, 134657.
8. Chen, L., et al. (2024). Machine learning approaches for predicting spoilage in refrigerated seafood. Trends in Food Science & Technology, 143, 104312.
9. Kumar, R., et al. (2023). Multivariate statistical and AI-based modeling for seafood shelf-life prediction. Food Analytical Methods, 16, 2150–2165.
10. Zhao, X., et al. (2022). Chemometrics in seafood quality and safety evaluation: A review. Critical Reviews in Food Science and Nutrition, 62(28), 7850–7872.
11. Domínguez, R., et al. (2021). Seafood freshness assessment: Advances in chemical and multivariate analytical approaches. Food Research International, 144, 110358.