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Non-Destructive Tilapia Quality Determination Using Near-Infrared Spectroscopy

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ABSTRACT

Tilapia represents a significant economic asset in the aquaculture industry due to its high nutritional value and commercial importance. However, internal abnormalities are frequently detected during processing operations, particularly those caused by Streptococcosis, which is among the most prevalent diseases affecting tilapia quality. These quality defects often lead to commercial disputes between aquaculture farmers and fillet processors, highlighting the critical need for non-destructive detection methods. This study utilizes sectioned fish samples to establish baseline spectroscopic characteristics for future development of non-destructive infection detection in intact fish. This study develops a near-infrared (NIR) spectroscopy approach for non-destructive determination of tilapia infection status, enabling quality assessment before processing. A total of 83 tilapia samples (42 normal and 41 abnormal) were obtained from multiple fishery production cooperatives throughout Taiwan. NIR spectra were collected from five spots on both fish meat and scale, generating 830 scanning spots for detailed spectroscopic analysis. Preprocessing techniques included multiplicative scatter correction (MSC) and Savitzky-Golay filtering (SG) to enhance spectral quality and reduce noise interference. Three machine learning algorithms were subsequently implemented for classification purposes: partial least squares discriminant analysis (PLS-DA), random forest (RF), and eXtreme gradient boosting (XGBoost). Results demonstrated that PLS-DA combined with SG filtering achieved reliable prediction performance, with classification accuracies of 0.80 for external side and 0.78 for internal side respectively. Single point analysis revealed optimal scanning locations that showed encouraging practical potential: the tail region on the meat side yielded 0.79 accuracy using PLS-DA, while the third dorsal point on the scale side achieved the highest accuracy of 0.86. The identification of optimal scanning locations provides practical guidance for implementing quality control systems in aquaculture processing operations.

Keywords: Non-destructive, near-Infrared, spectroscopy, machine learning, tilapia

INTRODUCTION

Tilapia represents the most significant aquaculture species in Taiwan, with annual production reaching 63,329 tons and generating approximately NT$28.3 billion in economic value (Jan, 2018). Internal abnormalities caused by Streptococcosis remains visually undetectable, causing substantial processing losses and commercial disputes. Streptococcosis infection induces tissue inflammation and cellular damage, altering biochemical composition and creating detectable spectral signatures in affected tissue. Near-infrared (NIR) spectroscopy offers advantages for quality assessment through non-destructive analysis, minimal sample preparation requirements, and rapid detection. Previous studies have demonstrated NIR application in measuring fat and pigment content in fish and evaluating freshness in salmon fillets (Folkestad et al., 2008; Kimiya et al., 2013). However, current aquaculture processing relies primarily on visual inspection and destructive sampling, creating bottlenecks in large-scale operations with potential for contaminated products reaching consumers. This study investigates NIR spectroscopy combined with machine learning algorithms to develop a non-destructive approach for predicting internal tissue abnormalities through external surface scanning, without requiring fish sectioning.

MATERIALS AND METHODS

SAMPLE PREPERATION

A total of 83 tilapia fillet samples were obtained for analysis, comprising 42 normal and 41 deteriorated samples affected by Streptococcosis infection. Spectral measurements utilized a near-infrared spectrometer (Antaris II; Thermo Fisher Scientific Inc., Waltham, MA, USA) operating at 770-2500 nm wavelength range with 2 nm resolution. Five measurement points were selected base on previous multi-point scanning studies on fish (Shimamoto et al., 2003) covering body areas including tail and dorsal regions, most susceptible to pathological conditions. Measurements were collected from external side (scaled surface) and internal side (meat surface) following sectional preparation (Fig. 1), yielding 830 individual spectral datasets.

DATASETS PROCESSING AND MACHINE LEARNING METHODS

The dataset was partitioned into 4:1 training-validation split with 5-fold cross-validation to prevent overfitting. Spectral preprocessing employed Multivariate Scatter Correction (MSC) and Savitzky-Golay filtering techniques. Three machine learning algorithms were evaluated: Partial Least Squares Discriminant Analysis (PLS-DA), Random Forest (RF), and eXtreme Gradient Boosting (XGBoost) for optimal classification performance.

Fig. 1 Five measurement points on internal and external sides.

RESULTS & DISCUSSION

PERFORMANCE EVALUATION OF QUALITY DETERMINATION MODELS

Classification results using external and internal spectral data with three modeling approaches showed PLS-DA and XGBoost achieving superior performance (Table 1). PLS-DA demonstrated classification accuracies of 0.80 and 0.78 for external and internal sample spectra, respectively.

DETERMINATION OF PROPER DETECTION POSITIONS

Individual analysis of five measurement positions identified locations for improved model accuracy. PLS-DA model consistently outperformed the XGBoost across all measures (Table 2), achieving average accuracies of 0.76 and 0.80 for external-only and combined datasets, respectively, compared to XGBoost results of 0.59 and 0.62. Notably, position 4, achieve accuracy of 0.79 with PLS-DA. Furthermore, external position 3, attained the highest accuracy of 0.86 using combined external and internal datasets, corresponds to the location where deterioration commonly manifests. These results demonstrate the model potential for detecting pathological conditions in tilapia quality assessment.

Table 1 Performance comparison of different classification models

Model / Data type	PLS-DA	RF	XGBoost
External side	0.80$^{(s)}$	0.66$^{(m)}$	0.70$^{(m)}$
Internal side	0.78$^{(s)}$	0.66$^{(s)}$	0.69$^{(m)}$

$^{(s)}$SG: Savitzky-Golay filter; $^{(m)}$MSC: Multiplicative Scatter Correction

Table 2 Accuracy of PLS-DA and XGBoost across different measurement points

Model / Data type	Both external and internal		Only external side	
	PLS-DA	**XGBoost**	**PLS-DA**	**XGBoost**
Position1	0.74$^{(s)}$	0.63$^{(s)}$	0.76$^{(s)}$	0.63$^{(s)}$
Position2	0.77$^{(s)}$	0.57$^{(m)}$	0.79$^{(s)}$	0.59$^{(s)}$
Position3	0.75$^{(s)}$	0.55$^{(s)}$	0.86$^{(s)}$	0.59$^{(s)}$
Position4	0.79$^{(s)}$	0.64$^{(s)}$	0.78$^{(s)}$	0.70$^{(s)}$
Position5	0.73$^{(s)}$	0.58$^{(m)}$	0.79$^{(s)}$	0.59$^{(s)}$
Average	0.76	0.59	0.80	0.62

$^{(s)}$SG: Savitzky-Golay filter; $^{(m)}$MSC: Multiplicative Scatter Correction

CONCLUSIONS

This study successfully developed predictive models for distinguishing normal and deteriorated tilapia fillets using NIR and machine learning approaches. PLS-DA achieved classification accuracies of 0.80 and 0.78 for external side and internal side spectra, respectively. Results indicate potential for accurate, non-destructive identification of deteriorated tissue conditions in tilapia. The NIR technique demonstrates considerable capability for quality control applications in aquaculture processing. However, the study is limited by small sample size, requiring more diverse sample populations to enhance model generalizability and robustness for practical implementation.

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REFERENCES

Jan, M. S. (2018). The Market Analysis of Tilapia Products of Taiwan. *Fisheries Extension Research Report*, *48*, 49-66.

Folkestad, A., Wold, J. P., Rørvik, K. A., Tschudi, J., Haugholt, K. H., Kolstad, K., & Mørkøre, T. (2008). Rapid and non-invasive measurements of fat and pigment concentrations in live and slaughtered Atlantic salmon (Salmo salar L.). *Aquaculture, 280*(1-4), 129-135.

Kimiya, T., Sivertsen, A. H., & Heia, K. (2013). VIS/NIR spectroscopy for non-destructive freshness assessment of Atlantic salmon (Salmo salar L.) fillets. *Journal of Food Engineering, 116*(3), 758-764.

Simamoto, J., Hasegawa, K., Hattori, S., Hattori, Y., & Mizuno, T. (2003). Non-destructive determination of the fat content in glazed bigeye tuna by portable near infrared spectrophotometer. *Fisheries science, 69*(6), 1247-1256.