

PEER-REVIEWED AI SENSORY PUBLICATION | LWT / J. FOOD ENG / ISO 16779

Deep Learning Multi-Spectral Fusion for Accelerated Sensory Shelf-Life and Staling Kinetics Prediction (ISO 16779 / FIZZ QC)

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EXECUTIVE ABSTRACT: Sensory shelf-life determination is essential for packaged food quality assurance but traditionally requires months of destructive testing and recurring panel evaluations. In this paper, we develop a multi-spectral deep learning framework combining Fourier-Transform Near-Infrared (FT-NIR) and UV-Vis spectroscopy with 1D-Convolutional Neural Networks (1D-CNN) and non-parametric survival analysis. The system predicts consumer sensory rejection cut-off points (ISO 16779) and lipid oxidation rancidity onset across 180 days of storage with $R^2 = 0.941$ and median error ± 4.2 days, reducing shelf-life determination lead times and inventory holding costs by 65%.

KEY METHODOLOGICAL TAKEAWAYS & EMPIRICAL FINDINGS

01. Accurately predicts Weibull hazard sensory acceptance thresholds ($p < 0.001$) across 180-day storage regimes.
02. Integrates non-destructive spectroscopic spectral features with calibrated FIZZ panel QDA oxidation descriptors.
03. Reduces storage inventory holding times and panel testing costs by 65% while maintaining 99.4% quality confidence.
04. Fully compliant with ISO 16779:2015 sensory shelf-life determination standards and FIZZ QC batch release protocols.

1. THE INEFFICIENCY OF CONVENTIONAL SENSORY SHELF-LIFE DATING

Determining shelf-life end-points traditionally relies on Accelerated Shelf-Life Testing (ASLT) under elevated temperature and humidity, requiring descriptive panels to evaluate aging samples every 2 to 4 weeks over 6 to 12 months. This process is time-consuming, expensive, and subject to panel fatigue.

Worse, chemical oxidation markers (peroxide value, hexanal, TBA) often decouple from actual human sensory rejection thresholds, leading to premature recalls or extended inventory holding.

2. MULTI-SPECTRAL DATA ACQUISITION & SENSORY GROUND TRUTH

We established a comprehensive multi-spectral pipeline: - Fourier-Transform Near-Infrared (FT-NIR, 4,000–10,000 cm^{-1}) capturing lipid overtone bands and moisture binding states. - UV-Vis diffuse reflectance (200–800 nm) tracking pigment degradation and Maillard browning intermediates. - Ground truth sensory data acquired via FIZZ QC: 12 ISO 8586 calibrated panelists scoring oxidized aroma, cardboard flavor, crispness loss, and overall consumer acceptability on continuous linear scales across 0, 30, 60, 90, 120, and 180 days.

3. 1D CONVOLUTIONAL DEEP SURVIVAL NETWORK

A 1D-CNN survival model was engineered: - Spectral Feature Extraction: Parallel 1D convolutional layers with kernel sizes 3, 5, and 7 to extract localized chemical absorption signatures without manual baseline correction or peak picking. - Survival Hazard Function: Implements non-parametric Weibull and Cox proportional hazards loss functions, mapping spectral representations directly to the probability of consumer rejection $P(\text{Reject} | t)$. - Model Performance: Cross-validated on 1,800 packaged biscuit, roasted nut, and UHT dairy samples, achieving $R^2 = 0.941$ in predicting sensory cut-off points with a median error of ± 4.2 days across an 180-day shelf-life horizon.

4. COMPARATIVE ACCURACY AGAINST TRADITIONAL WET CHEMISTRY

While traditional peroxide value (PV) and thiobarbituric acid (TBA) assays displayed poor correlation with human consumer rejection ($r = 0.58$ and $r = 0.64$), the 1D-CNN sensory multi-spectral model maintained $r = 0.963$ ($p < 0.0001$).

This confirms that multi-spectral AI captures the synergistic matrix changes driving human perception far more accurately than isolated single-analyte chemical tests.

5. COMMERCIAL IMPLEMENTATION & COST BENEFITS

Deployed within factory QC laboratories using FIZZ Quality Control interfaces, the AI framework reduced batch clearance lead times from 72 hours of sensory staging to 45 seconds of non-destructive spectral scanning, saving multinational packaging clients over \$280,000 annually per production site in testing overhead.