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Unsupervised Anomaly Detection of Tipburn in Leafy Vegetables Using Denoising Autoencoder

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ABSTRACT

Tipburn, a common physiological disorder in leafy vegetables, presents as marginal necrosis but its fuzzy boundaries make annotation costly and inconsistent. We present a label-free pipeline that combines CIE Lab-based preprocessing with a chroma-only denoising autoencoder (DAE) trained solely on healthy samples for real-time, pixel-level anomaly mapping. Lettuce images were acquired under controlled lighting, segmented in CIE Lab space, and reduced to the a channel and a/b chromatic ratio to emphasize tipburn-related chroma shifts while suppressing illumination effects. This one-class strategy leverages consistent healthy tissue as a baseline, since pathological cases are scarce and heterogeneous. Trained on 364 healthy images, the model produced residual heatmaps and image-level anomaly scores, with decisions derived from a robust 6σ cutoff. On a balanced test set (21 tipburn / 21 normal), the system achieved ~0.9 accuracy and detects early marginal lesions without manual labels.

Keywords: tipburn, abiotic stress detection, unsupervised learning, denoising autoencoder, real-time anomaly detection

INTRODUCTION

Tipburn is a necrotic disorder near lettuce leaf tips or margins in controlled-environment agriculture (CEA). Although visually recognizable, symptom boundaries vary across cultivars and lighting, making pixel-level labels expensive and subjective—a bottleneck for supervised learning (Fernández-Moreno et al., 2023). To sidestep this burden, we pursue unsupervised anomaly detection for label-free monitoring. Vanilla autoencoders, however, are sensitive to background and lighting noise.

To overcome this, we apply CIE Lab-based masking and a chroma-only (a, a/b) DAE trained on healthy images. Healthy samples offer a stable reference, while pathological cases are scarce and diverse. Because tipburn images are heterogeneous and sparse, one-class learning on healthy tissue provides a practical way to flag deviations. Building on this, we develop and validate a label-free tipburn detector designed for real-time deployment under a

single 6σ rule, a robust statistical cutoff assuming healthy scores.

MATERIALS AND METHODS

Three lettuce cultivars (Batavia, Butterhead, Romaine) were imaged with a mobile device in a blackout box under white LEDs. RGB images were converted to CIE Lab; plant tissue was segmented via Otsu thresholding on the b channel with mask repair/closing, and only the a channel and a/b ratio were retained to emphasize chroma. The dataset comprised 364 healthy images for training and 42 for evaluation (21 tipburn, 21 normal). At inference, residuals within masks generated heatmaps, and the image-level score was their masked mean. The decision boundary used a 6σ upper-tail cutoff ($\mu + 6\sigma$), assuming a near-Gaussian distribution of healthy scores to suppress false positives.

RESULTS & DISCUSSION

CIE Lab–based masking effectively reduced background residuals. Using the a channel and a/b ratio enhanced tipburn chroma and was less illumination-sensitive than HSV or L-only; b alone underrepresented lesions. The 6σ cutoff yielded ~ 0.90 accuracy, with heatmaps localizing early marginal lesions. False positives occurred mainly at veins and specular highlights. While tuned for tipburn, the one-class design may also flag other stresses (nutrient or pathogen-related), suggesting that the framework serves best as a general anomaly alarm unless expanded datasets are incorporated. Two simple refinements can reduce errors: (1) smoothing scores over 3–5 frames to avoid transient alarms, and (2) periodically recalibrating μ and σ from recent healthy images to track gradual lighting or cultivar shifts.

CONCLUSIONS

A CIE Lab–based, chroma-only autoencoder enables label-free detection of tipburn, producing interpretable residual heatmaps and achieving ~ 0.90 accuracy with high sensitivity under a 6σ cutoff. The system demonstrates practical value for real-time monitoring and integration with microclimate control while avoiding large-scale labeling. Future work will validate the system in production lighting, apply temporal smoothing and online recalibration, and expand diverse datasets to distinguish tipburn from other disorders.

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