ACTIVE THERMOGRAPHY TO DETERMINE GRAPE BUD MORTALITY: SYSTEM DESIGN AND FEASIBILITY

Authors: Guangxun ZHAI[1], Justine VANDEN HEUVEL[2], Steven LERCH[2], Yu JIANG[2*]

[1]*School of Electrical and Computer Engineering, Cornell University, USA*
[2]*Horticulture Section, School of Integrative Plant Science, Cornell University, USA*

*Corresponding author: yujiang@cornell.edu

Abstract:

Context and purpose of the study - Bud death due to cold damage is a recurrent and major economic issue with *Vitis vinifera L.* in the Northeastern U.S. winegrowing regions. Primary buds – and sometimes secondary and tertiary buds – are often damaged by fluctuating temperatures in the winter and early spring. To maintain balanced vegetative and reproductive growth of a vine, pruning practices need to be adjusted to account for bud damage. Conventional bud damage assessment requires growers to sample canes/spurs, cut nodes with a razor blade, and then visually assess bud damage. This process is laborious and becomes a major barrier for damage-compensated pruning decision-making, leading to too few live buds per vine and the associated excessive vigor and low yield that result. The overarching goal of this study was to develop an active thermographic system for non-destructive detection of bud damage in the vineyard.

Material and methods – An active thermographic system was developed by integrating a thermal camera, heating stimulation, and sample holder. A custom computer program was developed to synchronize the camera and heating unit to acquire a thermal image sequence of a grapevine cane under a predefined heating stimulation. The heating stimulation included an artificial heating phase using a set of heating lamps and a natural cooling phase. Regions of interest (ROIs) were selected for grape buds to extract thermal responsive curves between damaged and healthy buds.

Results – Results demonstrate that significant differences were observed in thermal responsive curves between damaged and healthy buds for all five representative cultivars used in this study. This lays a solid foundation to further establish classification models to differentiate grape buds with different mortality status effectively.

Keywords: Pulsed phase thermography; Grape bud status; Non-destructive detection; Grapevine pruning.

1. Introduction

Cold damage presents a recurring and significant economic challenge in the Northeastern U.S. winegrowing regions. Primary buds, and occasionally secondary and tertiary buds, are often impacted by fluctuating temperatures during winter and early spring. This leads to deacclimation of vines and a subsequent reduction in cold hardiness. When cold temperatures return swiftly, considerable bud loss can occur. In the Finger Lakes region of New York, primary bud damage on numerous vinifera cultivars, including Cabernet Franc, reached up to 80% in spring 2014.

To maintain a balance between vegetative and reproductive growth in a vine, it is essential to modify pruning practices in response to bud damage. For instance, if a grower aims for 30 shoots per vine and experiences 50% bud damage, they would need to leave 60 nodes, whereas with only 25% damage, pruning to 45 nodes would be necessary. Assessing primary bud damage requires growers to sample canes or spurs and cut nodes with a razor blade. However, few vineyards quantify bud mortality due to the extensive trained labor involved. Consequently, pruning decisions often fail to account for the precise amount of bud mortality, resulting in too few live buds per vine, excessive vigor, and reduced yield.

To address this challenge and facilitate precision pruning, it is crucial to develop alternative assessment methods that can determine grape bud mortality with reduced labor efforts and increased scanning throughput. Although numerous optical sensing modalities have been employed for non-destructive quality evaluation (Wu, et al., 2013; He, et al., 2022), such as fruit bruises (Jiang, et al., 2016; Kuzy, et al., 2018), these modalities (e.g., multispectral and hyperspectral imaging) are typically limited to the surface or shallow depth of organic tissues. Signal penetration into thick or opaque tissues (e.g., grape buds with dense shells) is often insufficient to produce valuable information for analysis. Radiation-based sensing modalities (e.g., X-Ray and thermal imaging) can offer enhanced penetration capabilities for evaluating tissues with opaque covers. Considering cost and safety factors, thermal imaging has gained popularity for agrifood applications. Pulsed thermography, a type of active thermography, leverages differences in thermal diffusivity and conductivity to identify temperature disparities in objects and has been utilized to detect quality variations among samples composed of the same material (Maldague, et al., 1996, 2002). In pulsed thermography, a single square wave or Dirac pulse of thermal stimulation is applied to the target.

The primary aim of this study was to explore the potential of employing active thermography to non-destructively determine grape bud mortality status. Specific objectives included 1) designing and implementing an active thermographic system and custom computer program for data acquisition, 2) collecting thermal image sequences of grape buds from representative cultivars with varying bud mortality, and 3) conducting statistical analyses to evaluate the capability of differentiating bud mortality status based on thermal response curves.

2. Material and methods

Design and implementation of an active thermographic system

A custom-designed active thermographic imaging system was developed to acquire thermal image sequences under tailored thermal stimulations (Figure 1A and Figure 1B). In this study, the system used heating stimulation provided by heat lamps. The system's hardware components encompassed: a thermal camera (A700, Teledyne FLIR, Wilsonville, Oregon, USA); a pair of 325-W heat lamps (Sunlite, Brooklyn, New York, USA); a Teflon sample stage with adjustable features; a USB-powered relay; a control terminal (Omen, Hewlett-Packard, Inc., Palo Alto, California, USA); and a frame fabricated from 25mm aluminum extrusions (80/20 Inc., Columbia City, Indiana, USA).

The imaging system was controlled by a custom computer program developed upon Python (3.7) (Figure 1C). The main functions of the computer program were: 1) Operation of the thermal camera by a software development kit (SDK, Spinnaker SDK, Teledyne FLIR, Wilsonville, Oregon, USA); 2) Precise activation and deactivation of the heat lamps by a USB-controlled power relay using a third-party digital link library; 3) Management of the high data volume using memory caching to prevent frame loss; and 4) Export of the collected data binary files for processing.

Plant materials

Plant materials – A total of 40 grapevine canes were randomly gathered from commercial vineyards in Geneva, New York, USA, comprising 5 representative cultivars: Gewurztraminer (*Vitis vinifera* L.), Merlot (*V. vinifera* L.), Cayuga White (*Vitis sp.* Hybrid), Noiret (*Vitis sp*. Hybrid), and Concord (*V. labrusca* hybrid). Eight replicate canes were selected from each cultivar. The canes were divided equally into two treatments: 1) natural cold damage and 2) supplemental freezing treatment (-17 °C for 24 hours following field collection) to guarantee all buds sustained damage. These two treatments would furnish ample samples with varying mortality statuses for subsequent analyses in this study.

Data acquisition and analysis of thermal image sequences

Data acquisition - Five grape buds on each cane were imaged using the custom-developed active thermographic system, with the thermal stimulation configured for 1 second prior to heating, 5 seconds of heating stimulation, and 10 seconds of cooling. This was equivalent to 480 frames in this study (thermal camera was set to 30 frames per second for 16 seconds). To minimize potential differences due to non-uniform heating stimulation among samples, only a single bud was placed at the center of the sample holder (and thus the image center). This process resulted in a dataset of 200 thermal image sequences (4 replicates for each of the 2 treatments across 5 cultivars). Following image acquisition, all bud samples were manually sliced and examined to identify any potential damage (e.g., cold damage and missing buds) to the buds.

Image analysis – For each thermal image sequence, the image frame exhibiting the maximum heating effect (the 180th image frame) was presented to a human evaluator who selected the bud's center. A region of interest (ROI) was subsequently generated, featuring the selected center and a predefined radius of 5 pixels, to extract the thermal response curve for that particular bud.

Statistical analysis – A multivariate analysis of variance (MANOVA) was conducted to test for statistical differences between buds with varying mortality statuses, in order to assess the feasibility of using an active thermographic system for determining grape bud mortality. All analyses were performed in R, with a significance level of 0.05.

3. Results and discussion

3.1. *Significant differences in thermal responsive curves between healthy and damaged grape buds*

In general, a significant difference was observed in the thermal response curves between damaged and healthy bud samples (Figure 2A). During the idle period (the first 30 frames), the thermal radiation of damaged and healthy buds did not exhibit a significant difference, indicating their comparable initial status. As the heating stimulation commenced (from the 31st frame), the thermal radiation of healthy buds increased considerably more rapidly than that of damaged buds, resulting in a higher maximum thermal radiation at the 180th frame. Once the heating stimulation ceased (from the 181st frame), the thermal radiation of both types of buds began to cool down. Since the damaged buds had a lower maximum thermal radiation, their thermal radiation returned to the initial status more quickly. Conversely, the thermal radiation of healthy buds decreased at a slower pace and concluded at an intensity higher than the initial status. This suggested that a longer cooling period would be necessary for healthy buds to fully cool off. MANOVA tests demonstrated a statistical difference between damaged and healthy buds, validating the feasibility of using the extracted thermal response curves to distinguish bud mortality status.

3.2. *Thermal responsive curves showed differences among cultivars*

While the overall differences between damaged and healthy buds were significant, these differences exhibited variations among the five cultivars used in this study (Figure 2B). Cayuga White displayed the most robust thermal radiation of healthy buds during heating stimulation and the largest difference between damaged and healthy buds. This pattern was also observed for Gewurztraminer, Merlot, and Noiret, albeit with a relatively weaker thermal radiation of healthy buds and a smaller difference between damaged and healthy buds. In

contrast, Concord demonstrated a considerably smaller difference between damaged and healthy buds. This was primarily due to the high thermal radiation intensity around the petiole scars on canes near the buds. These scars consistently exhibited high thermal radiation, which influenced the thermal radiation intensity of both surrounding buds and woody tissues, thereby reducing the difference between damaged and healthy buds. This factor could pose certain challenges in differentiating bud mortality status in practical applications.

4. Conclusions

An active thermographic system and a custom computer program were developed as a potentially effective tool for determining grape bud mortality to facilitate precision pruning. Under heating stimulation, damaged and healthy buds exhibited significant differences in thermal radiation that could be utilized for bud mortality differentiation. However, certain cultivars (e.g., Concord) displayed relatively smaller differences between mortality statuses. Future research will concentrate on feature extraction and classification, drawing upon the thermal response curves collected using the active thermographic system.

5. Acknowledgments

This study was financially supported by the New York Grape & Wine Foundation.

6. Litterature cited

Wu, D. & Sun, D. W. (2013). Advanced applications of hyperspectral imaging technology for food quality and safety analysis and assessment: A review - part ii: Applications. Innovative Food Science & Emerging Technologies 19, 15–28.

He, Y., Xiao, Q., Bai, X., Zhou, L., Liu, F., & Zhang, C. (2022). Recent progress of nondestructive techniques for fruits damage inspection: a review. Critical Reviews in Food Science and Nutrition, 62(20), 5476-5494.

Jiang, Y., Li, C., & Takeda, F. (2016). Nondestructive detection and quantification of blueberry bruising using near-infrared (NIR) hyperspectral reflectance imaging. Scientific Reports, 6(1), 35679.

Kuzy, J., Jiang, Y., & Li, C. (2018). Blueberry bruise detection by pulsed thermographic imaging. Postharvest Biology and Technology, 136, 166-177.

Maldague, X., & Marinetti, S. (1996). Pulse phase infrared thermography. Journal of applied physics, 79(5), 2694-2698.

Maldague, X., Galmiche, F., & Ziadi, A. (2002). Advances in pulsed phase thermography. Infrared physics & technology, 43(3-5), 175-181.

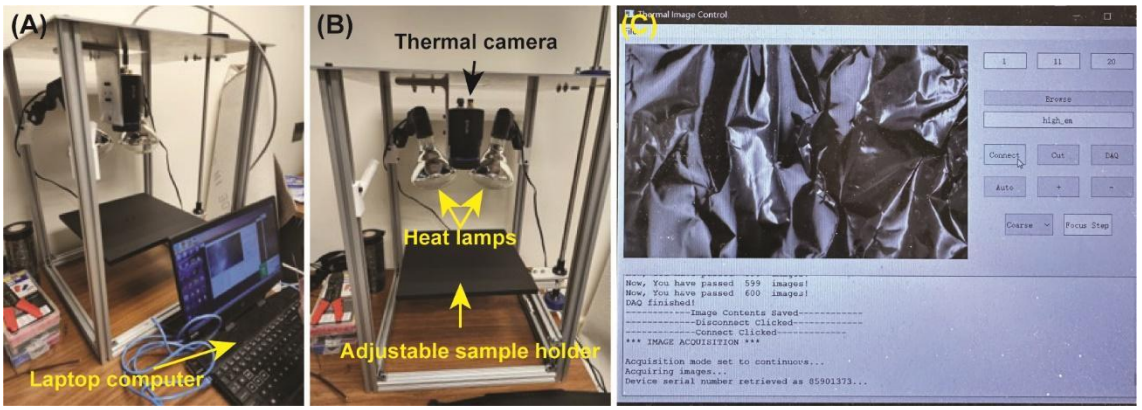

Figure 1: (A) and **(B)** Pictures of the developed active thermographic system for collecting thermal videos under custom thermal stimulation, and **(C)** developed custom computer program for data acquisition.

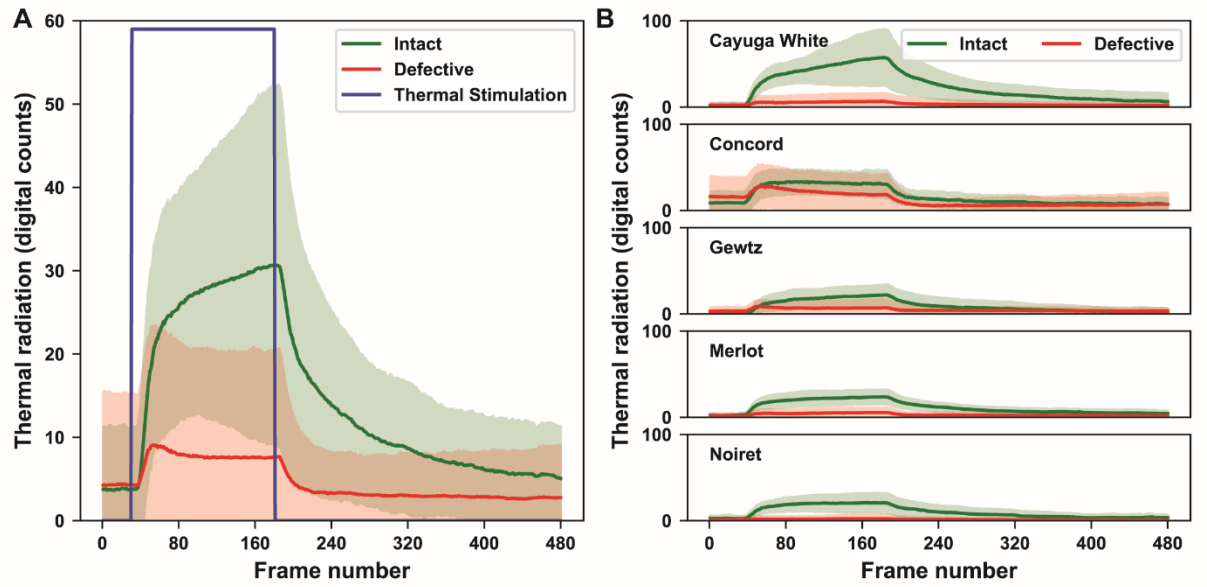

Figure 2: (A) Mean thermal responsive curves (solid lines) with standard deviation (shaded regions) of all samples with extracted thermal images for damaged (red line) and healthy (green) samples along with the thermal stimulation pulse curve (blue line); **(B)** Mean thermal responsive curves with standard deviation of samples of each cultivar for damaged and healthy samples.