Project title: Determining bud mortality via thermal & multispectral imaging

Principal Investigator with contact info:
Justine Vanden Heuvel
Professor
Horticulture Section, School of Integrative Plant Science
Director of Undergraduate Studies Viticulture &
Enology Cornell AgriTech at the NYS Agric. Expt.
Station Cornell University
Work: 315 945 7022
Email: justine@cornell.edu

Co-PI Collaborators with contact info:
Yu Jiang
Assistant Professor
Horticulture Section, School of Integrative Plant Science
Cornell AgriTech, Cornell University
Work: 315 787 2220
Email: yujiang@cornell.edu

New Research ☐ **Continued Research** ☒

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Project Summary Impact Statement: The previously developed laboratory active thermography system has been upgraded to a fully integrated, portable device that can be transported and configured flexibly for data acquisition and analysis. We conducted a full-size experiment with five representative cultivars to evaluate the performance of the newly upgraded system. Experimental results showed that 1) the system can provide distinctive thermal dynamic features between damaged buds from healthy ones and 2) the use of conventional algorithms achieve satisfactory classification performance between damaged and healthy buds.

Objectives:
1. Improve the previously developed laboratory active thermography system into a fully integrated, portable instrument for flexible deployment
2. Explore the feasibility of using the portable system for classifying damaged buds from healthy ones to estimate the damage ratio along a grapevine cane.

Materials & Methods:
Objective 1: Design and implementation of a fully integrated, portable active thermograph 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.

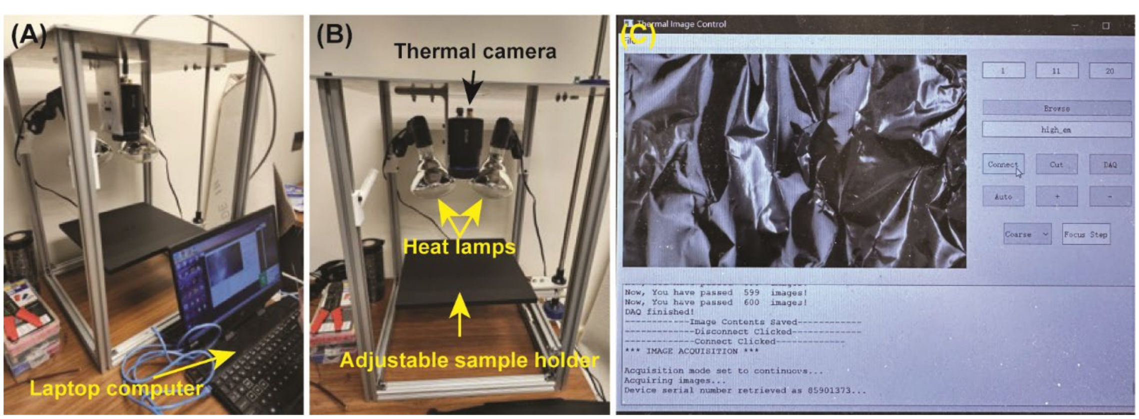

Figure 1: (A) and (B) Pictures of the developed active thermographic system for collecting thermal videos under custom thermal stimulation, and (C) developed custom computer program for data acquisition.

Objective 2: Explore the feasibility of using the pulsed thermal images for bud mortality determination

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 - 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.

Results/Outcomes/Next Steps:

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.

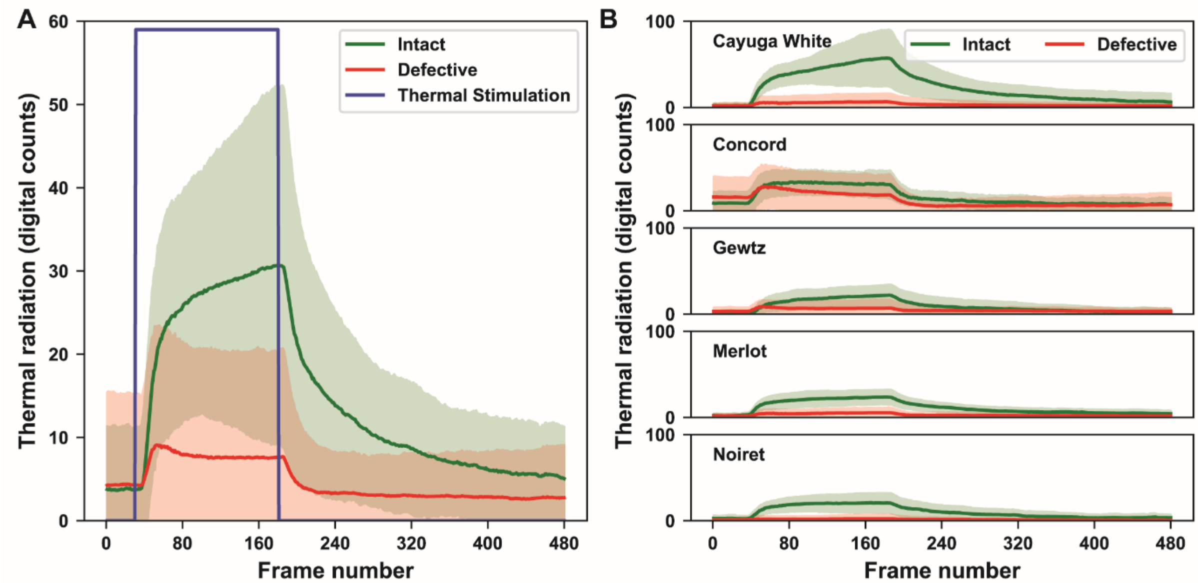

Figure 2: (A) Mean thermal responsive curves (solid lines) with standard deviation (shaded regions) of all samples with extracted thermal images for damaged (red line) and healthy (green) samples along with the thermal stimulation pulse curve (blue line); (B) Mean thermal responsive curves with standard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

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.

Technology Transfer Plan:
The newly upgraded portable system demonstrated its flexibility for the deployment in any possible onsite facilities (e.g., head house, packing house, farm office, modified enclosed trailer etc.) for data acquisition and analysis. This would allow the team to conduct a large-scale experiment involving researchers and growers to collect data in both research and commercial vineyards for testing the usefulness of the system and analysis algorithm for determining bud mortality, especially after severe weather conditions that may trigger cold damage. The team plans to scan more representative cultivars to evaluate the system generalizability as well.

Attachments: included in the report.