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MONITORING MANGO SURFACE VARIATIONS USING NON-DESTRUCTIVE THERMAL IMAGING

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ABSTRACT

Infrared thermal imaging is a powerful tool used to monitor the quality and safety of various agricultural products. In this study, infrared thermal imaging was used to study the temperature variation of mango during storage. In this study, an E76 thermal camera (FLIR systems) with a thermal sensitivity of <0.04°C was used to evaluate the surface temperature profiles of mango fruits. Thermal images of mangoes of the variety *Dasheri* were captured under heated and dark conditions and analyzed. The maximum temperature difference between healthy and deteriorated mangoes during storage was observed to be 10.97 ℃. This temperature difference is likely due to changes in the internal structure and physicochemical properties of the mangoes as they deteriorate. The findings suggest that infrared thermal imaging is feasible for non-destructive detection of deterioration caused by physiological changes in *Dasheri* mangoes is possible using active thermography for monitoring the fruit quality which could enhance the operation and postharvest handling of mango under storage.

Keywords: Infrared Thermal Imaging, Mango Storage Quality, Non-Destructive Detection, Postharvest Monitoring, Temperature Variation Analysis

Introduction

In India, mango varieties such as Alphonso, Kesar, Dasheri, and Totapuri are highly favored for processing. However, mango pulp processing faces significant challenges, particularly the absence of advanced technology to identify internal infestations and hidden damage that are not visible on the peel. Traditional visual inspection methods for detecting pest infestations in fruits are unreliable, time-consuming, and subjective. Hence, there is a pressing need for efficient, reliable, and accurate methods to detect internal defects in mangoes.

Various non-destructive techniques, including X-ray imaging, computed tomography, near-infrared spectroscopy, magnetic resonance imaging, ultrasound, and hyperspectral imaging, have been explored for assessing the internal quality of food products. Among these, thermal imaging offers unique advantages as it is noncontact, technically feasible, and economically viable. This technique works by converting the invisible radiation patterns (temperature) emitted by an object into a visible image known as a thermogram. Infrared radiation, with wavelengths ranging from 0.78 to 1000 µm, is emitted by objects as a function of their surface temperature; higher temperatures result in greater radiation intensity.

Non-destructive techniques have shown significant potential as tools for assessing fruit quality and safety, as highlighted by numerous studies. Infrared thermal imaging has emerged as a promising approach due to its non-contact nature and reduced labor intensity, making it suitable for various agricultural products (Ali *et al.*, 2020). This technique offers benefits such as high repeatability, ease of operation, and rapid detection, making it an effective method for monitoring the quality attributes of food and agricultural items (Roslidar *et al.*, 2020).

Recent advancements have utilized infrared thermal imaging for quality and safety evaluations of fruits like apples (Lipińska *et al.*, 2022), grapes

(Mastrodimos *et al.*, 2019), mangoes (Pugazhendi, 2023), and guavas (Low *et al.*, 2024). Despite its potential, industrial-scale applications of this technique remain limited. For instance, Senni *et al.* (2014) demonstrated its use in detecting foreign objects in biscuits through thermograms captured during the cooling process after baking. Similarly, Chandel *et al.* (2018) employed thermal imaging combined with micro-climate sensors and weather data to estimate apple surface temperatures. Zeng *et al.* (2020) explored thermal imaging to analyze bruising in pears under hot air treatment using high air velocity and temperature.

Thermal imaging has been successfully utilized in the agricultural and food industries for applications such as evaluating fruit maturity, detecting bruises in fruits, and identifying spoilage caused by microbial activity. Previous studies have explored its use in detecting storage pests in pulses, fruit bruises, and water cores in apple tissues. While the application of thermal imaging for detecting internal damage in mangoes is still being investigated, this research aims to explore its potential for surface temperature variation because of internal quality deterioration in mango fruits during storage effectively.

Materials and Methods

Sample

The matured and healthy mango fruits of *Dasheri* variety were used from ICAR-CIPHET, Ludhiana, Punjab and the same was stored at temperature 22 ℃ for 11 days and the study on temperature changes was carried out during the storage period. A total of 10 mango fruits were used in this study for thermal imaging.

Thermal imaging acquisition

The thermal imaging system mainly consists of a thermal camera (E76 Thermal Camera, FLIR Systems), an image acquisition and processing unit, and a heating unit. Thermal imaging of mango fruits was done by active thermography technique for the evaluation of surface temperature by nondestructive method (Shoba *et al.*, 2024). The schematic of the experimental setup is given in Figure 1.

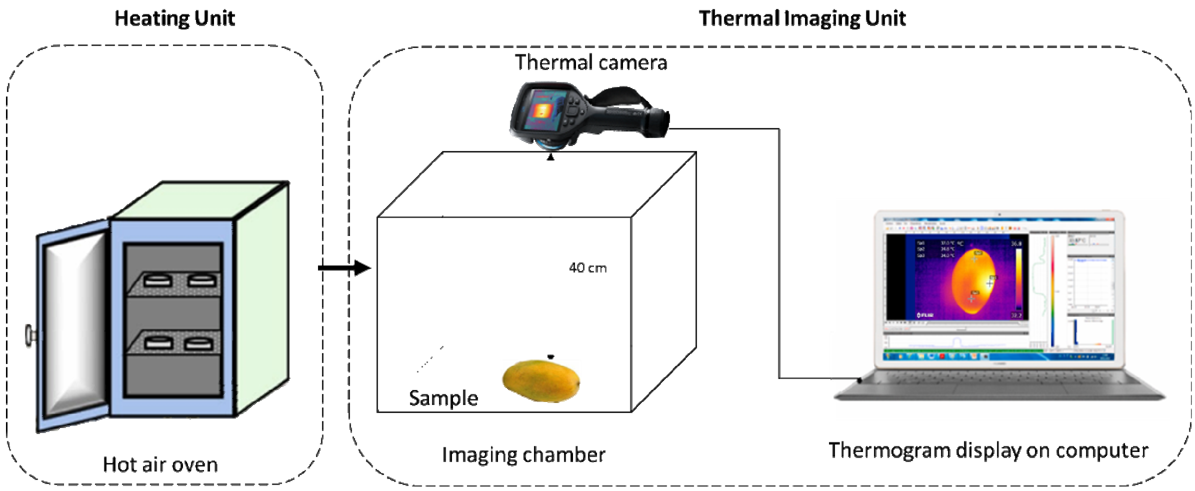

Fig. 1 : Setup to capture the thermographic images of the mango samples.

The camera was mounted at a height of 40 cm from the fruit samples by considering the minimum focus distance of the thermal camera. The surrounding temperature and light intensity have a profound impact on thermograms; therefore, the samples were imaged under room conditions by covering the sample with a box with black inner surface. Heating of samples was done by hot air oven by heating at 60 ℃ for 1 min. The images were captured at 10s after heating. All images were captured under heated and dark conditions as light play a key role in determining the true surface temperature of the mango fruit.

Analysis of thermal images

The analysis of acquired thermal images was done by using the analysis and reporting software known as FLIR Tools, which enabled the import of thermal images from the thermal camera and analyzed the surface temperatures at a pixel level. The extracted information on the surface temperature was imported into Microsoft Excel for further statistical analysis.

Results and Discussion

Thermal image acquisition

The Figure 1 presents thermal images of 10 mangoes captured daily over 11 days of storage, highlighting surface temperature variations. Each image is accompanied by a temperature bar on the right side, displaying a color gradient corresponding to specific temperature values, aiding visual interpretation. The image shows quantitative data on the surface temperature of the mangoes, such as the maximum, minimum, and mean values recorded each day. This comprehensive representation provides insights into the thermal dynamics of mango surfaces, enabling a non-destructive assessment of physiological changes and potential deterioration during storage. The thermal images of *Dasheri* (Sample 1) for 11 days of storage are shown in the Fig. 2.

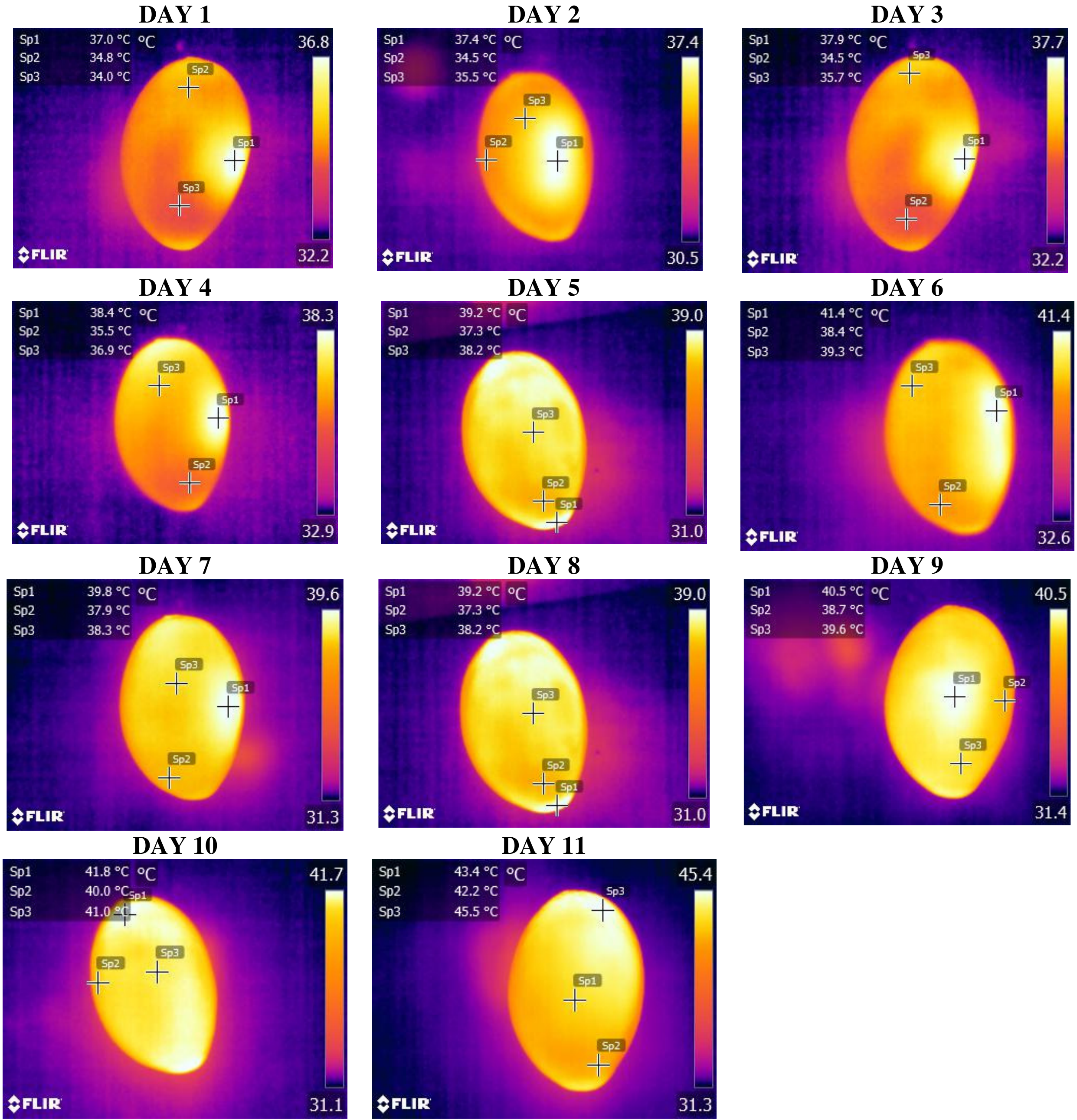

Fig. 2 : Thermal image of Dasheri mango on 1st day of storage.

Analysis of thermal images

The Table 1 presents the surface temperature variations of 10 mango samples monitored over 11 days of storage. Each mango's surface temperature was recorded daily, and the mean temperature values for each sample were calculated. The data captures the progressive changes in surface temperature from Day 1 to Day 11, reflecting the impact of storage conditions on the mangoes. Notable variations in temperature across samples were observed, particularly towards the later days, likely influenced by physiological changes and potential onset of deterioration. This comprehensive dataset provides insights into temperature dynamics during storage, emphasizing its role in monitoring fruit quality and postharvest handling.

Table 1 : Mean Temperature Variation on Mango Surfaces During Storage for 11 Days

	Temperature (℃)										
Sample	**DAY 1**	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**	**DAY 6**	**DAY 7**	**DAY 8**	**DAY 9**	**DAY 10**	**DAY 11**
1	35.27	35.8	36.03	36.93	38.23	38.47	38.67	39.6	39.7	40.93	43.7
2	34.53	34.8	35.5	35.63	37.77	37.8	38.13	38.43	39.27	39.53	41.3
3	34.83	34.9	35.37	36.00	37.67	37.93	38.97	39.67	39.87	40.63	45.8
4	34.4	35.43	35.9	36.33	37.4	37.47	38.4	38.87	38.9	39.17	42.43
5	34.63	35.2	35.93	36.00	36.37	37.97	38.1	38.30	39.13	44.1	45.3
6	34.7	34.93	35.27	36.27	36.53	37.6	37.83	37.87	38.13	42.07	45.33
7	33.33	34.73	35.07	35.73	35.93	36.13	36.67	37.23	37.9	40.2	43.1
8	31.85	35.8	35.7	35.9	36.07	36.23	36.33	37.97	38	40.57	42.5
9	35	35.67	36.67	36.93	37.15	37.17	37.77	37.90	38.4	40.07	40.93
10	34.13	36.67	36.83	37.47	37.93	37.80	37.85	38.57	39	41.27	42.8

The Figure 3 illustrates the surface temperature profiles of mangoes over the storage period. An increasing trend in surface temperature values is observed across all samples as the storage period progresses. This increase may be attributed to the rise in thermal diffusivity (Ishimwe *et al.*, 2014), a critical thermal property influencing heat transfer. Thermal diffusivity plays a significant role during the preheat treatment applied before image acquisition, facilitating the observation of temperature variations. These findings highlight the dynamic thermal behavior of mangoes under storage conditions, potentially linked to changes in their physicochemical properties over time.

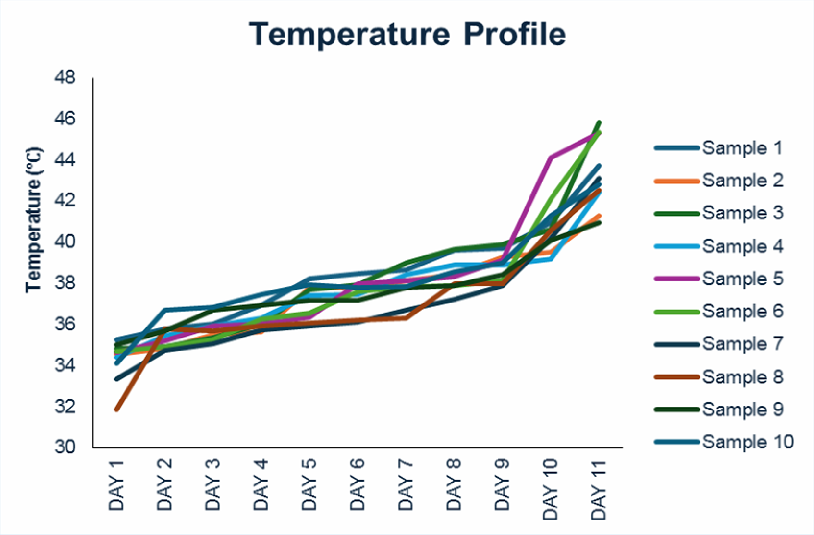

Fig. 3 : Temperature profile of the mangoes during the storage period.

The Table 2 presents the temperature difference values recorded from the surface of mangoes during storage. The observations reveal a minimum temperature difference of 5.93°C and a maximum temperature difference of 10.97°C respectively. These variations are indicative of changes occurring in the mangoes over time, likely influenced by physiological and physicochemical alterations as they deteriorate. The data underscores the effectiveness of using infrared thermal imaging to detect these temperature differences, providing a non-destructive method for assessing fruit quality and monitoring storage conditions.

Table 2 : Temperature difference between first day and last day of storage.

Sample	1	2	3	4	5	6	7	8	9	10
Temperature difference	8.43	6.77	10.97	8.03	10.67	10.63	9.77	10.65	5.93	8.67

Conclusion

This study highlights the potential of infrared thermal imaging as a non-destructive tool for monitoring the quality and safety of mangoes during storage. Using an E76 thermal camera with high sensitivity, the surface temperature profiles of *Dasheri* mangoes were effectively analyzed under heated and dark conditions. The observed temperature differences between healthy and deteriorated mangoes, ranging from 5.93°C to a maximum of 10.97°C, underscore the capability of this technique to detect physiological and physicochemical changes during storage.

The increasing trend in surface temperature values throughout the storage period suggests a correlation with the mangoes thermal diffusivity, influenced by their evolving internal structure and properties. These findings validate the feasibility of using active thermography for real-time quality assessment and postharvest handling of mangoes. By providing a rapid and non-invasive method for detecting deterioration, infrared thermal imaging offers significant potential to enhance the management and preservation of fruit quality in storage and distribution systems.

Authorship contribution

Thongam Sunita: Data curation, Investigation, Software, Writing – original draft, preparation, Visualization. **Dhritiman Saha**: Supervision, Validation, Writing – review & editing. **Sumit Kumar**: Data Acquisition, Formal analysis. **Thingujam Bidyalakshmi**: Writing – review & editing, Formal analysis. **Leena Kumari**: Supervision, Conceptualization.

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