Fruit Bruise Detection in Tomatoes by Using Infrared Thermography Based Approach

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Abstract:- Bruising represents a prevalent form of mechanical damage encountered throughout the postharvest process,spanning from harvesting to packaging. Its detection poses a growing challenge, especially when bruises aren't readily apparent externally. Currently, reliance on manual inspection for identifying bruises remains common, yet it's time-consuming and prone to errors, particularly with early-stage bruises. Prior to consumption, understanding the quality of fruits and vegetables is paramount. However, discerning between contaminants and indicators of freshness presents difficulties. Recent years have seen notable advancements in computer vision, leading to the exploration of various imaging techniques for automated bruise recognition in real-time. Among these, infrared imaging emerges as a valuable tool, capable of identifying bruises not visible to the naked eye. Notably, infrared imaging, particularly with sensitive mid-infrared thermal cameras, offers a promising avenue for detecting hidden bruises.

Keywords*: Fruit, Bruise, Thermography, Tomato.*

1. Introduction

The tomato, scientifically termed Lycopersicon esculentum, is renowned as one of the most widely grown vegetable crops worldwide, frequently featured in home gardens. Its origin lies in South America, and it shares botanical heritage with potatoes and eggplants within the Solanaceae family. Tomatoes are extensively cultivated globally, with the European Union (EU) notably dominating production. Between 1997 and 1999, annual production averaged 14.9 million tonnes. Italy, the leading EU producer, contributed a substantial 42% to this total, amounting to 6.2 million tonnes.

1.1.Bruise damage

As per Mohsenin (1986), a bruise denotes a type of subcutaneous tissue damage that occurs without breaking the skin. In numerous fruit varieties, this damage manifests as a discoloration in the affected tissue. However, in the case of tomatoes, this characteristic is not prevalent. Despite experiencing severe impacts, tomatoes may not exhibit a change in color in the affected area. Instead, the damaged tissue gradually softens over a period of two to three days. This enables the distinction between various levels of bruising, ranging from minor to more severe injuries.Mild bruising in fruit typically results in a distinct difference in the tissue structure compared to the surrounding undamaged areas, without rendering the fruit excessively fragile. Mildly bruised areas are characterized by softened tissue, while severe bruising may show visible accumulation of subcutaneous water. With the exception of the most severe cases, these tissue alterations are often imperceptible to the naked eye. Plastic deformation, in contrast to bruising, manifests visibly on the fruit's surface and is often misidentified as bruise damage. However, deformation typically does not lead to changes in texture. In this study, unless explicitly stated otherwise, deformation will not be categorized as bruise damage. Variations in physical damage exist among different cultivars of the same species, as well as changes in severity depending on the ripeness of the fruit, with ripe fruit generally sustaining more significant damage (Kader, 1996). Literature contains documentation of both internal and external bruises, but this dissertation focuses solely on external bruises, as they are the only type observable by consumers. Similar to other forms of physical damage, bruises significantly compromise the quality and safety of food products. They can serve as entry points for fungi and diseases, posing risks to both consumers and the overall food supply chain. Therefore, it is imperative to thoroughly inspect for damage visible from the exterior during grading processes. While graders typically remove tomatoes with evident holes, cracks, or bursts, bruises are often overlooked. Since bruises may not immediately manifest on the fruit's surface, they can evade initial inspection. These flaws tend to become apparent only after two to three days of incubation, by which time the fruit may have already been consumed by the end consumer. Consequently, growers face limitations in controlling the final quality of their product, and consumers may lose trust in the product's quality label. It's evident that developing a bruise detection technique is crucial. Ideally, bruises could be identified before they become visible, allowing affected tomatoes to be removed before the issue becomes apparent. An ideal detection method would be non-invasive, rapid, and cost-effective. However, preventing fruit bruises altogether would be even more desirable. Achieving this requires identifying the causes of bruise development. In other words, it's essential to determine the factors that make tomatoes susceptible to bruising damage.

2. Methods

2.1.Materials and preparation for measurements

Thermal imager- testo 872:

Thermal Imager – testo 872

- Ideal Image Clarity: To ensure the best image quality, the thermal imager has two resolution options: 320 x 240 pixels for regular resolution and 640 x 480 pixels with Testo Super Resolution Technology.
- Precision in Measurement: The instrument provides precise temperature readings with a thermal sensitivity of 0.05°C.
- Advanced Connectivity: Transfer data wirelessly from compatible devices, such as the Testo 770-3 clamp metre and Testo 605i humidity measuring instrument, by connecting to your smartphone with ease using the free Testo Thermography App.
- Safe High-Temperature Measurement: With a dedicated high-temperature option, some Testo thermal imager models can measure temperatures as high as 1200°C, guaranteeing accurate and safe measurements even in extremely hot weather.
- inbuilt Laser Marker: This device's inbuilt laser marker improves analysis accuracy by enabling accurate visualisation of measuring points within the thermal image.

2.2.IR Software:

IR software

- IRSoft Thermography Software: Use IRSoft to process and analyse infrared images on a PC quickly and accurately. This programme provides a wide range of investigative features designed for thermal image processing professionals.
- Material Emission Correction: It is simple to adjust various materials' post-capture emission levels. For improved accuracy, users can modify image regions down to individual pixels.
- Visualisation of Critical Temperatures: Images can have their critical temperatures highlighted thanks to thermography analysis tools. This covers pixels falling inside particular temperature ranges as well as limit value overshooting and undershooting.
- Adaptable Measurement Point positioning: There are no limitations when it comes to the positioning of several measuring points thanks to the programme. Users are able to remark on the thermographic application and point out hot and cold places in the photographs.

2.3.Principles of infrared thermography:

Infrared radiation represents the energy emitted by an object's surface when its temperature exceeds absolute zero. The intensity of this radiation correlates directly with the object's temperature: higher temperatures result in greater emission of infrared energy. When radiant energy interacts with an object, it can be dispersed through three primary processes: absorption, transmission, and reflection.

The proportions of radiant energy associated with each process are termed the absorptivity, transmissivity, and reflectivity of the object. These characteristics are defined using three parameters, each varying with the wavelength of the radiation:

Spectral Absorptance ($\alpha\lambda$): This parameter denotes the ratio of the spectral radiant power absorbed by the object. It quantifies the object's capacity to absorb infrared radiation at specific wavelengths.

Spectral Reflectance ($\rho\lambda$): This parameter represents the ratio of the spectral radiant power reflected by the object. It measures the extent to which the object's surface reflects incident infrared radiation at a particular wavelength.

Spectral Transmittance ($\tau\lambda$): This parameter indicates the ratio of the spectral radiant power transmitted through the object. It gauges the object's ability to permit the passage of infrared radiation at a given wavelength.

It's important to recognize that absorptance, reflectance, and transmittance are all wavelength-dependent parameters. Understanding these aspects is vital for characterizing how materials interact with infrared radiation, which holds significance across scientific, engineering, and industrial domains.

The sum of these three parameters must be one at any wavelength, as in Equation (1),

$$\alpha\lambda + \rho\lambda + \tau\lambda = 1$$

In the case of opaque materials, Equation (1) is simplified as Equation (2), that is, all of the striking energy is either absorbed or reflected. It could also be said that the striking energy that is not absorbed is reflected.

$$\alpha\lambda = 1 - \rho\lambda$$

Materials in which the transmissivity and the reflectivity are null are called blackbodies. In these materials, all of the striking radiant energy is absorbed ($\alpha\lambda = 1$). Electromagnetic radiation emitted from a blackbody ($W\lambda b$) can be calculated using Planck's law, as in Equation (3), where C1 and C2 are constants, λ is the wavelength and T is the temperature. The result of Plank's law is the power emitted per unit area per unit wavelength, which is a function of λ and T.

$$W\lambda b = \frac{C1\lambda^{-5}}{e^{C2/\lambda T} - 1}$$

The temperature of the object affects the electromagnetic radiation's wavelength, with greater temperatures producing shorter wavelengths. The distribution is not entirely different, but there is a shift in wavelength. Equation (4), which expresses Wien's law, makes it possible to determine the peak wavelength connected to a certain temperature. This law is obtained by finding the wavelength at which radiation intensity is maximised by differentiating Planck's law (Equation 3) with regard to wavelength (λ).

$$\lambda peak = 0.0029/T$$

Equation (3) is integrated across all wavelengths (λ from zero to infinity) to obtain Equation (5), which is the total hemispherical radiation intensity of a blackbody, where σ is a constant. The Stefan-Boltzmann formula is the name given to this equation.

$$Wb = \sigma \cdot T ^4$$

Equation (6) technically defines the emissivity of a body at a given wavelength λ as the ratio of the radiant energy emitted by the body to the radiation that a blackbody at the same temperature would emit.

$$\varepsilon\lambda = W\lambda/W\lambda b$$

A body's thermal energy emission is usually smaller than that of a blackbody at the same temperature. This phenomena is characteristic of a greybody, in which the wavelength-dependent emissivity is constant. This is represented by Equation (7):

$$\varepsilon\lambda = W\lambda/W\lambda b = W/Wb = \varepsilon$$

Real-world objects are too diverse to be simply classified as "greybodies" because of wavelength-dependent variations in their emissivity. However, a standard procedure is to approximate real objects as greybodies by assuming that their emissivity is rather constant over short wavelength ranges. Despite emissivity's wavelength dependence, this approximation becomes feasible by averaging emissivity throughout these intervals, which are usually within the range that infrared sensors can detect. This averaging procedure is made easier by the slow change in emissivity that solid materials, in particular, show with wavelength. However, other states, such gases or liquids, cannot be treated with this method. Equation (8) is the Stefan-Boltzmann formula specific to greybody radiators and can be obtained by integrating Equation (7) into Equation (5).

$$W = \varepsilon \cdot \sigma \cdot T^4$$

If all of the radiation energy falling on an object is absorbed (no transmission or reflection), the absorptivity is one. At a steady temperature, all of the energy absorbed must be re-radiated (emitted), so that the emissivity of such a body would be one. Therefore, the absorptivity in a blackbody is equal to emissivity, which is one. In general, according to Kirchhoff's law, the emissivity and absorptivity of any material are equal at any specified temperature and wavelength. This can be expressed as Equation (9),

$$\varepsilon\lambda = \alpha\lambda$$

From Equations (9) and (2), Equation (10) is obtained for opaque materials.

$$\rho\lambda = 1 - \varepsilon\lambda$$

Greybodies emit only a fraction of the thermal energy emitted by an equivalent blackbody; therefore, emissivity in these bodies is always less than one and reflectivity greater than zero.

2.4.Methodology:-

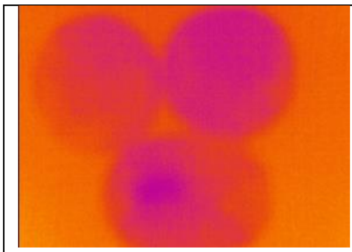
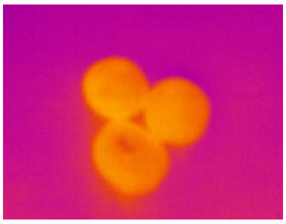
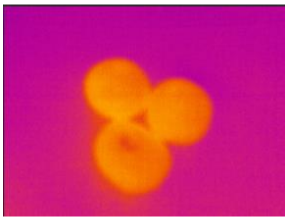
The utilisation of thousands of tiny micro-bolometers contained within an infrared camera has led to the introduction of thermal infrared imaging. The thermal infrared radiation that objects emit can be detected by these cameras. After being detected, the signals are transmitted by changing the transistor's electrical resistance, which then converts the signal into RGB image data.This contrast can be easily seen on the infrared camera display when analysing fruit bruising, which usually has a lower temperature than intact skin. It appears as different colours. Thermal and emollient treatments are used to improve the temperature range of both skin types. Before being brought to room temperature for imaging, fruits are initially kept in cold storage. In the photos that are taken, this procedure makes it easier to distinguish injured regions from the surrounding tissue.While thermal infrared imaging works well to find bruises on fruit, there are other very precise infrared methods available as well. These methods frequently have disadvantages, though, like longer setup and operating times. For instance, to get their results, hyperspectral imaging systems use a variety of infrared wavelengths. By focusing light on the skin of fruits and measuring the light reflection with a hyperspectral camera. The findings show that the reflection characteristics of fruit bruise areas are poorer than those of non-bruise areas.Moreover, different infrared frequency ranges show the impact of bruising depth in distinct ways. While mid wave has a higher accuracy in detecting deeper bruises, short wave is more effective in detecting shallower bruises. High precision bruise detection has been achieved by the use of infrared thermography. This method detects and reflects heat waves rather than light reflected from fruit skin. Constant reflection frequency indicates that the camera has detected normal skin; varying signals returned from bruised areas show up on the camera as darker patches. This technique is also good at finding bruises that are hidden beneath the skin's surface. Although there are a number of infrared application techniques available for detecting fruit bruising, the significant resources required for picture collecting and analysis have prevented many of them from being directly applied in real-world scenarios. On the other hand, this barrier has less of an impact on techniques for heating and cooling as well as infrared thermal imaging. It is possible to detect heat conduction precisely, and differences in thermal characteristics account for the difference in temperature between injured and uninjured tissue. Furthermore, this procedure can be carried out quickly and continuously. The difference in temperature between damaged and unbroken tissue is caused by the dehydration of the injured portions, which have a lower density than the healthy tissue. Both passive and active thermography approaches are taken into consideration for a more thorough examination of both injured and intact tissue. The process of measuring radiation temperatures under natural temperature differences between the items being studied and their surroundings is known as passive thermography. On the other hand, active thermography requires an external heating source in order to either raise or lower the test object's temperature before conducting an experiment. The qualities of the test item and the strategy that produces the best results will determine which approach is best. One benefit of passive thermography is that it can stop any chemical reactions that might happen when the fruit's temperature fluctuates. On the other hand, the main advantage of active thermography is its ability to magnify the injured region, making it visible with an infrared thermal camera and statistically recorded on a thermometer. It is anticipated that early on, within twenty-four hours of the damage occurring, thermal differences between the bruised and non-bruised portions of an apple can be determined by the use of active thermography. Cooling temperatures are important to maintain the fruit's condition without causing harm. As a result, the ideal temperature for fruit preservation is carefully chosen. Image data collection employing active thermal heating and cooling processes offers difficulties. Despite efforts to control object and ambient temperatures, radiation and reflections from external sources can have an impact on the results. Light sources can confuse camera operations, providing the appearance of heat on the apple skin. Furthermore, light reflections can cause considerable temperature changes. In our experimental setting, ambient noise contributes less than 20% of the temperature of our test object. Due to the apple's high emissivity value and the fact that our experiment was conducted well above sub-zero temperatures, it is crucial to calibrate the infrared thermal camera before recording thermal images. This calibration ensures the accurate functioning of the camera in the specific environment. Initially, the emissivity level needs to be adjusted to match the test object. Emissivity value is determined by the radiation characteristics of an object, which directly expose its true temperature to the camera. The emissivity value of an object, which shows its capacity to display its absolute temperature, is usually set to 1 for blackbody objects. Objects that cannot reliably display their true temperature, or null objects, are assigned a value of zero. The fruit has an emissivity of roughly 0.95, which is comparable to the emissivity of the human body. As a result, this number is picked for calibration. Furthermore, careful selection of the camera's temperature display window is required to ensure accurate reading. There are various sorts of display windows, each with a unique color pattern and temperature depiction. The "white hot" and "black hot" color palettes often use three colors in the image, with the maximum temperature showing as black or white. The rainbow palette, on the other hand, uses more than seven colors to accentuate even the tiniest temperature changes. However, for this research, the "Ironbow" palette provides the most detailed portrayal. Colors in this palette include white, yellow, orange, red, pink, blue, and purple, which indicate the image's highest to lowest temperatures. Using seven color representations in defect detection investigations is consistent with our research needs. We can assign certain colors to different areas of interest: the bruised area can be represented in purple, the healthy apple area in blue and pink, and the surrounding areas in other colors. To achieve a highly detailed color presentation for each pixel, we will define upper and lower camera temperature limits within a specific range. This method improves the accuracy of flaw detection while giving clear visual contrasts between different sections of the image. To present crucial information in an image, we can modify the temperature window range based on the fact that bruises and healthy tissue have a temperature differential of at least 1˚C.Temperature range T is our variable, which can be adjusted as long as it is less than or equal to six degrees. Color resolution R identifies areas with temperature differences of 1˚C or higher. If there is a bruise in the image, it will be clearly visible. . The goal of this study was to collect raw image data from an infrared thermal camera to detect early fruit bruises, then input this data into a pre-trained deep learning neural network to detect bruises and split each image into bruise or non-bruise categories. There are various issues to consider during the experimentation and programming steps. The system will be modified to increase its robustness against unusual events while also giving precise information for the study. Infrared thermography presents a promising approach for non-invasive, non-contact, and radiation-free imaging, enabling the assessment of abnormal infrared radiation emitted by objects. Studies have shown that thermal imaging can detect up to 100% of fruit bruises by distinguishing surface temperature variations between bruised and non-bruised tissues. This technique involves converting infrared radiation into visible images, illustrating temperature differences across a scene captured by a thermal camera.

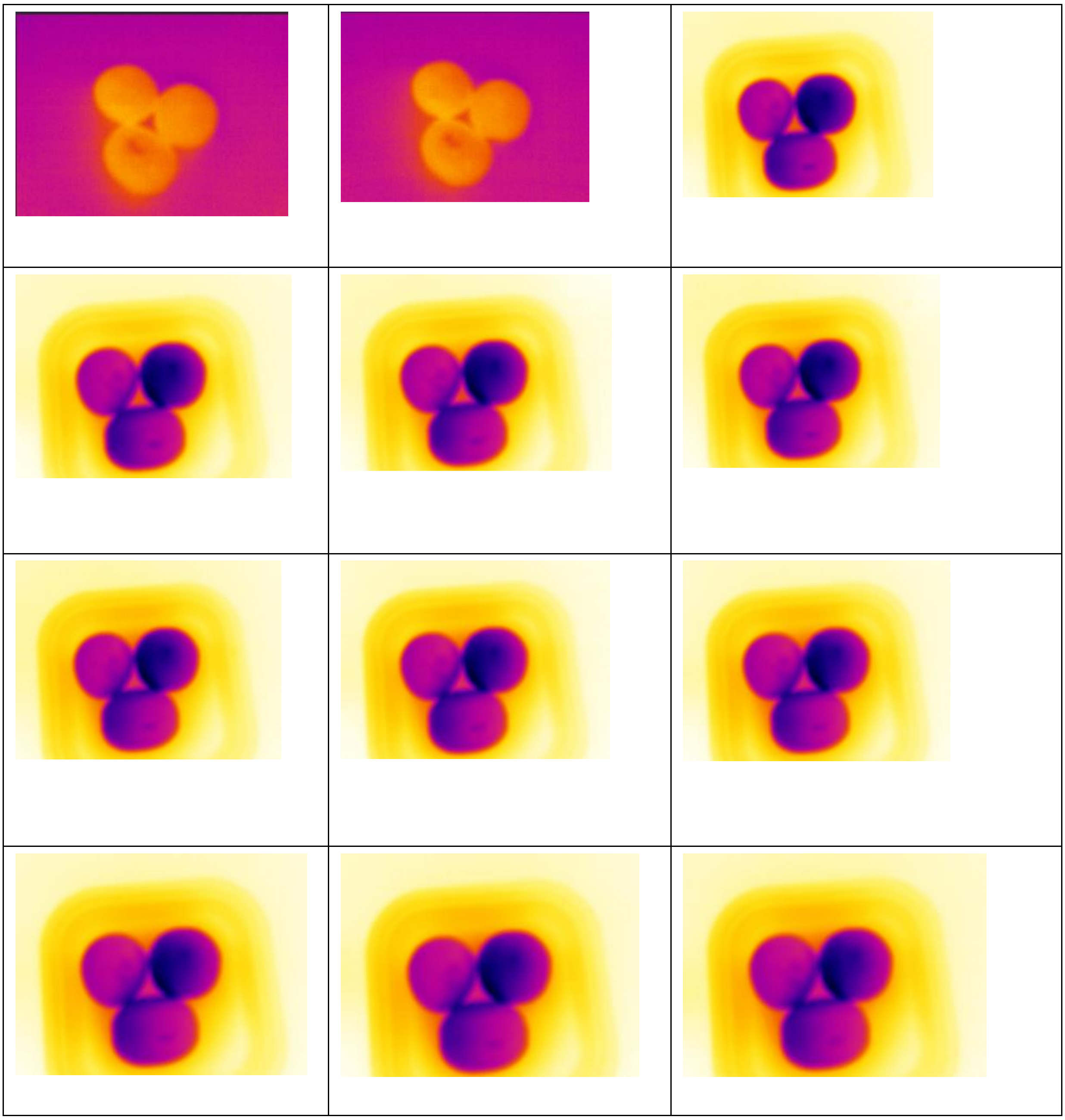
For our project, we utilize the Testo 872 thermal imager, renowned for its high image quality with an infrared resolution of 320x240 pixels and a thermal sensitivity of 0.05°C. With this camera, we capture images of our samples, which are then analyzed using infrared software, facilitating easy processing of infrared images on a computer. Graphical representations of temperature, known as histograms, reveal the distinct emission levels of various surfaces, aiding in the interpretation and analysis of thermal data.

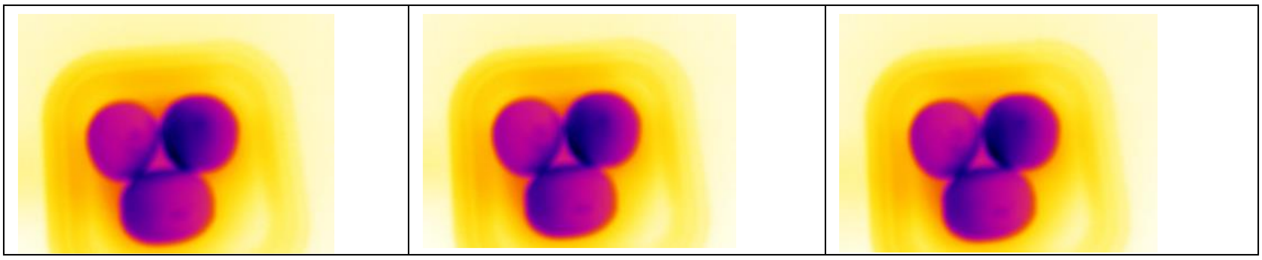
3. Results

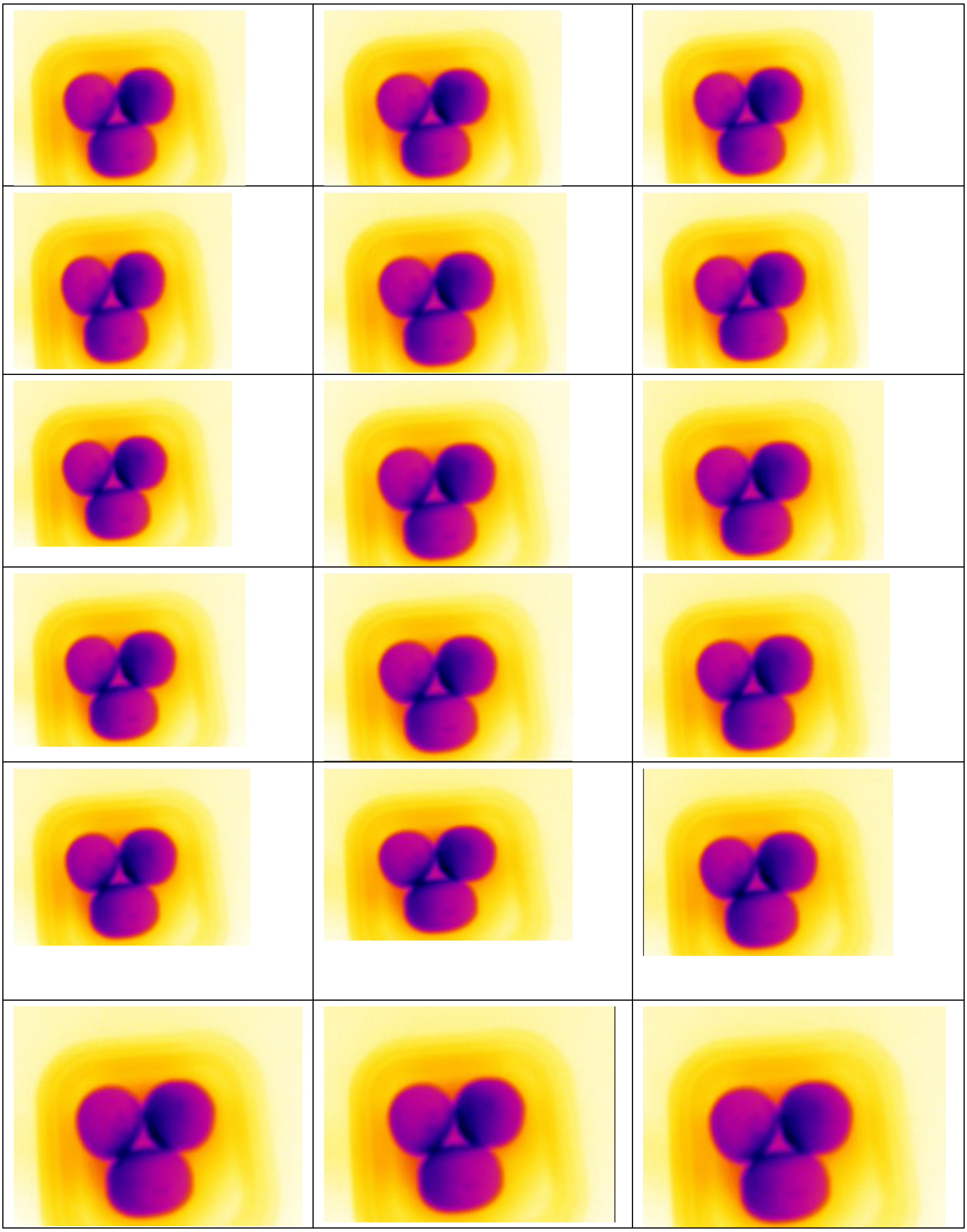
3.1. Conditions

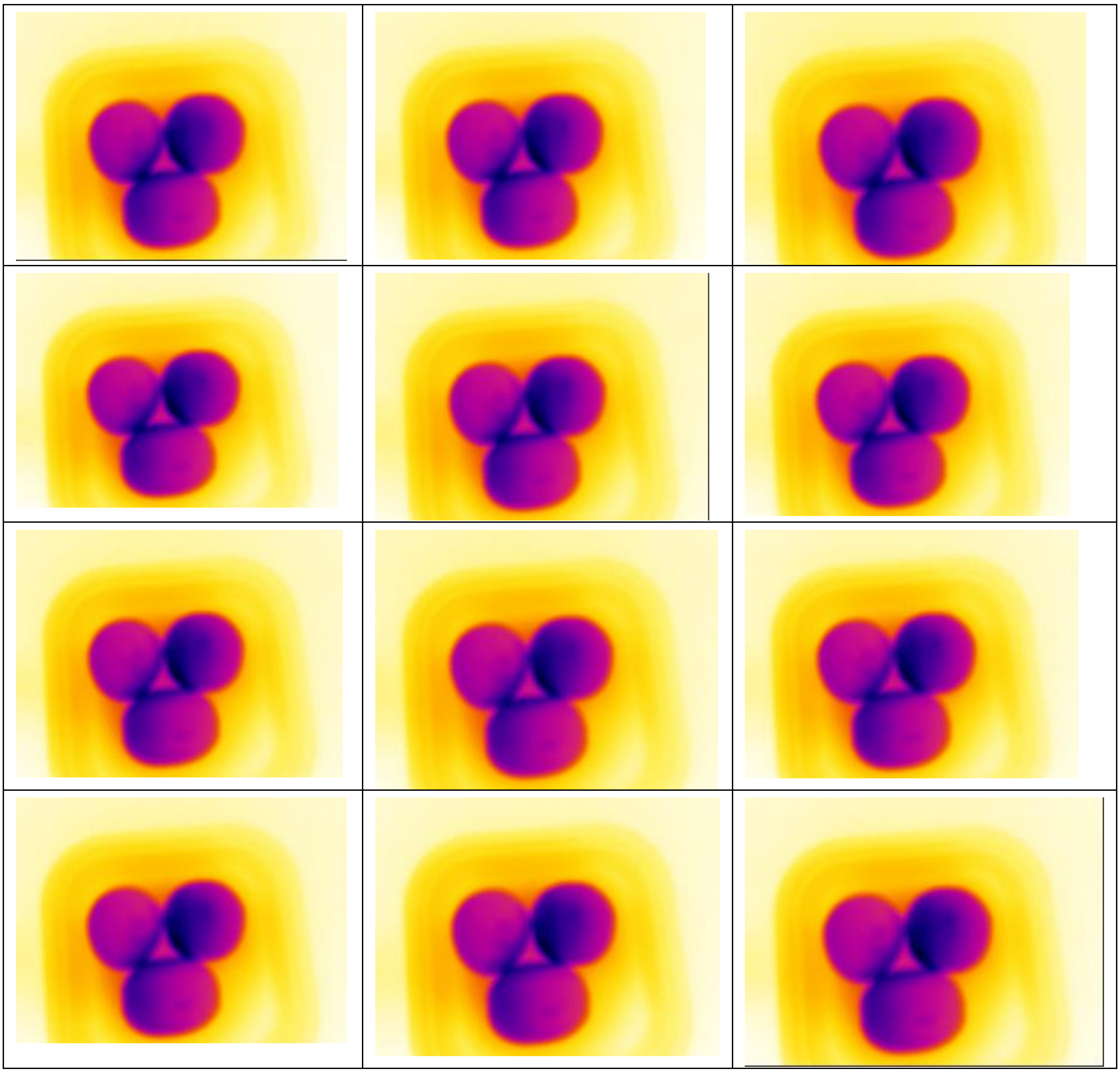
- Room temperature – 28.9°C
- Distance (Base to camera) – 28.5cm
- Distance between tomato and camera -3.5cm
- Heating or cooling treatment were applied in order to expand the temperature range on both type of skin, by storing the fruits in low temperature before transfer them to room temperature and took pictures. The bruise parts can be clearly distinct from surrounding area in those image.
- In this project we had done cooling process because the specimen taken is organic matter (i.e,tomato)

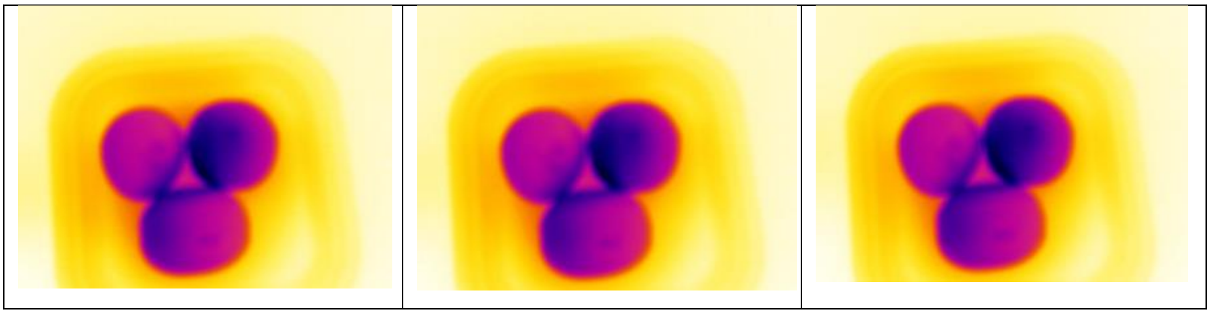
		

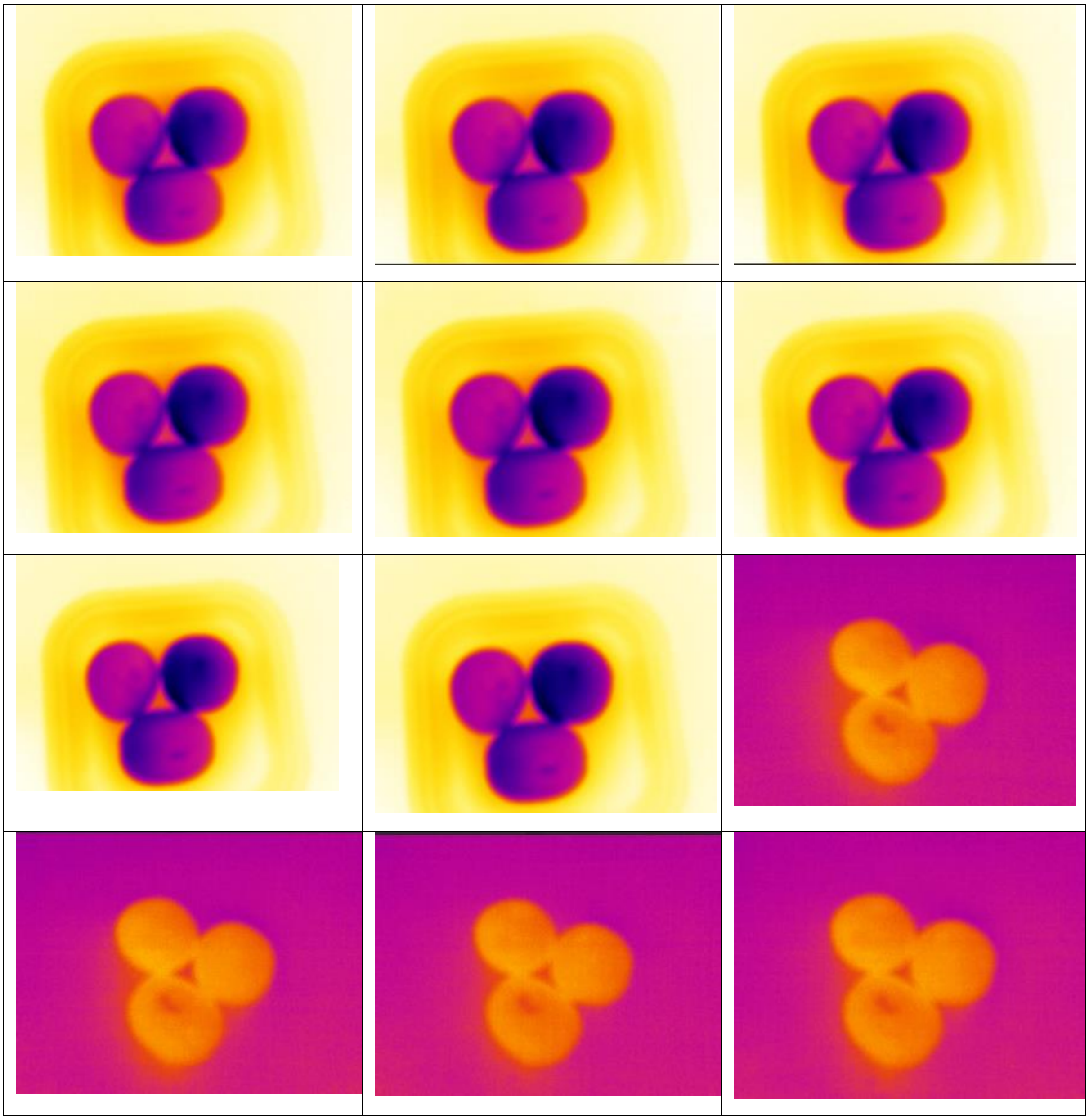






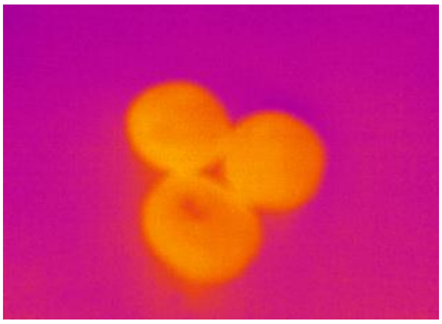


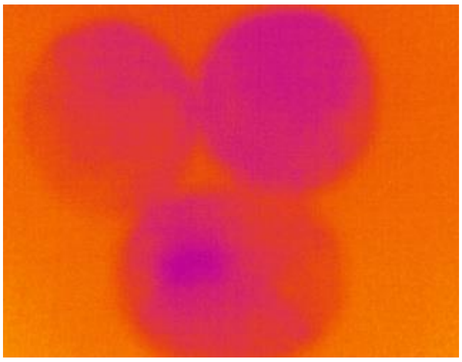
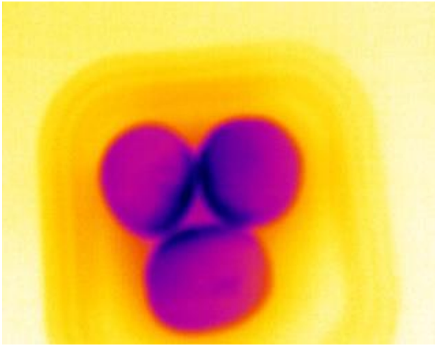
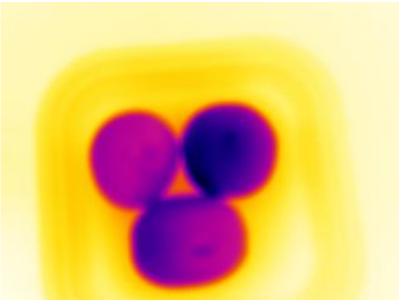
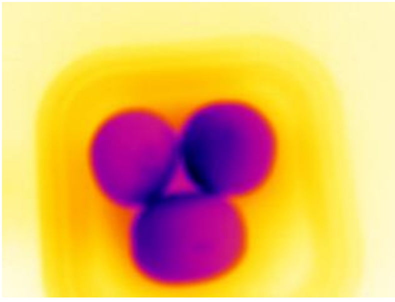




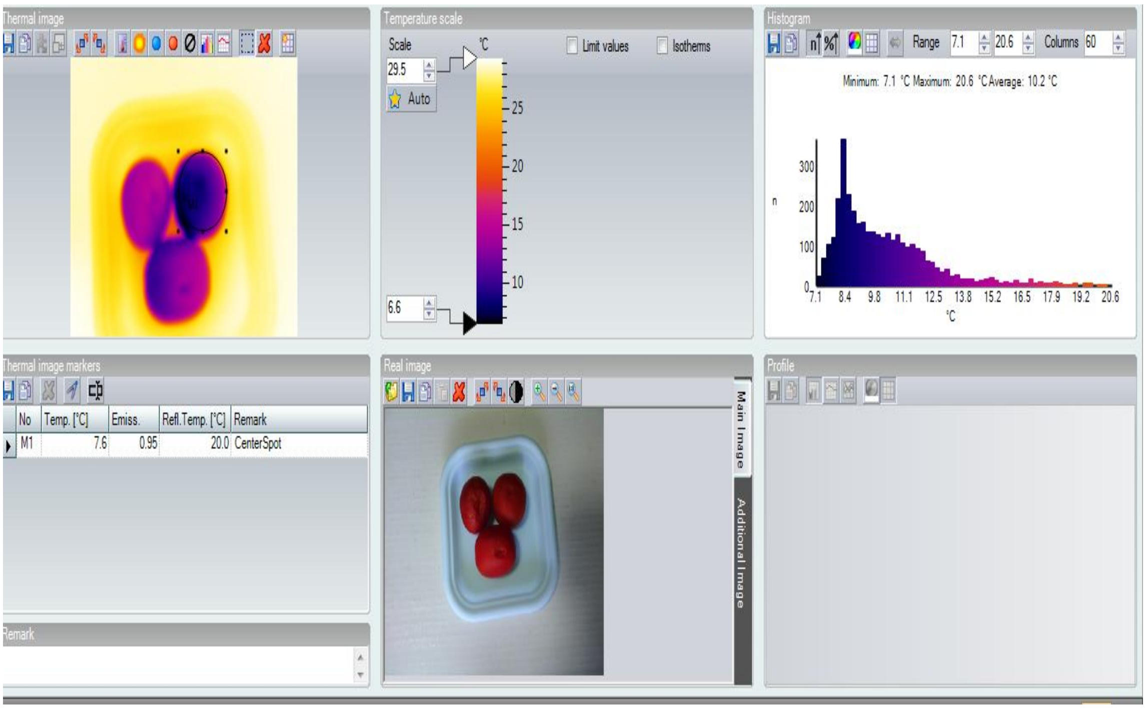
Thermal data set

3.2. Analysis

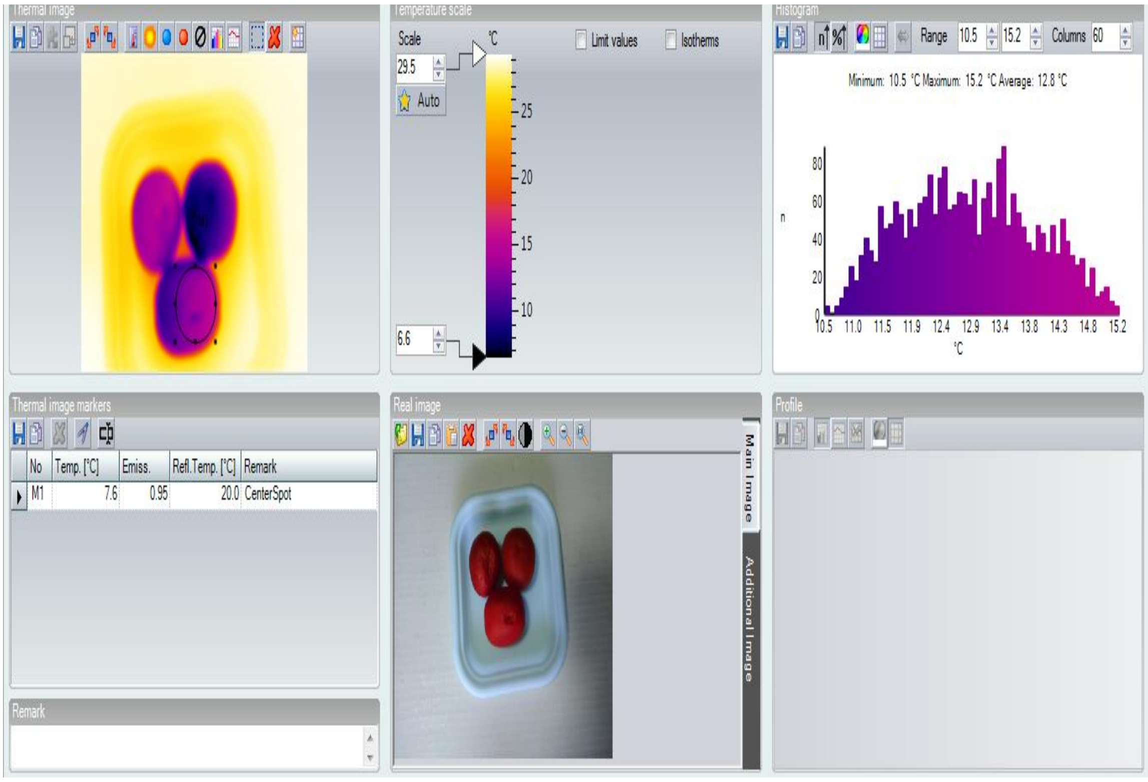
CONDITION:- BEFORE COOLING TEMPERATURE- 28.9°C 	CONDITION:- BEFORE COOLING TEMPERATURE- 28.9°C 

CONDITION:- BEFORE COOLING TEMPERATURE- 28.9°C 	CONDITION:- AFTER COOLING TEMPERATURE- 7°C 
CONDITION:- AFTER COOLING(AFTER 2 MIN) TEMPERATURE- 12°C 	CONDITION:- AFTER COOLING(AFTER 6 MIN) TEMPERATURE- 16°C 

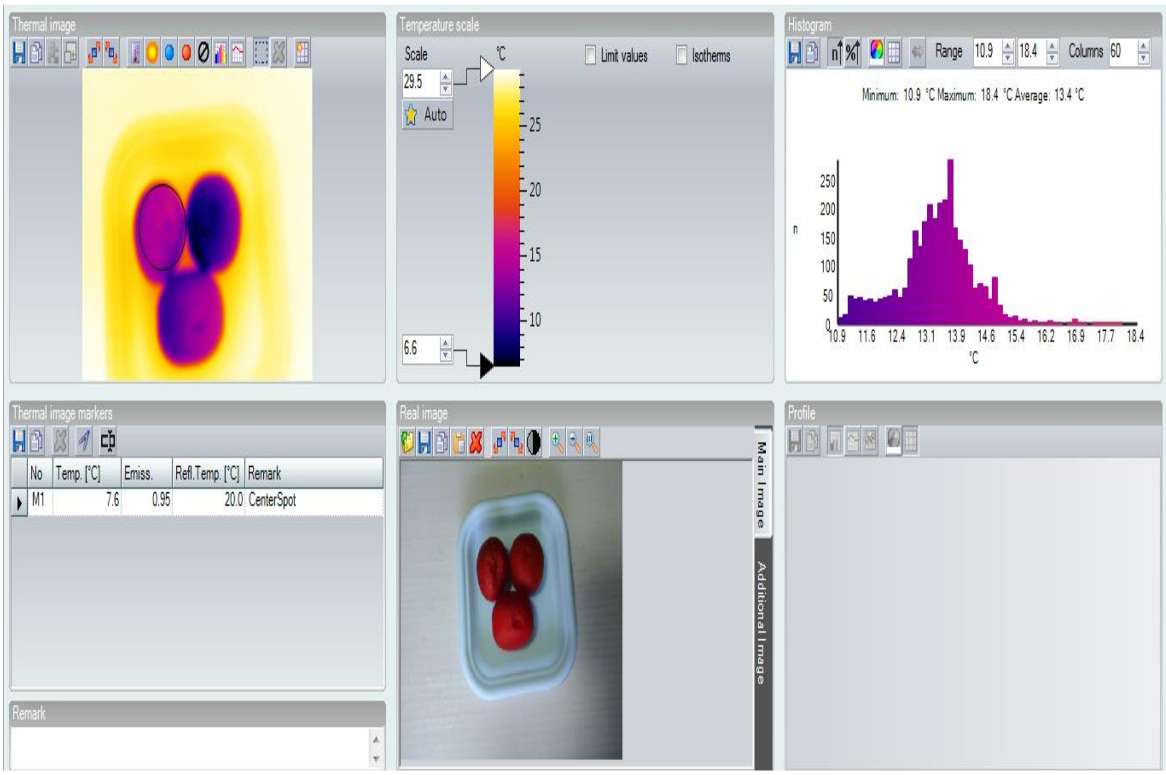
Thermography images of tomatoes



Histogram analysis of normal tomato



Histogram analysis of damaged tomato



Histogram analysis of rotten tomato

4. Conclusion

It has been shown that it is possible to distinguish between normal, rotten, and damaged tomatoes using an infrared (IR) thermography-based methodology. This advancement in imaging technology offers a chance to improve the ability to identify bruises on fruits and vegetables. Through accurate identification of bruised food, financial losses can be reduced. Additionally, it allows for the separation of things that require immediate processing from those that are in good enough condition for extended storage by assessing the degree of damage. By simplifying the handling and delivery of perishable items, this technique improves food quality overall and supports sustainability initiatives.

This approach further can be implemented in computer vision technique.

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