IMPROVING SHELF-LIFE OF FRUITS USING THERMOGRAPHY

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ABSTRACT
Novel technologies have always been an indispensable part of the scientific enterprise and a catalyst for new discoveries. The invisible radiation patterns of objects are converted into visible images called thermograms or thermal images. Thermal images can be utilized to estimate the ripeness of some fruits which do not change their color from yellow to green when they are ripe. Thermal imaging techniques are very helpful since color and fluorescent analytical approaches cannot be applied to these fruits. In this work, we show the different ripeness levels of avocado using thermal images non-destructively, in two-dimension. The work is based on the fact that fruits have different specific heat capacities at different temperatures, thus making their thermal images clear indicators of ripeness.

NOMENCLATURE

T	Temperature
C_p	Specific heat

INTRODUCTION
It has been the traditional way of estimating the ripeness of a fruit by either naked eye inspection to check the change of color of the fruit skin or by pressing the fruit with hand. There have been Quantitative approaches too in the literature using image processing [1] and artificial neural networks [2], to check the various ripeness levels of the fruit. Moser et al showed Fluorescent signals from the green fruit investigated under ultraviolet (UV) radiation can also be analyzed for the determination of the ripeness level of the whole fruit [3].
Recently, Sarun Sumriddetchkajorn et.al showed that for spatial evaluation of the ripeness level of the fruit, both white light and UV radiation can be used [4]. Infrared technology has enabled the design and implementation of human mass temperature screening system [5] and a deception detection system [6]. Based on the fact that the specific heat of the fruit differs depending on the level of ripeness of the location of the fruit and hence its temperature, the infrared technology can be used to do the ripeness estimation, not bothering the change of their skin color [7-11].

Thermography is a non-invasive analytical tool that does not require physical contact with the substance. Thus, thermography can be used for the studies without a physical damage or any contamination to the study object [12]. Infrared thermography is applied in food processing studies to control citrus surface drying by thermal image analysis [13].

Baranowski and Mazurek detected physiological disorders and mechanical defects in apples using infrared (IR) thermography [14].Gan-Mor et al. developed post-harvest precision steam-disinfection technologies for carrots using thermal image analysis [15].

In addition, Vadivambal et al. employed thermal imaging to observe hot and cold spots in rye and oats during microwave heating [16]. Furthermore, Veraverbekeet al.applied thermography to investigate the surface quality of waxed apples. Thermal imaging has been used for injury detection on the surface of apples and tomatoes before the appearance of visible injuries [13,14,17].

Sarun Sumriddetchkajorn & Yuttana Intaravanne showed the spatial classification of the whole fruit into immature, ripe, and overripe states via the infrared technology concerning the color of the fruit [18]. This comes from the fact that the ripe fruit has higher heat capacity and therefore its body temperature slowly changes.

In the next section we will describe the experimental setup and explain the procedure followed to perform the experiment to demonstrate the changes in the temperature of fruits using thermal images. We will also show that these changes in the temperature can be used to determine whether the fruit has become ripe for the fruits which do not change their color from green to yellow during the ripening process. Finally, the discussion of the experimental results, and the future work are explained in the conclusion.

MATERIALS AND METHODS
The experiment requires recording the temperature of the fruits through thermal images which was done using an infra-red camera (E5 IR CAMERA W/ MSX 120X90 RES). The fruits were also required to be kept at a constant temperature during the experimental phase which was taken care by performing the experiment in a room where the temperature was maintained at a constant temperature by conditioning the air. The fruits were kept in card board box with the top side open to make sure there was no undesirable heat transfer from/to the fruits. The first batch of fruits under evaluation were four unripe bananas, peaches with a designated number. The fruits were selected in

such a way that they were free from any physical defects, washed and dried naturally. The fruits were placed on a cardboard box for each variety separately with a sufficient gap among the fruits to avoid any physical contact. Each fruit is identified with a number. Then The specimen is evaluated using infrared technology in five designated areas. The areas are labeled in advance and the images correlate with the designated areas.

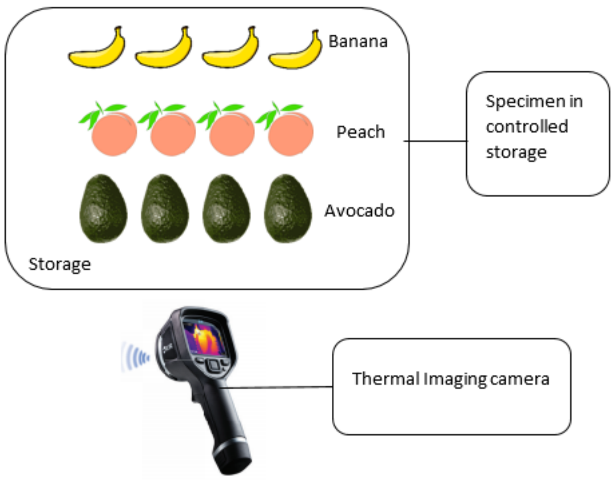

Fig.1 The experimental setup used to take thermal images.

The thermal images were recorded using the infra-red camera on the first day at 6.52 PM. The temperature was recorded at five different locations by marking the spot on each fruit. The procedure was repeated for five consecutive days at the same time to obtain the thermal images and hence their temperatures. The ripeness level for these fruits can be determined by our eyes just by noticing the changes in their skin color. But, the experiment was carried out to obtain the temperature changing pattern of the fruits during ripening process.

The room temperature was maintained at 710 F all through the five days and there was no physical contact with the fruits while taking the images to avoid any local heat transfer to the fruit.

The experiment was repeated with the same procedure for the same size of the batch of kiwi and avocado() for five consecutive days with the same room temperature of 710 F and the thermal images were recorded. Kiwi and avocado had all the similar characteristics that which we wanted to evaluate in regards to the inability to determine the ripeness via color.

RESULTS AND DISCUSSION

Fig 2(a), (b) and (c) show the normal and thermal images of kiwi, peach and avocado, respectively. As seen in these images, the temperature at a specific location can be read from the thermal image of the fruits. Fig.3 – 6 show the variation of the temperature of fruits as the number days increase. Further, the figures 3(a), 4(a), 5(a) and 6(a) represent the variation of average temperature at four different locations of four peaches, five bananas, four kiwis and four avocados. The figures 3(b), 4(b), 5(b) and 6(b) represent the average temperature at the same locations of four peaches, five bananas, four kiwis and four avocados. The thermal images show that during the ripening process, the temperature of the fruit keeps increasing since the specific heat of the fruit is changing. We see a general pattern of increase in temperature of the fruits from the plots. There could be slight changes in the temperature of the fruit depending on the location of the fruit since the rate of ripening could be different throughout and hence the specific heats. Hence there are some points in the plots where the temperature drops which could be due to the fact that the average temperature could be fluctuating slightly for the reason mentioned above.

From the figures 5 and 6, we see the gradual increase in the temperature of the fruits as they ripe with time, too. It may be noted that for the fruits such as avocado and kiwi the temperature is changing though the skin color remains the same during the ripening process. Hence, it is possible to identify the level of ripeness of these fruits non-invasively through the thermal images. This approach will not require any force to be applied to find out the level of ripeness which might damage the fruit otherwise. The shelf-life of the fruits which do not change their skin color with ripening process can be determined by their thermal images. The Fig. 7 shows the complete temperature profile for the consecutive five days of the ripening process of kiwi at a constant 71^0F room temperature.

We conducted multiple studies over a course of three months to confirm the same pattern. The studies involved peaches, kiwis, bananas and, avocados. The temperature changed from 19^0C to 26^0C.for peaches, 19^0C to 25^0C for bananas. whereas the temperature ranged from 21^0C to 25^0C for kiwis and 21^0C to 27^0C.for avocados.

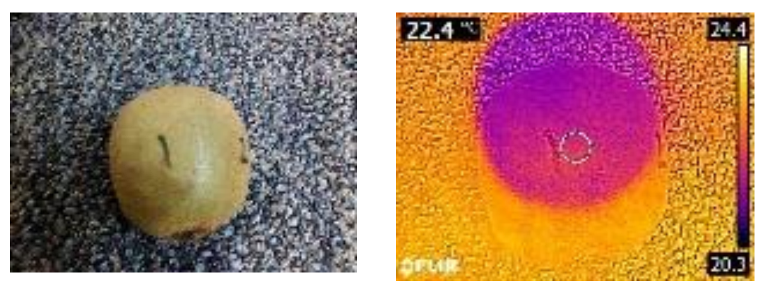

Fig. 2 (a) Normal and thermal image of a kiwi

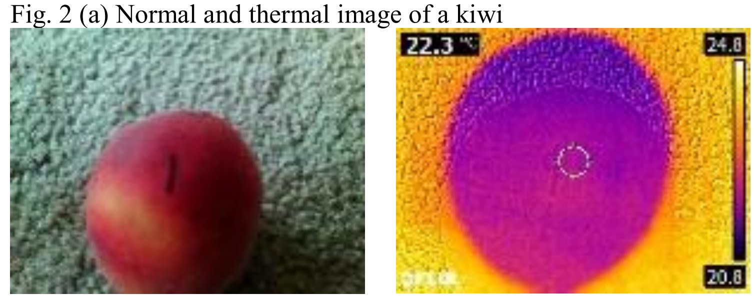

Fig. 2 (b) Normal and thermal image of a peach

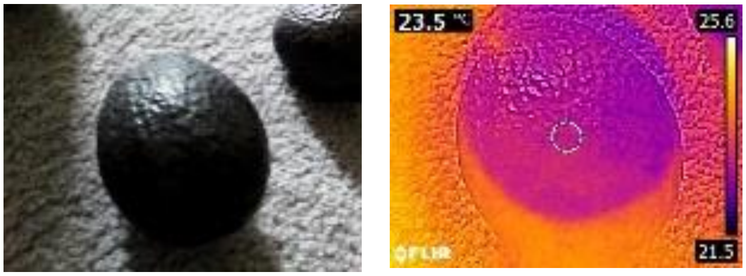

Fig.2 (c) Normal and thermal image of an avocado

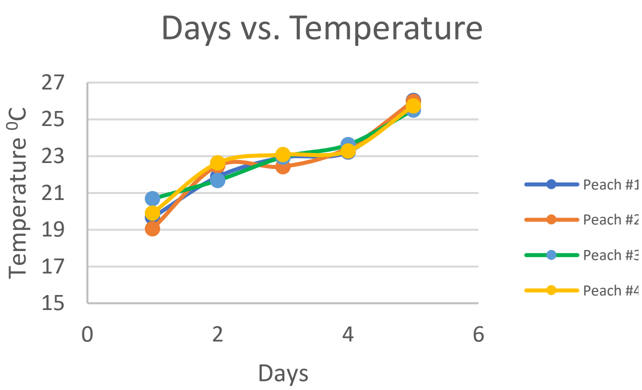

Fig. 3(a) The variation of average temperature of peaches with time

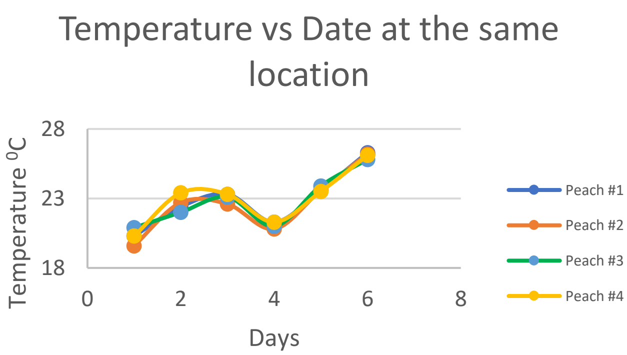

Fig. 3(b) The variation of temperature of peaches at the same location with time

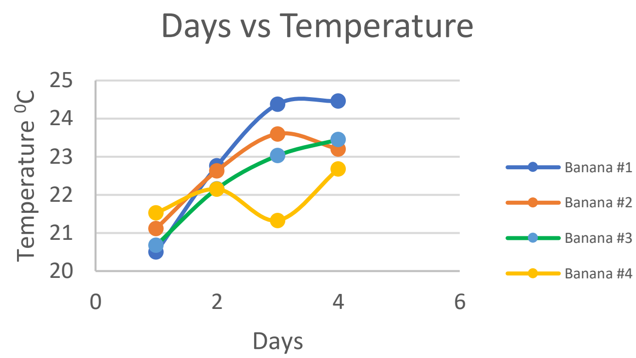

Fig. 4(a) The variation of average temperature of bananas with time

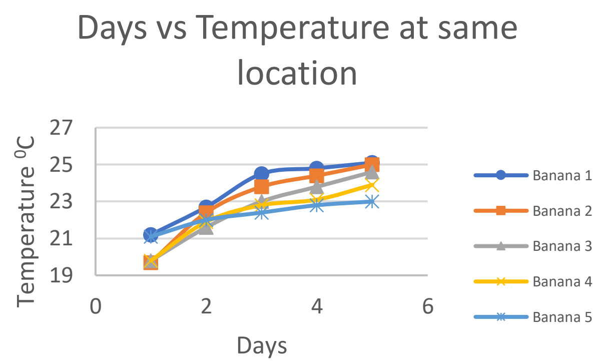

Fig. 4(b) The variation of temperature of bananas at the same location with time

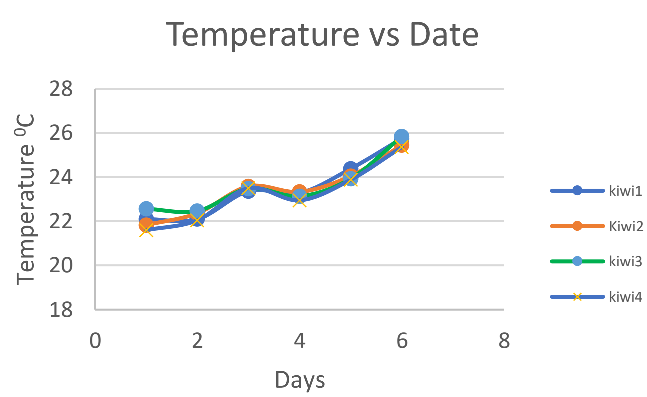

Fig. 5(a) The variation of average temperature of kiwis with time

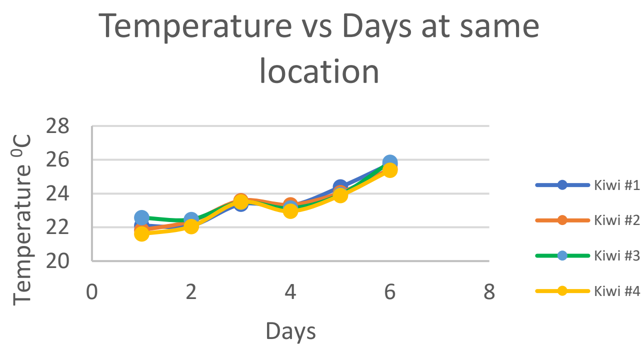

Fig. 5(b) The variation of temperature of kiwis at the same location with time

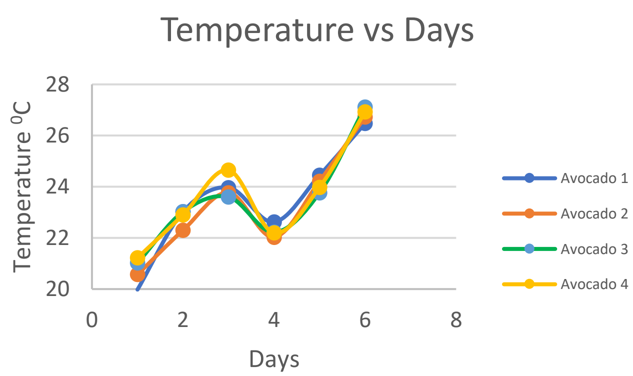

Fig. 6(a) The variation of average temperature of avocados with time

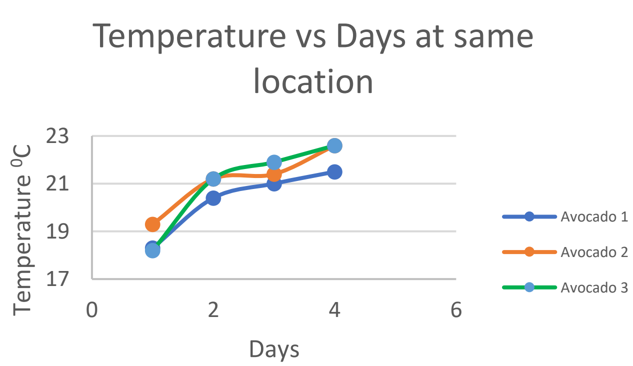

Fig. 6(b) The variation of temperature of avocados at the same location with time

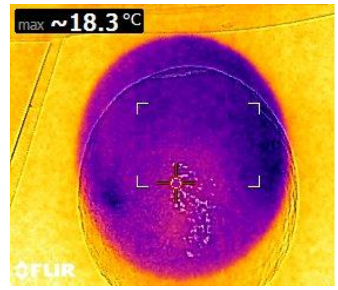

Fig. (a) Day #1

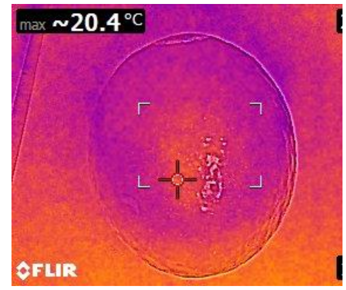

Fig. (b) Day #2

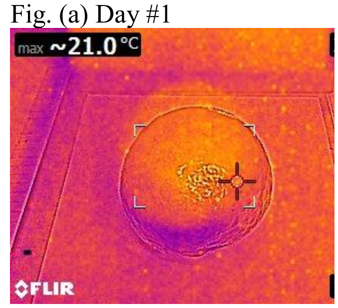

Fig. (c) Day #3

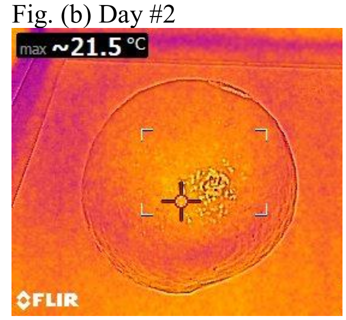

Fig. (d) Day #4

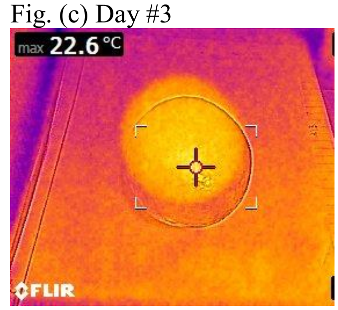

Fig. (e) Day #5

Fig.7 The increase of temperature of kiwi with time

CONCLUSION

In this study, the temperature changes of different fruits during their ripening process were investigated using thermography. The temperatures of the fruits were found increasing during the ripening process. It is because the specific heat of the fruits change during the ripening process which reflects on their temperature. It was also shown that for the fruits which do not change their skin color during the ripening process such as kiwi, avocado (type) it is possible to determine whether a fruit has become ripe through its temperature using their thermal images.

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I would like to dedicate this paper to my PhD supervisor, Umit SONMEZ, who passed away due to a sudden heart attack in December 2011.

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