Thermal Image Method to Detect Fruit Maturity of Avocado (*Persea americana* Mill.) and Red-Guava (*Psidium guajava* L.)

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Abstract. The fruit stages at which the avocado and red-guava fruits should be harvested are very important in determining the market life, storage, transport, eating and processing qualities. This is especially true for avocados because the fruit is harvested in a green-mature stage. The fruit surface temperatures were measured using a thermal image method and the information was used to determine the maturity stages of red-guava and avocado fruits. Five levels of avocado fruit maturities and three levels of red-guava fruit maturities were used. Thermal image parameters were measured and then correlated to the physical and chemical quality parameters of the fruits. The objective of this study was to correlate the surface temperatures of avocado and red-guava fruits using a thermal image method with their physical and chemical characteristics by analyzing at different stages of fruit maturities. The results showed that mature fruit of avocados had a lower temperature than immature fruit, but when fruit was getting ripe, the mature fruit had a higher temperature than immature fruit. There was a close correlation between thermal image and physical and chemical parameters of the avocados. Meanwhile, the level of fruit maturities of red-guava correlated with fruit temperature, the higher the ripeness of the fruit, the higher the temperature of the fruit. Thus, it can be concluded that the thermal image method has the opportunity to be used as a method for detecting the level of maturities of both fruits.

Keywords: Avocado, Guava, Thermal Image.

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1 Introduction

Avocado is one of the fruits that is widely consumed because of its protein and fat content. Besides citrus fruits, mangoes and bananas, avocados are also one of the fruits that are widely traded and studied. The Central Statistics Agency (CSA) of Indonesia noted that avocado production reached 669,260 tons in 2021 and 865,780 tons in 2022. That means the national avocado production in 2022 has increased by 29.37% compared to the previous year which amounted to 196,520 tons. Last year's avocado production was also the largest in the last decade. Seeing the trend, avocado production tends to increase during the last decade [1].

Avocados are one of the climacteric fruits that experience a spike in respiration and ethylene gas after harvesting, resulting in physical and chemical changes during ripening. As a climacteric fruit, avocados do not ripen on the tree, so they must be harvested under physiological conditions appropriate to the stage of maturity to obtain edible taste characteristics [2]. Visually it is very difficult to determine the exact stage of harvest maturity of avocado because this fruit does not show any changes in appearance [3]. Harvesting based on criteria for physical changes will result in yields consisting of several levels of physiological maturity, and in this case fruit with the same criteria may have different levels of physiological maturity [4].

Red-guava (*Psidium guajava* L.) is a tropical fruit commodity that has a fairly high economic value. Its fruit contains high vitamins A, B1 (thiamine), B2 (riboflavin) and C (ascorbic acid) [5]. The red-guava fruit is marketed in both fresh and processed forms, such as juice, jelly and jam.

In the cultivation of red-guava, the main obstacle faced by farmers is the determination of its right harvest time. The red-guava fruit is harvested only based on physical fruit parameters, even though the same physical parameter could be in different physiological maturity because it cannot describe the overall physiological impact that can be detected from the early maturation [4]. The harvest of red-guava fruit also depends on the distance traveled by the marketing area. For long distance marketing, harvesting is done when the fruit is still green with a proper level of maturity so that the fruit is not damaged during transportation.

The principles of thermodynamics state that any object that has a temperature above absolute zero (0 Kelvin or about -273.15 °C) will emit thermal radiation, the intensity of which depends on the temperature of the object [6]. On the basis of these principles, thermal radiation imaging is now widely used as non-invasive, non-contact and non-destructive analytical tool in the agricultural and food industries [7-9] in line with the development of image processing and computer vision technologies [10]. Through thermal radiation imaging it is possible to measure the temperature variation in a field of objects dynamically during real-time measurements so that useful analysis and interpretation of the data is faster and easier. Some applications of thermal imaging in agriculture and food include detecting the presence of foreign bodies in food [11], detecting mechanical damage (bruising) [12-15] and disease in fruits and vegetables [16-18], and determining the degree of ripeness of fruits [19-21].

This study aims to analyze various levels of avocado and red-guava fruit maturities using the thermal image method and obtain a thermal image correlation with their physical and chemical qualities.

2 Material and Method

2.1 Avocado

This research was conducted in May-July 2021 at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia. The main material for this study consisted of avocados with five maturity levels obtained from farmers in the village of Mengandung Sari, sub-district of Sekampung Udik, district of East Lampung, Lampung Province, Indonesia.

The research material used was avocado from 5 different maturity levels based on fruit size-maturity (K1-K5). Fruit samples were selected based on the level of maturities determined from the farmer-adopted harvest time, namely, 4 days before harvest to 4 days after harvest, and fruit size. Harvesting was done according to the local practice. Based on this pre-defined harvest period and closely homogeneous fruit size (diameter), five maturity levels were determined: K1 was the most immature and K5 was the most mature. Fruit diameter was measured after sorting the uniformity of the fruit according to each maturity level. In this treatment, each maturity level had five replications, so that there were 25 experimental units. For the analysis of the chemical qualities of the fruit sent to the Quality Processing Laboratory, Lampung State Polytechnic, Bandar Lampung, Indonesia, three replications were used, bringing to a total of 15 fruits, and 25 fruit samples were stored at room temperature (26-28 °C), so that a total of 65 fruits were used.

Thermal imaging was then used to measure each sample. Samples that have been analyzed using TI were then measured for fruit diameter, weight, firmness and total soluble solids (TSS) (called the main samples, coded D1), while for ripe samples an analysis of fruit firmness was carried out when ripe. In addition, TI testing was also carried out on the condition of mature (D3) and ripe fruit (D5). Sample D1 was the main sample that was not stored, while samples D3 and D5 were fruit samples at storage temperature in mature and ripe conditions.

The observation was carried out as thermal image, fruit physical quality analyses (fruit firmness, diameter and weight), and chemical quality analyses [fat content, starch, glucose, sucrose, free acid, free fatty acid (FFA), and total soluble solids]. The physical quality analyses and TI were conducted at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia. After taking the physical quality measurements, the fruit samples were then sent to the Quality Processing Laboratory, Lampung State Polytechnic, Bandar Lampung, Indonesia for chemical quality analyses

2.2 Red-guava

The research on red-guava was done at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia. The research was done on February - April 2021. The main research material was red-guava fruits which have been classified based on three level of maturities, namely green, yellowish green, and greenish yellow, and directly received as fresh harvest from the Great Giant Foods, Co. Ltd., Terbanggi Besar, Central Lampung, Indonesia, through the PG4, Labuhan Ratu, East Lampung, Indonesia. The research equipment was the same as in the avocado research.

The TI measurement and its data analysis were conducted as in the avocado research [20,22]. The observation was carried out as thermal image, fruit physical quality analyses (fruit firmness and weight), and chemical quality analyses (starch, sucrose, free acid, and total soluble solids). The physical quality analyses and TI were conducted at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung, Bandar Lampung, Indonesia. After taking the physical quality measurements, the fruit samples were then sent to the Quality Processing Laboratory, Lampung State Polytechnic, Bandar Lampung, Indonesia for chemical quality analyses.

The data of the TI analyses of both avocado and red-guava fruits were then correlated with the physical and chemical parameters of the fruits with a regression value (R^2) and analyzed using the analysis of variance (ANOVA), then further tests were carried out using the Least Significant Difference (LSD) test at the level of 5 and 15% (Statistix 8).

2.3 Image Measurement and Analysis

Preparation. Before thermal imaging was done, the avocados and red-guava fruits were left for 12 hours to acclimate to the conditions of the lab.

Image Acquisition. A FLIR thermal camera (E5-XT) was used to measure each fruit sample. The sample is positioned directly beneath the 35 cm camera in an image chamber (Fig. 1). The resulting image displays the temperature distribution in pseudo color. The final JPG-formatted photos are saved for later processing. GNU Octave was used to analyze images.

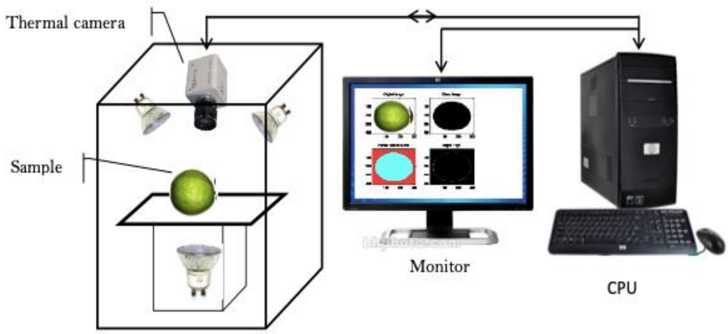

Fig. 1. Illustration of the thermal image acquisition system

Object Segmentation. Image segmentation (Fig. 2) is used to identify and separate objects or unwanted elements from the region of interest (ROI). Next, a window of 70 × 70 pixels was chosen from each sample for further analysis such as temperature measurement and feature extraction.

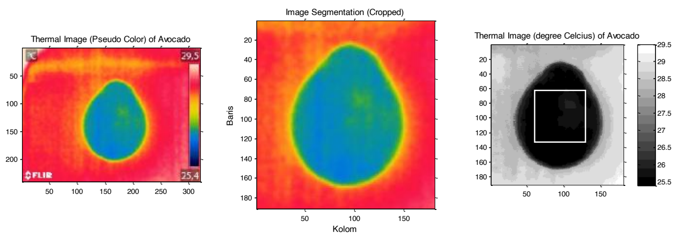

Fig. 2. Image segmentation and temperature extraction.

Notes: Original thermal image in pseudo color with colorbar (left); cropped image of the sampel (center); temperature distribution and ROI with temperature bar(right)

3 Results and Discussion

3.1 Avocado

Prior to harvesting, it's critical to assess the fruit's maturity to prevent improper harvesting, which could result in losses to avocado fruits. In addition, proper harvesting of avocados also avoids fruit damage by consumers because they squeeze the fruit so that the fruit becomes bruised and damaged. For this reason, it is necessary to detect the level of ripeness of avocados through temperature radiation emitted using a thermal camera.

Requote our reported data [23], Fig. 3 showed the temperature emitted by avocados at various levels of ripeness and storage times. Sample D1 was the main sample that was not stored, while samples D3 and D5 were samples of fruit at storage temperatures when mature/unripe and ripe, consecutively. In samples D1 and D3 the average temperature values tended to decrease followed by a higher level of maturity, while in sample D5 where the condition of the fruit in a ripe state showed the average temperature values tended to increase followed by a higher level of fruit maturity. That is, the more-ripe the fruit, the higher the temperature radiation emitted by the fruit at each level of fruit maturity. This is supported by the theory which states that infrared technology can be used as an estimation of fruit maturity to classify whole fruit into immature and ripe states regardless of fruit color. The fact is that ripe fruit has a higher heat capacity content, therefore the object temperature slowly changes [24].

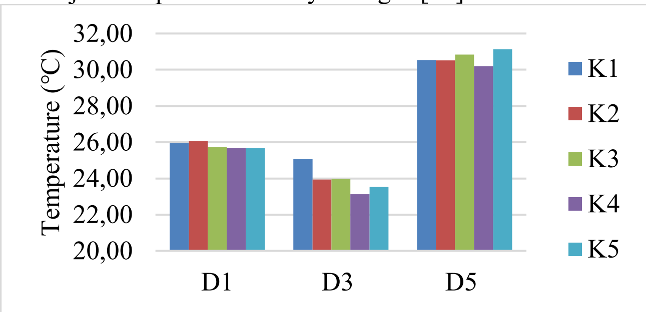

Fig. 3. Average value of avocado fruit temperature.

Note: D1 = fruit without storage (day-1); D3 = mature fruit on the 3rd day of storage; D5 = ripe fruit on storage (5th day); K1 = youngest fruit; (2) K2 = young fruit; (3) K3 = slightly old fruit; (4) K4 = old fruit; (5) K5 = the oldest fruit [23].

Judging from the temperature captured (Fig. 1), it showed that the temperature radiation was not able to distinguish the level of matureness through the emitted temperature, but it seemed to be able to distinguish the level of ripeness in avocados. Avocado is a climacteric fruit which is characterized by a spike in ethylene during ripening [25, 26]. In the study of Jeong et al., [26], that ethylene production in the control treatment began to increase after 7 days of storage at 13 °C and the maximum production value reached 40.6 mg/kg/hour after 16 days at 13 °C.

Based on the data in Table 1, physical observations for parameters of fruit diameter and weight showed a significant effect on each level of maturity according to LSD 5 and 15%, and for the temperature parameter only K2 and K5 which showed a significant effect on BNT 15%. In general, the highest average value was in K1 and decreased with the younger maturity level. This might be caused the fruit was harvested before reaching the peak of maturity in K1 so that the fruit had not yet reached its highest weight. Researchers Widodo et al., [27] stated that harvesting at a picking age earlier than the normal picking age can reduce yield weight by more than 10% although it can prolong the pre-climacteric phase of fruit for 3-5 days.

Table 1. Fruit temperature and physical parameters of avocado*.

Maturity Levels**	Temperature (°C)	Diameter (cm)	Weight (g)	Fruit firmness (kg/cm^2)
K1	a 25.95 ab	c 7.24 d	c 218.06 c	a 0.40 a
K2	a 26.08 a	c 7.30 c	c 229.46 c	a 0.36 a
K3	a 25.75 ab	b 7.75 b	b 269.88 b	a 0.34 a
K4	a 25.69 ab	b 7.75 b	b 272.28 b	a 0.30 a
K5	a 25.67 b	a 8.17 a	a 325.74 a	a 0.28 a
(R^2)		0.79	0.71	0.75

*Values followed by the same notation are not significantly different according to LSD 5% on the left of the number and 15% LSD on the right of the number.

**K1: youngest fruit, (2) K2: young fruit, (3) K3: slightly old fruit, (4) K4: old fruit, (5) K5: the oldest fruit.

On the parameter of fruit firmness in ripe fruit conditions, it did not show a significant effect according to LSD 5 and 15% (Table 1). This parameter indicates that the oldest maturity level (K5) had a lower fruit firmness value compared to the youngest fruit maturity level (K1). This showed that the avocado fruit which had a low firmness value had changed in texture to become softer due to the degradation process of starch and polysaccharides in the cell wall. In addition, the activity of cell metabolism in avocados also causes avocados to become soft. Researchers [28] found that at storage days 0, 4, 8 and 12, the fruit firmness decreased from approximately 130.51 N to 54.62 N, 19.92 N and 7.37 N, consecutively, when stored at 15 °C.

The average value of fruit temperature was in line with the value of avocado fruit firmness which tended to increase along with the level of maturity, that was getting younger. It was different with the measurement parameters of diameter and fruit weight which increased along with the maturity levels of the fruit getting older. Based on the regression test, the correlation values of the parameters above was relatively high between temperature, diameter and fruit weight and fruit firmness, namely 0.79, 0.71 and 0.75 (Table 1).

The results of the chemical parameters (Table 2 - 3) did not show significant effects except for the starch content according to the LSD 5% test, while according to the LSD 15% showed significant effects, except for two parameters, namely free acid and fat content.

Table 2. Glucose, sucrose, starch, and free acid contents (%) of avocado fruit*.

Maturity levels**	Glucose	Sucrose	Starch	Free Acid
K1	a 2.52 a	a 1.41 ab	c 3.75 c	a 1.48 a
K2	a 2.35 ab	a 0.80 b	c 3.88 c	a 1.48 a
K3	a 2.53 a	a 1.87 a	c 3.85 c	a 1.40 a
K4	a 2.37 ab	a 0.95 b	b 4.34 b	a 1.32 a
K5	a 2.26 b	a 1.48 ab	a 4.91 a	a 1.40 a
(R^2)	0.86	0.59	0.80	0.71

*Values followed by the same notation are not significantly different according to LSD 5% on the left of the number and 15% LSD on the right of the number.

**K1: youngest fruit, (2) K2: young fruit, (3) K3: slightly old fruit, (4) K4: old fruit, (5) K5: the oldest fruit.

Table 3. Free fatty acid, fat, and total soluble solid contents (%) of avocado fruit*.

Maturity levels**	Free fatty acid	Fat	Total soluble solid
K1	ab 6.55 abc	a 3.11 a	a 8.33 b
K2	ab 5.93 bc	a 3.10 a	a 10.00 a
K3	b 5.31 c	a 3.06 a	a 10.33 a
K4	ab 7.45 ab	a 2.73 a	a 9.67 ab
K5	a 7.67 a	a 2.52 a	a 9.33 ab
(R^2)	0.38	0.83	0.20

*Values followed by the same notation are not significantly different according to LSD 5% on the left of the number and 15% LSD on the right of the number.

**K1: youngest fruit, (2) K2: young fruit, (3) K3: slightly old fruit, (4) K4: old fruit, (5) K5: the oldest fruit.

Based on Table 2 - 3, the observations of chemical parameters, namely sucrose content and total soluble solids (TSS) at the older maturity level, showed mostly a higher average value than the younger maturity level, namely at K1. At the oldest maturity level (K5) the average values were 1.48 and 9.33% for sucrose and total dissolved solids, consecutively, while glucose at the oldest maturity level was lower than the slightly older (K3) and young fruit (K1). This was presumably because the fruit was in the ripening stage to optimize the chemical composition of the fruit, and had not yet reached the peak of maturity at harvest.

The starch content tended to decrease along with the younger the maturity level of the avocado (Table 2). This means that the higher the maturity level of the avocado, the average value of the avocado content was also higher. The highest average content value at the oldest maturity level (K5) was 4.91%, while the smallest average was at the young fruit maturity level (K1) of 3.75%. At the oldest level of maturity (K5) it ripened faster, and seemed to be related to the dry matter content; the higher the dry matter, the faster the fruit ripens and the shorter the ripening time. Fruit harvested with dry matter content below the recommended minimum will ripen irregularly and even not fully ripen. Likewise, fruits harvested with high dry matter experienced rapid ripening and reduce shelf life [14]. Minimum dry matter requirements varied from 19 to 25%, depending on the cultivar (19.0% for Fuerte, 20.8% for Hass and 24.2% for Gwen) and country (21% for Australia, 21.6-22, 8% for the US and 23.0% for Mexico, South America and South Africa for 'Hass' avocado) [3, 29, 30].

Furthermore, the free acid variable tended to increase in the younger samples (Table 2). The average value of the highest free acid content in the K1 treatment was 1.48%, which means that K5 was the oldest maturity level. This was because at the oldest level of maturity it had passed the phase of optimizing the chemical content in fruit such as sugar, fat, starch so that the free acid level in young fruit became high. In another study Kosiyachinda and Mendoza [31] it was stated that the titrated acidity decreased with the onset of ripening, but there was no general value for the maximum titrated acidity. The highest values were in fruit harvested 11 weeks after fruit formation, and decreased significantly in fruit harvested at 12, 13, 14, 15 and 16 weeks after fruit formation. The lowest values for total acidity were observed in fruits harvested at 16 weeks after full bloom.

In the observation parameter (Table 3), the fat content increased along with the younger the fruit maturity level, which means that the average value of fat content at the K1 maturity level was higher than the K5 maturity level. The fat content in avocados depends on several factors, such as cultivar [30, 31, 32], agro-ecological growing conditions [3, 33] and fruit development stage [28, 34, 25].

The content of free fatty acids (FFA) as oleic acid decreased along with the lower level of maturity of the avocado (Table 3). This means that the older the avocado maturity level, the higher the FFA contained. At the maturity level of K5 the average FFA value was 7.67% and at K1 it was 6.55%. This was supported by Osuna-Garcia et al [36] compared the fat characteristics of three Malaysian avocado cultivars (*Persea americana*) with fat from the Australian 'Hass' avocado variety as a general characteristic. The fat from both local cultivars and the 'Hass' cultivar was found to have oleic acid as the most dominant fatty acid. Researchers Dodd et al [33] even suggested oleic acid as a potential biochemical marker to distinguish the origin of imported 'Hass' avocados.

As mentioned earlier (Table 1), the average temperature value tended to increase along with the level of maturity of the avocado fruit which was getting younger. This was followed by chemical observation parameters on glucose, free acid and fat content. However, the parameters of starch content, sucrose, TSS and free fatty acids tended to increase along with the level of maturity of the avocado fruit which was getting older. The correlation value shows that several observational parameters have a close relationship with fairly high regression values such as glucose, starch, free acid and fat of 0.86, 0.80, 0.71 and 0.83 (Table 2).

3.2 Red-guava

The results of the measurement of the thermal image temperature of the red-guava fruit and the physical parameters of the fruit, namely fruit weight and fruit firmness, were as shown in Table 4. At the temperature of red-guava fruit the level of green maturity had a lower temperature than the maturity level of yellowish green and greenish yellow, namely 28.24, 28.45 and 28.73 °C, consecutively. The more ripe the red-guava fruit, the higher the temperature of the red-guava fruit (Table 4). The results were similar with the research of Yanty et al [37] stated that ripe fruit had a higher heat capacity than unripe fruit, resulting in an increase in the temperature of the fruit.

Table 4. Fruit temperature and physical parameters of red-guava*.

Maturity Level	T (°C)	Weight (grams)	Firmness (kg/cm^2)
Green	c 28.24 c	a 258.30 a	a 20.54 a
Yellowish green	b 28.45 b	a 262.20 a	b 13.24 b
Greenish Yellow	a 28.73 a	a 260.00 a	c 7.47 c
R^2		0.150	0.985

*Values followed by the same notations in the same column were not significantly different according to LSD 5% on the left of the number and 15% LSD on the right of the number.

The thermal image temperature variable was influenced by the fruit maturity levels (Table 4). The level of maturity and thermal image did not correlate to fruit weight, but correlated to the firmness level of the red-guava fruit. The higher the maturity level, the higher the temperature, and the lower the firmness level of the red-guava fruit. Researchers Sumriddetchkajorn and Yuttana [38] stated that during the ripening process, several biochemical changes occured, including fruit ripening, changing the composition of the cell wall and lowering cell turgor pressure, and then followed by fruit softening process. Although the fruit weight was not statistically significant, however, the application of sensoring fruit temperature may follow changes in the level of fruit maturity. The relationship between the temperature emitted by the fruit and the firmness of the fruit showed a very strong correlation ($R^2 = 0.985$). An increase in the fruit maturity levels was followed by a decrease in firmness and an increase in fruit temperature. Meanwhile, the correlation between fruit temperature and fruit weight was very weak ($R^2 = 0.150$).

On the Table 5, the maturity level and thermal image had a correlation with chemical parameters, namely °Brix, free acid, sucrose, and starch contents. The °Brix content of red-guava at the level of green maturity had a value of 7.20%, yellowish green of 7.40% and greenish yellow of 8.00%. The higher the level of maturity, the higher the temperature, and the °Brix would increase. Ripe fruit was then sweeter than unripe fruit. The increase in TSS (°Brix) value of guava might be explained to be due to oxidation of organic acids and enzymatic hydrolysis of starch during fruit metabolism into simple sugars [39].

Table 5. Fruit temperature and chemical parameters of red-guava*.

Maturity Level	T (°C)	°Brix (%)	Free Acid (%)	Sucrose (%)	Starch (%)
Green	c 28.24 c	c 7.20 c	4.50	0.76	1.14
Yellowish green	b 28.45 b	b 7.40 b	3.07	0.89	1.10
Greenish Yellow	a 28.73 a	a 8.00 a	2.11	0.99	0.98
R^2		0.948	0.974	0.985	0.918

*Values followed by the same notations in the same column were not significantly different according to LSD 5% on the left of the number and 15% LSD on the right of the number.

The free acid content of red-guava fruit at the green maturity level initially had a value of 4.50% and decreases at the level of yellowish green by 3.07% and greenish yellow by 2.11% (Table 5). The higher the level of maturity, the higher the temperature, the free acid content would decrease. When the red-guava was ripe, the acidity of the fruit decreased. It was supported by the study Rana et al [40] stated that at the beginning of maturity the acidity level was still high, and as the fruit ripe the acidity of the fruit decreased over time due to the degradation of organic acids.

If the red-guava fruit was getting ripe, the temperature would increase and the sucrose content would be high (Table 5). That means if the red-guava fruit was getting ripe, it would taste sweeter. This was in line with research Tovar et al [41] that during fruit ripening the value of sucrose increases while glucose and fructose decreases during ripening of guava fruit.

The starch content of red-guava fruit at the green maturity level had a value of 1.14%, yellowish green of 1.10 and greenish yellow of 0.98 (Table 4). This implies that the carbohydrate content of fruit decreases with ripeness, or that ripe fruit has less starch than immature fruit. The result was similar with the research of Soares et al [42] stated that initially the starch content increased and then decreased due to the ripening process of guava fruit.

4 Conclusion

There is a unique pattern of fruit temperature changes in climacteric and non-climacteric fruits. The results showed that mature fruit of avocados had a lower temperature than immature fruit, but when fruit was getting ripe, the mature fruit had a higher temperature than immature fruit. There was a close correlation between thermal image and physical and chemical parameters of the avocados. Meanwhile, the level of fruit maturities of red-guava correlated with fruit temperature, the higher the ripeness of the fruit, the higher the temperature of the fruit. Thus, it can be concluded that the thermal image method has the opportunity to be used as a method for detecting the level of maturities of both fruits without damaging, real time, fast and cheap. More fruit varieties, both climatic and non-climatic, with varying properties like respiration rate and fruit morphology, among others, should be tested with this technique.

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