Measurement of Fruit Thermal Radiation to Identify Optimal Harvestable Maturity of Avocado (*Persea americana* Mill.)

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Abstract. Avocado belongs to the climacteric fruit group and is perishable in nature after harvest. The stage at which the fruits should be harvested is very important in determining the market life, storage, transport, eating and processing quality. Harvesting avocado at the right stage of maturity can also reduce the amount of losses during post-harvest handling. This study uses the radiation temperature of the fruit body to identify the level of maturities of avocados. Avocado fruit at 5 levels of maturity, from immature to mature fruit, with 5 replicates for each level of maturity was used for the experiment. Thermal image parameters were measured and then correlated to the physical quality parameters of the fruit, including: diameter, weight, and fruit hardness as well as the chemical quality of the fruit, including: fat content, starch, free acid, glucose, sucrose and total dissolved solids were measured. Furthermore, the data were statistically analyzed using Completely Randomized Design (CRD) and the Least Significant Difference (BNT) test. The results showed that mature fruit had a lower temperature than immature fruit, but when fruit was getting ripe, the mature fruit had a higher temperature than immature fruit. The results of statistical analysis state that there is a close correlation between thermal image parameters and the physical and chemical parameters. The coefficient of determination was found to be 0.79, 0.71, 0.86, 0.59, 0.80, 0.71, 0.83, 0.20 and 0,38 for diameter, weight, glucose, sucrose, starch, free acid, fat, total soluble solids and free fatty acid of the avocado fruits, respectively. The relationship of thermal radiation and glucose, sucrose, starch, fat, total soluble solids and free fatty acid followed the polynomial equations while diameter, weight and free acid followed a linear relationship at different maturity stages. Thus, it can be stated that the fruit body temperature radiation represented by the thermal image of the fruit has the opportunity to be used as a method of detecting the level of maturity in avocados.

Keywords: radiation temperature, stage of maturity, thermal image processing technique

1. Introduction

Avocado is one of the fruits that is widely consumed by the community because of its protein and fat content that is beneficial for the body. Besides citrus fruits, mangoes and bananas, avocados are also one of the fruits that are widely traded and become research material. Based on CBS data from 2016 to 2020, avocado production increases every year. In 2016 production reached 304, 938 tons until 2020 reached 609, 049 tons [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 [5]. Visually it is very difficult to determine the exact stage of ripeness of 'Hass' avocado at harvest because this fruit does not show any change in appearance [9]. Harvesting based on criteria for physical changes will result in yields consisting of several levels of physiological maturity, in this case fruit with the same criteria may have different levels of physiological maturity [16].

Thermal image (TI) is a non-invasive, non-contact and non-destructive technology used to determine the thermal properties and features of various objects. Potential uses of thermal in agriculture include nursery and greenhouse monitoring, irrigation scheduling, detection of plant diseases, estimation of fruit yield, evaluation of fruit maturity and detection of damage (bruising) on fruits and vegetables [7]. Thermal image can be a method of determining the level of ripeness of avocados through temperature distribution in the fruit. This tool is able to detect the level of fruit maturity through the heat released by the fruit, so that it is known between ripe fruit and ripe fruit.

This study aims to analyze various levels of avocado fruit maturity using the thermal image method and obtain a thermal image correlation with the physical and chemical qualities of avocados. This rationale is the background for the author to conduct research to determine the harvest time of avocados based on temperature radiation from several levels of maturity.

2. Materials and Method

This research was conducted in June 2021 at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung. The research material used was avocado from 5 different maturity levels based on age-youngness (K1-K5). The tools used are a thermal camera (FLIR E5-XT with an accuracy of ± 2 C, 160 X 120 pixels resolution, thermal sensitivity < 0.10 C, image capture box (chamber), digital scale, automatic caliper, penetrometer, and 'Atago'. ' hand refractometer.

For each fruit sample using five replications, the main treatment fruit samples were taken using 25 IT data, 15 were sent to the Quality Processing Laboratory, Lampung State Polytechnic for chemical quality analysis (3 replications each) and 25 fruit samples were stored at room temperature, so that a total of 65 fruits were used.

The study was carried out when the fruit had been acclimatized indoors for >24 hours to be analyzed by thermal radiation with thermal image and other avocado samples were stored for ripening at room temperature (26-28 oC). Samples that have been analyzed using TI were measured for fruit diameter, fruit weight, fruit hardness and Total Dissolved Solids called the main sample, while for ripe samples an analysis of fruit hardness was carried out when ripe. In addition, TI testing was also carried out on the condition of ripe fruit (D3) and ripe fruit (D5). The results of this cooking treatment will be reinforcing data from the main treatment results.

Taking thermal images three times with an interval of 1 minute for each image capture. Measurements are made by placing a fruit sample in the center of the box, then the tool will capture the temperature radiation emitted by the fruit and a display will appear on the monitor, then the image can be captured and saved in txt and jpg formats. The thermal results are processed using the matlab program. The main procedure starts with pre-processing, segmentation and feature extraction. The results of the TI analysis in the form of the average amount emitted by the fruit were then correlated with the physical and chemical parameters of the fruit with a regression value (R2) and analyzed using analysis of variance, then further tests were carried out using the Least Significant Difference (LSD) test at the level of 5% and 15%.

This observation was carried out with 10 observation parameters including thermal image, physical quality analysis (fruit hardness, diameter and weight), and chemical quality analysis (fat content, starch, glucose, sucrose, free acid, free fatty acid, and total soluble solids).

1. Thermal Images. Thermal Image is taken using a temperature detector, namely a thermal camera (FLIR E5-XT) in the form of photos, but this tool works using infrared waves that are able to capture radiation emitted by the heat of an object. The measurement of the main sample is coded D1 and the treatment at the temperature in the ripe state is coded D3 and in the mature state using the code D5.

2. Physical Quality Analysis

2.1 Fruit Firmness. Fruit Firmness was measured using a penetrometer (type FHM-5 model KM-I, cylindrical tip 5 mm in diameter; Takemura Electric Work, Ltd., Japan) with units of kg/cm2. This measurement is done by inserting a penetration device into the fruit equator before and after the fruit is ripe.

2.2 Fruit weight. Fruit weight was measured using a digital scale in grams. This measurement is carried out before the destructive physical quality test is carried out.

2.3 Fruit diameter. Avocado diameter measurements were carried out using an automatic caliper. Diameter data were taken on average from transverse and longitudinal measurements.

3. Chemical Quality Analysis

3.1 Total Soluble Solids (TSS). Measurement of total soluble solids was measured using a hand refractometer 'Atago' N-3E Brix (%), by dripping fruit juice using filter paper on the refractometer and pointing the instrument towards the light. source. This measurement was carried out before and after the fruit was ripe.

3.2 Free Acid. Measurement of free acid levels by titration method using 0.1 N NaOH indicator and Ptaline Phenol (PP).

3.3 Fat Content. This analysis was carried out using a Soxhlet apparatus as a fat solvent extractant

3.4 Determination of glucose. The method used in testing the reducing sugar content is the Luff Schoorl method.

3.5 Determination of Sucrose. The method used in testing the reducing sugar content is the Luff Schoorl method.

3.6 Starch. This analysis uses (Direct Acid Hydrolysis Method; AOAC, 1970).

3.7 Free fatty acids (FFA). The analysis was carried out using the titration method, using sodium hydroxide and pp indicator. Percentage of free fatty acids is expressed as oleic.

3. Results and Discussion

3.1 Thermal image

It is important to determine the level of maturity before harvesting to avoid improper fruit harvesting, causing losses to avocado cultivators. 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. Fruits that have been acclimatized for more than 24 hours are analyzed using a FLIR camera so that the final result is the average amount of temperature radiation emitted by the fruit. Figure 1 shows the temperature emitted by avocados at various levels of ripeness and storage time. Sample D1 is the main sample that is not stored, while samples D3 and D5 are samples of fruit at storage temperatures when ripe and ripe (Figure 1).

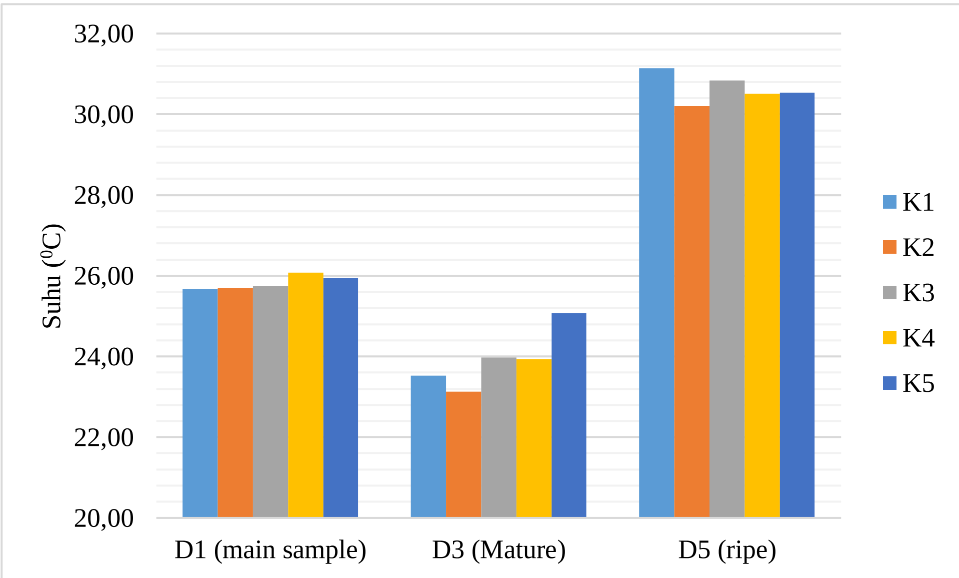

Figure 1. Average value of avocado fruit temperature

Based on Figure 1, in samples D1 and D3 the average temperature value tends to increase along with the lower level of maturity, while in sample D5 where the condition of the fruit is ripe, the average temperature value tends to decrease along with the lower level of fruit maturity, This means that the more fruit ripens, 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 [18]. Judging from the temperature, it shows that the temperature radiation is not able to distinguish the level of ripeness through the emitted temperature, but it seems 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 [17,8]. In the study of [8] that, ethylene production in the control treatment began to increase after 7 days of storage at 13 oC and the maximum production value reached 40.6 mg/kg/hour after 16 days at 13 oC.

3.2 Physical Observation

Table 1. Value of fruit temperature and physical parameters of avocado

Maturity Levels	term (^{0}C)	Diameter (cm)	Weight (g)	Fruit Firmness (kg/cm^2)
K1	a 25.67 b	a 8.17 a	a 325.74 a	a 0.28 a
K2	a 25.69 ab	b 7.75 b	b 272.28 b	a 0.30 a
K3	a 25.75 ab	b 7.75 b	b 269.88 b	a 0.34 a
K4	a 26.08 a	c 7.30 c	c 229.46 c	a 0.36 a
K5	a 25.95 ab	c 7.24 d	c 218.06 c	a 0.40 a
Regresi (R^2)		0.79	0.71	-

Note: the 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

Based on Table 1, physical observation parameters in the form of diameter and fruit weight showed a significant effect at each level of maturity according to LSD 5% and 15%, and at temperature showed a significant effect on LSD 15%. The highest average value is in K1 and decreases with the younger maturity level, this is because the fruit is harvested before reaching the peak of maturity in K5 so that the fruit has not yet reached its highest weight. [15,20] 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.

On the parameters of fruit hardness, ripe fruit conditions, did not show a significant effect according to LSD 5% and 15%. This parameter has a higher average value along with the younger the level of fruit maturity. This means that the maturity level of K1 has a lower fruit hardness value than the maturity level of K5. This shows that the avocado fruit which has a low hardness value has 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. [19] found that at storage days 0, 4, 8 and 12, the hardness decreased from approx. 130.51 N to 54.62 N, 19.92 N and 7.37 N, respectively, when stored at 15 °C. C.

The average value of fruit temperature is in line with the value of avocado fruit hardness which tends to increase along with the level of maturity that is getting younger. It is different with the measurement parameters of diameter and fruit weight which increase along with the maturity level of the fruit getting older. The correlation value of the parameters above is quite high between temperature with diameter and fruit weight, namely 0.79 and 0.71.

3.3 Chemical Observation

Table 2. Value of fruit chemical parameters of avocado (%)

Maturity Levels	Glucose	Sucrose	Starch	Free Acid	FFA	Fat	TSS
K1	a 2.26 b	a 1.48 ab	a 4.91 a	a 1.40 a	a 7.67 a	a 2.52 a	a 9.33 ab
K2	a 2.37 ab	a 0.95 b	b 4.34 b	a 1.32 a	ab 7.45 ab	a 2.73 a	a 9.67 ab

K3	a 2.53 a	a 1.87 a	c 3.85 c	a 1.40 a	b 5.31 c	a 3.06 a	a 10.33 a
K4	a 2.35 ab	a 0.8 b	c 3.88 c	a 1.48 a	ab 5.93 bc	a 3.10 a	a 10.00 a
K5	a 2.52 a	a 1.41 ab	c 3.75 c	a 1.48 a	ab 6.55 abc	a 3.11 a	a 8.33 b
Regresi (R^2)	0.86	0.59	0.80	0.71	0,38	0.83	0.20

Note: the 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

The results of the chemical parameters did not show a significant effect except for the starch content according to the LSD 5% test, while according to the LSD 15% showed a significant effect except for two parameters, namely free acid and fat content.

Based on Table 2, the observations of chemical parameters on the content of sucrose and TSS have the highest average value at K3, followed by K1 and K5. At the maturity level of K1 the average value is 1.48% and 9.33% for sucrose and TSS, while glucose at the K1 maturity level is lower than K3 and K5, which is due to the fruit being in the climacteric phase where sugar is used to respiration process so that the value at K1 is lower than K3 and K5. While the K3 treatment showed the highest values of 1.87%, 2.53% and 10.33% this was due to the breakdown of starch into sugar for metabolism, but this sample was not stored so that the oxidation of sucrose was probably not too high, and at K5 the average value is 1.41% and 8.33% because the fruit is in the ripening phase to optimize the chemical content of the fruit and at the time of harvest it has not yet reached the peak of maturity. According to [11] when the process of breaking down polysaccharides into simple sugars has been completed, the respiration process to provide energy to be used in fruit metabolism continues to cause the sugar to continue to be oxidized.

The starch content tends to decrease along with the younger the level of maturity of the avocado. This means that the higher the level of ripeness of the avocado, the average value of the avocado content is also higher. The highest average content value in the K1 treatment was 4.91%, while the smallest average was in the K5 treatment of 3.75%. At maturity level K1 ripens faster this seems to be related to the dry matter content, the higher the dry matter, the faster the fruit ripens and the cooking time is shorter. Fruit harvested with dry matter content below the recommended minimum will ripen irregularly and not fully ripen. Likewise, fruits harvested with high dry matter experience rapid ripening and reduce shelf life [20]. Minimum dry matter requirements vary 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) [6,12,9].

Furthermore, the free acid variable tends to increase in the younger samples, which means that the average value of the highest free acid content in the K5 treatment is 1.48%, which is known that K1 is the highest level of maturity. This is because at the oldest maturity level, the fruit has gone through the optimization phase of chemical content such as sugar, fat, starch so that the free acid level in young fruit is high. In previous studies it was stated that the total acidity decreased with the onset of fruit ripening. 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. The titrated acidity decreases with the onset of ripening, but there is no general value for the maximum titrated acidity.

In the observation parameter, the fat content increased along with the younger the fruit maturity level, which means that the average value of fat content at the K5 maturity level was higher than the K1 maturity level. The fat content in avocados depends on several factors, such as cultivar [2,3,12], agro-ecological growing conditions [10,9,4] and fruit development stage [14,13,19].

The content of Free Fatty Acids using oleic acid decreased along with the lower level of ripeness of the avocado. This means that the older the avocado maturity level, the higher the FFA contained. At the maturity level of K1 the average FFA value is 7.67% and at K5 it is 6.55%, this is supported by [22] 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 variety was found to have oleic acid as the most dominant fatty acid. [4] suggested oleic acid as a potential biochemical marker to distinguish the origin of imported 'Hass' avocados.

As previously mentioned, the average temperature value tends to increase along with the level of maturity of the avocado fruit which is getting younger, this is followed by chemical observation parameters on glucose, free acid and fat content. In contrast to the parameters of starch content, sucrose, TSS and free fatty acids which tend to increase along with the level of maturity of the avocado fruit which is getting older. The correlation value shows that several observational parameters have a close relationship with a fairly high regression value such as glucose, starch, free acids and fats of 0.86; 0.80; 0.71 and 0.83.

Conclusion

Thermal images cannot detect different levels of ripeness of avocados, but are able to distinguish levels of ripeness through temperature radiation emitted by the fruit, the radiation increases as the fruit ripens. The thermal radiation relationship showed a close relationship with the parameters of sucrose, weight, free acid, diameter, starch, fat and glucose, but a low correlation between temperature radiation and the parameters of total dissolved solids, and free fatty acids.

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