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KRITERIA PANEN FISIOLOGIS DAN PENANGANAN PASCAPANEN UNTUK MENCEGAH INSIDEN PEMASAKAN DINI DALAM EKSPORT BUAH PISANG ‘CAVENDISH’

(TAHUN 1 DARI 3 TAHUN)

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KRITERIA PANEN FISIOLOGIS DAN PENANGANAN PASCAPANEN UNTUK MENCEGAH INSIDEN PEMASAKAN DINI DALAM EKSPORT BUAH PISANG 'CAVENDISH'

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BAB I. RINGKASAN

Berdasarkan data di lapangan, insiden buah pisang Cavendish masak di perjalanan saat eksport (pemasakan dini, *early ripening*) sering terjadi, dan menimbulkan kerugian eksport yang tidak sedikit. Hal ini terjadi karena kriteria panen dilakukan secara fisik, pada hal buah dengan kriteria fisik yang sama bisa memiliki tingkat kematangan fisiologis yang berbeda. Untuk mengatasi insiden pemasakan dini ini dapat ditempuh dengan dua pendekatan, yaitu (1) mengubah kriteria panen berdasarkan pada kriteria fisik buah ke kriteria fisiologis, dan (2) menggunakan teknologi pascapanen untuk memperpanjang masa simpan-hijau (*green life*). Penelitian ini diajukan selama 3 tahun, dengan tujuan pada tahun I adalah (1) menguji metode *thermal image* sebagai pendeteksi tingkat kematangan buah (*fruit maturities*) pisang 'Cavendish; (2) memperoleh korelasi hasil *thermal image* dari berbagai tingkat kematangan buah terhadap mutu fisik dan kimia pisang 'Cavendish'. Penelitian ini dilaksanakan pada tanggal 11 Juni sampai 01 Juli 2021, di Laboratorium Hortikultura dan Pascapanen, Jurusan Agronomi dan Hortikultura, Fakultas Pertanian, Universitas Lampung. Penelitian ini dilakukan dengan mendatangkan 10 tandan buah pisang Cavendish (stadium I; sebagai panen segar dengan kematangan standar) dari PT Great Giant Foods di Terbanggi Besar, Lampung Tengah. Dari 10 tandan tersebut, dipilih 5 tandan pisang dengan ukuran yang relatif seragam. Pisang kemudian dipisahkan dari tandan dan diberi kode sampel sesuai urutan sisir dari atas tandan, misalnya C1U1 (sisir pertama, ulangan ke-1) sampai C8U5 (sisir ke-8, ulangan ke-5). Kemudian dari masing-masing sisir diambil 4 *finger* buah pisang yang digunakan untuk analisis SEM (*Scanning Electron Microscope), thermal image*, kualitas kimia (ºBrix, asam bebas, glukosa, sukrosa, pati), dan kualitas fisik (bobot buah, diameter, dan kekerasan buah). Sampel-sampel yang telah dianalisis dengan *thermal image* ini kemudian disimpan di ruang simpan dengan dua suhu berbeda, yaitu suhu ruang (27-28 ºC) dan suhu dingin (14-16 ºC), dan diamati perubahan warna kulitnya setiap hari hingga 21 hari, sebagai batas minimal durasi *green-life*. Hasil penelitian menunjukkan bahwa (1) *thermal image* dapat membedakan tingkat kematangan baik tingkat kematangan antar-sisir pada tandan pisang 'Cavendish' maupun pisang pada fase masak (*ripe*) dan belum masak (*unripe*); (2) Hasil citra termal memiliki korelasi yang erat dengan kualitas fisik (berat, diameter, kekerasan buah) dan kimia (glukosa, sukrosa, pati), tetapi tidak memiliki korelasi dengan kondisi permukaan buah (SEM), ºBrix dan kandungan asam bebas berdasarkan koefisien korelasi (R^2); (3) Sisir pada bagian atas tandan memiliki suhu yang lebih tinggi, yaitu 28,91℃ dibandingkan dengan tangan di bawah, yaitu 28,71℃. Pisang 'Cavendish' pada hari ke-7 (*ripe*) memiliki suhu yang lebih tinggi, yaitu 29,17 ℃ dibandingkan dengan pisang pada hari 1 (*unripe*) yaitu 28,92 ℃. Penelitian tahun I ini telah melahirkan 5 artikel dari 5 mahasiswa (3 mahasiswa S2 dan 2 mahasiswa S1) yang telah dipresentasikan di 2 Seminar Internasional (ICoSITER 2021 dan ISODOTF 2021; 4 artikel) dan Seminar Nasional PERHORTI (1 artikel). Ke-4 artikel Internasional tersebut direncanakan dalam waktu dekat akan diterbitkan di jurnal Internasional bereputasi.

Kata kunci: panen, pascapanen, pemasakan-dini, pisang Cavendish, thermal image

BAB II. PENDAHULUAN

2.1 Latar Belakang dan Masalah

Pisang ‘Cavendish’ sebagai buah pisang utama yang diperdagangkan secara Internasional telah lama diproduksi oleh PT Great Giant Foods (PT GGF) di Terbanggi Besar, Lampung Tengah. Sebagai buah klimakterik, buah pisang mengalami masalah pascapanen, yaitu masa simpan yang pendek. Untuk konsumsi eksport, buah pisang ‘Cavendish’ mendapat perlakuan pascapanen pembersihan, sortasi/grading, perendaman, pemvakuman, dan pengemasan dalam kotak karton sebelum dikirim di dalam *container* berpendingin.

Sebagai buah klimakterik, buah pisang dipanen berdasarkan sifat fisik, yaitu berdasarkan pada diameter buah *finger* pisang di sisir ke dua bagian tengah yang diukur dengan alat *skimming* mencapai minimal 38, berumur 8-11 minggu setelah *bagging*, dengan tingkat kematangan mencapai 75-85% matang [1 dan 2]. Tingkat kematangan ini diduga berada pada fase sebelum buah mencapai kematangan fisiologis (*physiological maturity*), sehingga buah tidak akan masak secara alamiah. Oleh karena itu, selama pengiriman untuk eksport di dalam *container* berpendingin buah pisang ‘Cavendish’ diharapkan tidak masak, dan hanya akan masak jika dipacu dengan etilen setelah buah sampai pada tempat yang dituju.

Berdasarkan data di lapangan (R. A. Wardhana, PT GGF; komunikasi pribadi) insiden buah pisang Cavendish masak di perjalanan saat eksport (pemasakan dini, *early ripening*) sering terjadi dengan volume yang bervariasi. Peneliti lain [3] menyebutnya sebagai “*mixed ripe*”, yaitu istilah yang diberikan untuk buah yang dikirim ke pasar dalam kondisi hijau tetapi beberapa di antaranya telah mulai masak (*ripe*) pada saat tiba di pasar. Kondisi ini menyulitkan dalam pemasakan-buatan dan pemasaran serta merugikan petani atau eksporter. Jika ini terjadi maka buah pisang akan di-*reject* sehingga menimbulkan kerugian materiil dan non-materiil eksport yang tidak sedikit. Hal ini terjadi karena kriteria panen dilakukan secara fisik, sebagaimana tersebut di atas, di mana buah dengan kriteria fisik yang sama memungkinkan memiliki tingkat kematangan fisiologis yang berbeda [3]. Buah klimakterik yang telah mencapai kematangan fisiologis [buah mencapai matang sempurna (*full mature*)] akan masak sempurna secara alamiah. Kejadian ini tidak diinginkan di eksport pisang Cavendish.

Untuk mengatasi insiden pemasakan dini (*early ripening*) yang menyebabkan kondisi *mixed ripe* pada eksport buah pisang Cavendish dapat ditempuh dengan dua pendekatan, yaitu (1) dengan mengubah kriteria panen berdasarkan pada kriteria fisik buah ke kriteria fisiologis, dan hal ini belum pernah dilakukan, dan (2) menggunakan teknologi pascapanen untuk memperpanjang masa simpan-hijau (*green life*). Pendekatan pertama karena terkait dengan kriteria panen, maka mutlak harus *non-destructive* dan mudah, sedangkan dengan pendekatan ke dua, seorang peneliti [4] mensyaratkan bahwa buah pisang eksport harus memiliki durasi *green life* tidak boleh kurang dari 20 hari.

2.2 Tujuan Penelitian Tahun I

Penelitian ini diajukan selama 3 tahun, dengan tujuan pada tahun I adalah untuk mempelajari pencitraan suhu (*temperature image*) berbagai tingkat kematangan fisiologis, yang darinya akan lahir kriteria kematangan fisiologis sebagai kriteria panen alternatif pengganti kriteria fisik buah yang rawan insiden *early ripening* atau *mixed ripe*.

BAB III. TINJAUAN PISTAKA

3.1 Panen dan Pascapanen Pisang 'Cavendish'

Pisang dipanen mentah dan dipacu pemasakannya secara buatan. Pisang 'Dwarf Cavendish' siap panen dalam waktu 11-14 bulan setelah penanaman, sementara kultivar 'Tall Cavendish' membutuhkan waktu sekitar 14-16 bulan untuk panen. Tandan buah biasanya memerlukan 90-120 hari hingga matang setelah munculnya bunga, bergantung pada iklim dan teknik budidaya. Kematangan pisang ditandai dengan pengeringan daun bagian atas, perubahan warna kulit buah dari hijau gelap menjadi hijau muda dan kecenderungan ujung bunga buah bisa jatuh dengan sedikit sentuhan oleh tangan. Buah yang matang menjadi montok dan semua sudut terisi sepenuhnya. Saat diketuk buahnya mengeluarkan suara logam. Metode panen tergantung pada ketinggian tanaman. Varietas yang tumbuh rendah dipanen oleh memotong batang tandan sekitar 30-35 cm di atas tangan atas. Dengan varietas yang lebih tinggi, batang sebagian tanaman akan ditebang untuk membawa tandan ke bawah dalam jangkauan pemanen.

Pada perkebunan besar agroindustri pisang, khususnya pisang 'Cavendish', penentuan saat panen didasarkan pada dua metode, yaitu dengan alat *skimming* dan umur buah. Ukuran alat *skimming* disesuaikan dengan kebutuhan konsumen, dan digunakan dengan mengukurkannya pada buah *finger* pisang di sisir kedua bagian tengah. Buah pisang siap panen jika ukuran *skimming*-nya mencapai minimal angka 38. Jika menggunakan umur buah, maka pisang siap dipanen jika umur tandan buahnya sudah mencapai 8-11 minggu setelah pembungkusan (*bagging*). Namun pada musim hujan biasanya umur panennya 1-2 minggu lebih cepat dibandingkan panen pada musim kemarau. Pada saat itu, tingkat kematangan buah mencapai 75-85%.

Kriteria panen yang dilakukan berdasarkan pada kriteria fisik, sebagaimana tersebut di atas, menimbulkan resiko hasil panen yang terdiri atas beberapa tingkat kematangan fisiologis, pada hal buah dengan kriteria fisik yang sama memungkinkan memiliki tingkat kematangan fisiologis yang berbeda [3]. Kondisi tersebut akan memunculkan insiden buah pisang Cavendish masak di perjalanan saat eksport (pemasakan dini, *early ripening*) atau "*mixed ripe*", yaitu istilah yang diberikan untuk buah yang dikirim ke pasar dalam kondisi hijau tetapi beberapa di antaranya telah mulai matang pada saat tiba di pasar [3]. Kondisi ini menyulitkan dalam pemasakan-buatan dan pemasaran dan merugikan petani.

Usaha-usaha untuk mengatasi hal tersebut sudah banyak dilakukan, utamanya adalah dengan pendekatan *color image processing* didasarkan pada warna kulit buah [5, 6, 7, 8, 9]. Mereka menggunakan *color image* untuk menduga tingkat kematangan yang sangat dipengaruhi perkembangan warna kulit. Pada hal warna kulit akan sangat dipengaruhi oleh *bagging* yang sudah umum diterapkan di agroindustri pisang Cavendish [10]. Oleh karena itu, penelitian ini akan menggunakan mendekatan pengukuran suhu buah. Hal ini dilakukan karena dengan berlangsungnya respirasi maka panas akan dilepaskan ke lingkungan dan ini akan ditangkap dengan alat yang kami rancang, sehingga kondisi fisiologis buah akan terpantau setiap waktu.

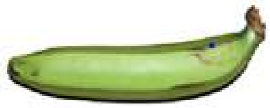
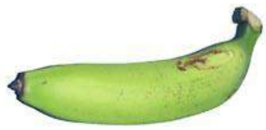
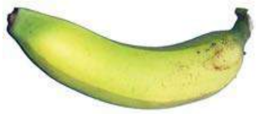
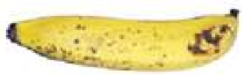
3.2 Mutu Buah Pisang 'Cavendish'

Tahap kematangan buah pisang segar adalah sebuah faktor penting yang mempengaruhi mutu buah selama pemasakan (*ripening*) dan mutu buah saat pemasaran. Kemampuan mengidentifikasi kematangan buah pisang segar akan menjadi dukungan besar bagi petani untuk melakukan panen pada fase yang optimal, sehingga akan menghindari buah pisang yang dipanen tidak sesuai dengan stadium yang diinginkan [9].

Pada proses budidaya pisang 'Cavendish' biasanya dilakukan pembungkusan (*bagging*). Kantong pelindung buah dengan berbagai warna, berlubang dan tidak berlubang, telah digunakan secara luas di wilayah tropis dan negara-negara penghasil pisang subtropis untuk meningkatkan hasil dan mutu [11]. Penentuan panen pada buah pisang didasarkan pada dua kandungan terpenting dalam buah pisang, yaitu pati dan gula [2]. Hal ini mengindikasikan bahwa dua kandungan ini berpengaruh terhadap mutu buah. Pisang memiliki dua mutu, yaitu mutu fisik (warna, bobot buah, durasi *green life*, dan kondisi permukaan kulit buah), dan mutu kimia (pati, gula, asam, dan *vlolatie*).

Buah pisang 'Cavendish' yang telah masak sangat mudah dikenali melalui perubahan warna kulitnya. Oleh karena itu, indeks warna kulit menjadi penting, dan digunakan sebagai penanda tingkat kemasakan buah pisang secara fisik. Tabel 1 berikut menyajikan deskripsi kemasakan buah pisang berdasarkan warna kulitnya [12].

Tabel 1. Deskripsi kemasakan buah pisang berdasarkan warna kulit

Indeks Warna	Keadaan buah	Pati (%)	Gula (%)	Deskripsi
1		20	0.5	Seluruh permukaan buah berwarna hijau, buah masih keras
2		18	2.5	Permukaan buah berwarna hijau dengan sedikit warna kuning
3		16	4.5	Warna hijau lebih dominan daripada warna kuning
4		13	7.5	Kulit buah dengan warna kuning lebih banyak daripada warna hijau
5		7	13.5	Seluruh permukaan kulit berwarna kuning, bagian ujung masih hijau
6		2.5	18	Seluruh jari buah pisang berwarna kuning, matang penuh
7		1.5	19	Buah pisang berwarna kuning dengan sedikit bintik kecoklatan, matang penuh dengan aroma yang kuat
8		1	19	Buah pisang berwarna kuning dengan banyak bercak coklat, terlalu matang, daging buah lunak, aroma sangatb kuat.

3.4 *Thermal Image* dan Kegunaannya di Bidang Pertanian

Thermal Image merupakan salah satu teknologi inframerah yang digunakan untuk mendeteksi distribusi termal yang ada pada suatu objek. Sebagian besar buah akan mengalami perubahan selama proses pematangan dan pemasakan. Perubahan ini sangat erat kaitannya dengan komposisi kimiawi yang terkandung di dalam buah [9]. *Thermal image* merupakan salah satu alternatif yang baik untuk analisis kimiawi dari banyak produk dalam kendali mutu [8].

Sampai saat ini penentuan panen pada buah pisang ditentukan berdasarkan kriteria fisik, padahal buah dengan diameter yang sama memungkinkan untuk memiliki tingkat kematangan fisiologis yang berbeda. Selain itu, buah pisang yang dipanen berdasarkan kriteria fisik memiliki peluang untuk terjadinya pemasakan dini (*early ripening* atau *mixed ripe*). Selama proses pematangan buah akan melakukan respirasi sehingga menghasilkan panas. Suhu panas yang dihasilkan akan terekam oleh alat *thermal image* dan diinterpretasikan dalam bentuk citra warna. Citra analog ini harus diubah ke dalam citra digital [13]. Buah pisang merupakan citra analog yang harus diubah ke dalam citra digital dengan menggunakan alat *thermal image camera* untuk proses pengolahan citra sehingga kondisi fisiologis pada buah akan terpantau.

Termal image (TI) merupakan teknologi yang non-invasif, non-kontak, dan non-destruktif yang digunakan untuk menentukan sifat dan fitur termal dari berbagai objek. Potensi pemanfaatan penginderaan jauh termal di bidang pertanian meliputi pembibitan dan pemantauan rumah kaca, penjadwalan irigasi, deteksi penyakit tanaman, pendugaan hasil buah, evaluasi kematangan buah dan deteksi kerusakan (memar) pada buah dan sayuran [14]. Peneliti lainnya [15] menyatakan bahwa *thermal image* dapat digunakan untuk menunjukkan perbedaan dari buah yang belum matang, matang, dan *overripe*. Hal ini didasari bahwa buah yang masak memiliki kapasitas panas yang lebih tinggi.

BAB IV. METODE PENELITIAN TAHUN I

4.1 Waktu dan Tempat Penelitian

Penelitian ini dilaksanakan di Laboratorium Hortikultura dan Pascapanen, Jurusan Agronomi dan Hortikultura, Fakultas Pertanian, Universitas Lampung. Penelitian ini dilaksanakan pada tanggal 11 Juni sampai 01 Juli 2021.

4.2 Bahan dan Alat Penelitian

Bahan utama penelitian ini terdiri atas tandan buah pisang ‘Cavendish’ pada stadium I (hijau) dengan berbagai tingkat kematangan (*maturity*) yang memiliki ukuran diameter *finger* yang berbeda (Gambar 1). Sampel pisang diperoleh dari PT Great Giant Foods (GGF) di Terbanggi Besar, Lampung Tengah. Bahan penelitian lainnya adalah aquades, 0,1 N NaOH, fenolftalein, glukosa, fruktosa, pati, asam sitrat, soda murni ($Na_2CO_3.10H_2O$). Alat yang digunakan pada penelitian ini adalah *thermal image* camera (Flir E5-XT), kotak pengambilan citra (*chamber*), timbangan, penetrometer, refraktrometer-tangan ‘Atago’, biuret, gelas ukur, sentrifus, erlenmeyer, *plastic vacuum*, labu ukur, gelas piala, pipet gondok, pipet tetes, tabung sampel, blender, pisau, talenan, saringan, piring *styrofoam*, tisu, ember, spidol, kamera, dan biuret beserta peralatan gelas untuk analisis mutu kimia buah. Instrumen yang digunakan yaitu aplikasi Interface FLIR E5-XT, MATLAB V2017b, Image J, dan Statistix 10.

Gambar 1. Sisir buah pisang ‘Cavendish’

4.3 Metode Penelitian

Penelitian ini menggunakan Rancangan Acak Lengkap (RAL) dengan 8 perlakuan (sisir) yang diulang sebanyak 5 kali (tandan). Perlakuan yang digunakan yaitu perbedaan ukuran diameter *finger* sesuai dengan susunan sisir pada tandan, yaitu C1 (sisir 1), C2 (sisir 2), C3 (sisir 3), C4 (sisir 4), C5 (sisir 5), C6 (sisir 6), C7 (sisir 7), dan C8 (sisir 8) sehingga jumlah satuan percobaannya adalah 40 satuan percobaan (8 perlakuan x 5 ulangan). Sampel pisang pada stadium 1 disimpan pada suhu ruang (28°C).

Hasil *thermal image* (TI) dan *Scanning electron microscope* (SEM) akan diolah menggunakan aplikasi Image J & MATLAB. Hasil pengatamatan mutu fisik dan kimia akan olah menggunakan aplikasi Statistix 10 dan dicari korelasinya dengan hasil *thermal image* menggunakan nilai regresi ($R^{2)}$.

4.4 Pelaksanaan penelitian

Penelitian ini dilakukan dengan cara mendatangkan sampel tandan buah pisang dari PT Great Giant Food (GGF) di Terbanggi Besar, Lampung Tengah sebanyak 10 tandan. Dari 10 tandan pisang buah pisang 'Cavendish' ini kemudian dipilih 5 tandan pisang yang memiliki ukuran yang relatif seragam. Selanjutnya sisir pisang dipisahkan dari tandan pisang dan diberi kode sampel sesuai dengan urutan sisir misalnya, C1U1 (sisir ke-1 ulangan ke-1) hingga C8U5 (sisir ke-8 ulangan ke-5). Kemudian dari masing-masing sisir diambil 4 *finger* pisang yang akan digunakan untuk analisis SEM, mutu fisik (bobot, diameter, penetrometer), mutu kimia (Brix, asam bebas, glukosa, sukrosa, pati), dan *thermal image*. Analisis SEM dilakukan di UPT Laboratorium Terpadu dan Sentra Inovasi Teknologi (UPT LT-SIT), Universitas Lampung, sedangkan analisis kimia dilakukan di Laboratorium Teknologi Hasil Pertanian, Politeknik Negeri Lampung.

Pengambilan *thermal image* dilakukan pada kondisi suhu ruang pada 28℃, tidak ada kontak fisik dengan buah saat mengambil gambar untuk menghindari perpindahan panas lokal ke buah. Pengambilan gambar dilakukan secara berkala dua hari sekali hingga pisang mencapai fase masak (*ripe*).

4.5 Peubah Pengamatan

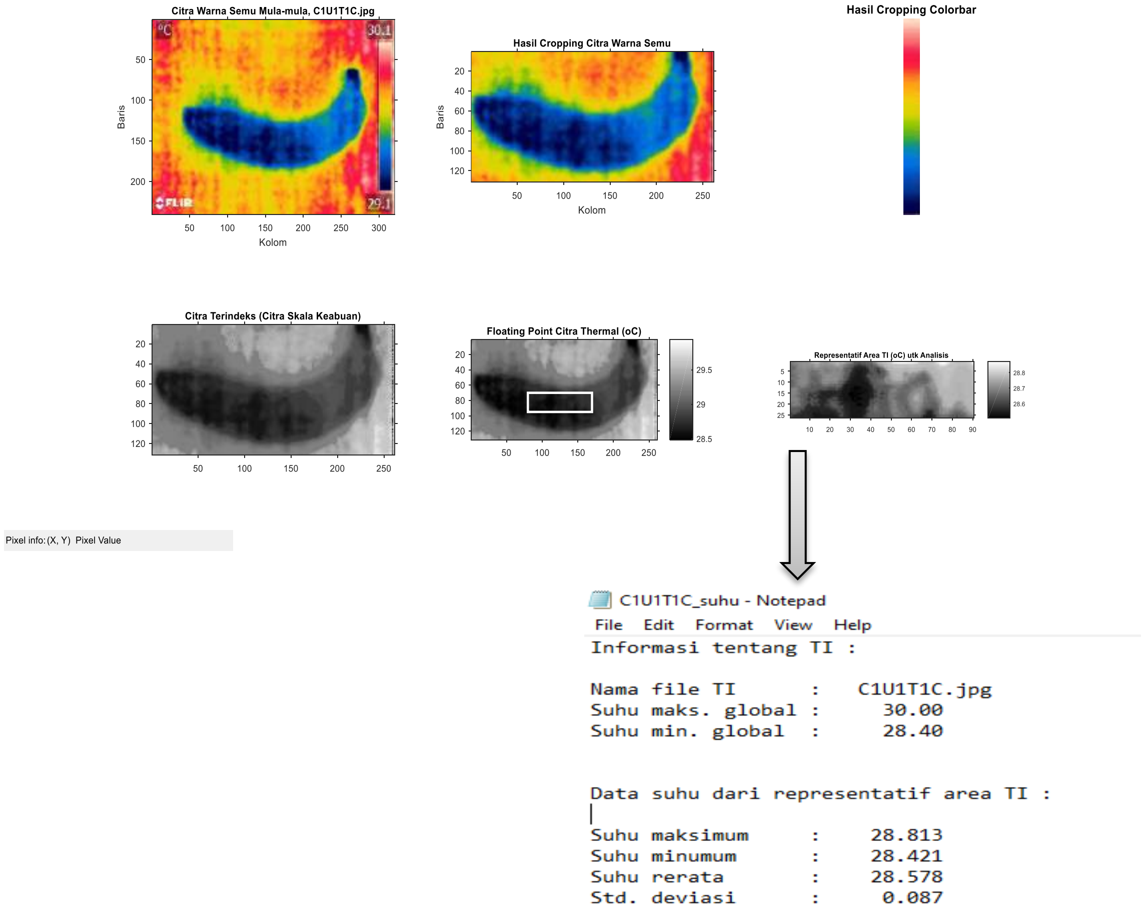
4.5.1 Thermal *Image*

Sampel buah pisang 'Cavendish' yang telah dipersiapkan kemudian diletakkan per unit sampel pada kotak pengambilan citra untuk diambil citra *thermal*nya. Citra *thermal* buah sampel dipotret menggunakan kamera inframerah FLIR E5-XT (Gambar 2) akurasi ± 2 ℃, resolusi 160 X 120 piksel, sensitifitas *thermal* $<$ 0,10 ℃ yang dipasang pada kotak pengambilan citra pada ketinggian 25 cm dari sampel. Untuk setiap sampel buah diambil citra *thermal* nya sebanyak tiga kali, dengan selang waktu pengambilan citra 2 menit. Langkah pertama adalah persiapan unit pengambil citra (*image acquisition*), pengecekan kelengkapan alat pada kotak pengambilan citra seperti kamera, dasar penempatan obyek, dan program kendali untuk mengambil (*capture*) citra yang sudah ter-*install* pada komputer laptop. Jarak antara dudukan obyek dengan muka lensa kamera diatur sejauh 25 cm. Selama pengambilan data citra, jarak tersebut harus diusahakan tetap sehingga besarnya proyeksi seluruh obyek sama.

Langkah kedua adalah pengambilan obyek citra *visible*. Obyek gambar diletakkan pada tempat pengambilan citra. Posisi obyek berada tepat di bawah lensa kamera dengan jarak antara kamera–obyek gambar sekitar 25 cm. Pengambilan gambar dikendalikan dan dilakukan melalui komputer. Apabila obyek gambar telah tampil pada layar monitor dengan posisi yang cukup representatif (di tengah-tengah bidang citra), setelah itu *setting* di monitor laptop pada bagian *distance* diubah dari 1.0 ke 0.4 kemudian pengambilan citra dapat dilakukan dengan menekan tombol pada menu pengambilan (*capture*) gambar. Gambar digital dari obyek yang sudah diambil tersebut disimpan dengan nama file kode data tertentu untuk memudahkan perunutan kembali saat dilakukan analisis. Adapun langkah dalam mengolah citra hasil *thermal image* adalah sebagai berikut.

- Nama file pada MATLAB harus diubah disesuaikan dengan nama kode sampel TI.
- Untuk menyederhanakan proses, file citra *thermal image* (TI) diletakkan dalam satu folder dengan *script* program MATLAB yang digunakan untuk pengolahan citra.
- Obyek proyeksi TI dibuat ditengah dan ada di dalam *frame cropping*. Jika hal ini tidak terpenuhi (cropping tidak pas) lakukan pengubahan titik koordinat cropping. Perintah ini dalam MATLAB ada di baris #40 (Gambar 4).
- ‘Kotak Putih’ berada di dalam obyek proyeksi TI. Jika sudah terpenuhi maka dapat dilanjutkan ke sampel berikutnya. Jika hal ini tidak terpenuhi (area sampel representatif TI tidak pas) lakukan pengubahan titik koordinat area sampel. Perintah ini dalam MATLAB ada di baris #40
- Setelah *thermal image* (TI) di *running* maka akan muncul hasil pengolahan seperti pada Gambar 3.

Gambar 2. *Thermal Imaging Camera* FLIR E5-XT



Gambar 3. Tampilan proses pengolahan *thermal image* menggunakan aplikasi MATLAB

```
clc;    close all;  clear;   workspace;
format long g; format compact; fontSize = 10;

%================================================================================
% Memasukkan informasi ttg file TI dan suhu maksimum-minimumnya yang akan
diolah.
baseFileName = 'C1U1T1C(2).jpg'; % Assign the one on the button that they
clicked on.
fp = fopen('C1U1T1C(2)._suhu.txt','w');           % Membuat file teks utk
penyimpanan data

% % Ubahlah nilai suhu maksimum dan suhu minimum sesuai skala bar pada TI
highTemp = 30.0;   lowTemp  = 28.4;

ext = '.jpg';  folder = pwd;
fullFileName = fullfile(folder, baseFileName);
noOfClusters = 1;
%================================================================================

% Membaca citra sampel.
originalRGBImage = imread(fullFileName);

% Menampilkan gambar.
figure(1); subplot(2, 3, 1);
imshow(originalRGBImage, []);
axis on;
caption = sprintf('Citra Warna Semu Mula-mula, %s', baseFileName);
title(caption, 'FontSize', fontSize, 'Interpreter', 'None');
xlabel('Kolom', 'FontSize', fontSize, 'Interpreter', 'None');
ylabel('Baris', 'FontSize', fontSize, 'Interpreter', 'None');
set(gca,'FontSize', 8);
drawnow;

grayImage = min(originalRGBImage, [], 3); % Digunakan utk menemukan bagian citra
dan color map dari sampel .

% Memotong bagian color bar.
xmin = 301;         ymin = 29;          %menentukan awal kolom (sb. x) dan awal
baris (sb. y)
lebar = 15;         tinggi = 182;       %nilai baris ini jangan diubah
colorBarImage = imcrop(originalRGBImage, [xmin, ymin, lebar, tinggi]);
b = colorBarImage(:,:,3);

% Memotong bagian citra RGB sampel.
xmin2 = 35;          ymin2 = 60;        %menentukan awal kolom (sb. x) dan awal
baris (sb. y)
lebar2 = 260;        tinggi2 = 130;     %nilai baris ini jangan diubah
rgbImage = imcrop(originalRGBImage, [xmin2, ymin2, lebar2, tinggi2]);
```

Gambar 4. *Script* MATLAB (V2017b) untuk pengolahan *thermal image*

4.5.2 Analisis Mutu Fisik

4.5.2.1 Bobot buah

Bobot *finger* buah pisang ‘Cavendish’ diukur pada saat buah berada di stadium 1 (hijau) menggunakan timbangan *digital* tipe *mini scale* dengan tingkat ketelitian 0.1 g.

4.5.2.2 Diameter Buah

Diameter buah pisang ‘Cavendish’ diukur menggunakan jangka sorong dengan tingkat ketelitian 0.1 mm. Pengukuran dilakukan pada pertengahan *finger* buah pisang yang cukup representatif untuk mengukur diameter buah.

4.5.2.3 Kekerasan buah

Kekerasan buah (dalam kg/cm^2) diukur dengan alat penetrometer (type FHM-5, ujung berbentuk silinder diameter 5 mm; Takemura Electric Work, Ltd., Jepang). Pengukuran kekerasan buah dilakukan pada tiga tempat tersebar acak di sekitar pertengahan atau sisi terlebar dari *finger* buah pisang ‘Cavendish’.

4.5.2.3 Kondisi permukaan kulit buah

Kondisi permukaan kulit buah diamati menggunakan SEM (*Scanning electron microscope*) di UPT Laboratorium Terpadu dan Sentra Inovasi Teknologi (UPT LT-SIT) Unila. Tahapan utama preparasi sampel sebelum diamati menggunakan SEM adalah pemotongan sampel dengan orientasi yang diinginkan, fiksasi, dehidrasi, pengeringan, serta melapisi dengan lapisan konduktif. Tahapan fiksasi dilakukan untuk menjaga struktur asli dari sampel agar tidak mudah kempis atau hancur. Fiksasi yang umumnya dilakukan memiliki dua tahap yaitu tahapan pertama menggunakan *glutaraldehyde* ditambah dengan *cacodylate buffer* kemudian tahapan kedua adalah menggunakan *osmium tetroxide* pada *buffer*. Dehidrasi bertujuan untuk menghilangkan kandungan air dari sampel. Dehidrasi dilakukan dengan proses perendaman dalam alkohol dengan tingkat konsentrasi yang bertambah secara bertahap hingga mencapai 100%. Pengeringan biasanya dilakukan menggunakan *critical point drying* (CPD) atau mengaplikasikan bahan kimia tertentu seperti *hexamethyldisilazane* yang bertujuan untuk menghilangkan kandungan cairan dari sampel tanpa membuat sampel menjadi kempis. Pelapisan dengan material konduktif dapat dilakukan menggunakan *sputtering machine* dengan material konduktif emas.

Tahapan preparasi yang dilakukan pada sampel ini adalah fiksasi menggunakan formalin, dehidrasi, dan paraffin *embedding*. Sampel yang telah ditanam dalam paraffin kemudian disayat menggunakan mikrotom dengan ketebalan akhir sampel adalah 3µm, kemudian sayatan diletakkan diatas *cover glass.* Selanjutnya dilakukan deparafinasi terhadap sayatan tersebut yaitu melakukan pencucian dengan *xylene* pada suhu 37 ℃ selama 4 x 30 menit. Setelah itu sampel dicuci menggunakan *ethanol* 100% pada suhu ruang selama 4 x 15 menit. Sampel kemudian dibiarkan semalam pada suhu ruang agar kering. Sebelum diamati dengan SEM, sampel direkatkan dengan *carbon tape* pada *sample stage* kemudian dilapisi dengan lapisan konduktif yaitu lapisan emas menggunakan ion *sputtering machine* yang dapat dilihat pada Gambar 5.

Gambar 5. Pengujian SEM

4.5.3 Analisis Mutu Kimia

4.5.3.1 Pengukuran kandungan °Brix

Kandungan °Brix diukur dengan menggunakan refraktometer tangan ‘Atago’. Nilai °Brix buah pisang diukur dengan cara menghancurkan buah pisang dengan cara diparut kemudian disaring menggunakan kertas saring untuk mengambil cairan dari buah pisang dan meneteskannya pada lensa refraktometer.

4.5.3.2 Pengukuran kandungan pati

Pengukuran kandungan pati menggunakan metode *Direct Acid Hydrolysis Method.* Adapun tahapan analisis yang dilakukan sebagai berikut:

- Bahan padat sebanyak 2 – 5 g yang telah dihaluskan dimasukkan kedalam gelas piala 250 ml, selanjutnya ditambahkan 50 ml aquades dan diaduk selama 1 Jam. Suspensi disaring dengan kertas saring dan dicuci dengan aquades sampai volume filtrate 250 ml. filtrate ini mengandung karbohidrat yang terlarut dan dibuang.
- Untuk bahan yang mengandung lemak, maka pati yang terdapat sebagai residu pada kertas saring dicuci 5 kali dengan 10 ml ether, dibiarkan ether menguap dari residu, kemudian dicuci lagi dengan 150 ml alcohol 10% untuk membebaskan lebih lanjut karbohidrat yang terlarut.
- Residu dipindahkan secara kuantitatif dari kertas saring ke dalam erlenmeyer dengan pencucian 200 ml aquades dan tambahkan 20 ml HCl 25% tutup dengan pendingin balik dan dipanaskan pada penangas air mendidih selama 2,5 jam.
- Setelah dingin dinetralkan dengan larutan NaOH 40% dan diencerkan hingga volume 500 ml kemudian disaring.
- Diambil 25 ml larutan dan dimasukkan ke dalam Erlenmeyer, ditambah 25 ml larutan Luff –Schoorl. Dibuat perlakuan blanko yaitu 25 ml larutan Luff-Schoorl ditambah 25 ml aquades.

- Setelah ditambah beberapa butir batu didih, Erlenmeyer dihubungkan dengan pendingin balik dan didihkan selama 10 menit.
- Kemudian cepat-cepat dinginkan, ditambahkan 15 ml KI 20% dan dengan hati-hati ditambahkan 25 ml H2SO4 26,5%.
- Yodium yang dibebaskan dititrasi dengan larutan Na-Thiosulfat 0,1 N memakai indicator pati 1% sebanyak 2-3%. (Titrasi diahiri setelah timbul warna krem susu)

Perhitungan :

$$\frac{(\text{Titrasi Blanko} - \text{Titrasi sample}*)\ \text{X Fakt.Pengenceran}}{Mg\ Sampel} \text{ X } 100$$

Ket : * Masukkan dalam Tabel

Dengan mengetahui selisih antara titrasi blanko dan titrasi contoh kadar gula reduksi dalam bahan dapat dicari dengan menggunakan Table 2. Bobot glukosa dikalikan 0,9 merupakan bobot pati.

Tabel 2. Penentuan glukosa, fruktosa dan gula invert dalam suatu bahan dengan metoda Luff Schoorl

Ml 0,1 N Na- Thiosulfat	Glukosa, fruktosa, gula invert mg $C_6H_{12}O_6$		Ml 0,1 N Na-Thiosulfat	Glukosa, fruktosa, gula invert mg $C_6H_{12}O_6$	
		Δ			Δ
1.	2,4	2,4	13.	33,0	2,7
2.	4,8	2,4	14.	35,7	2,8
3.	7,2	2,5	15.	38,5	2,8
4.	9,7	2,5	16.	41,3	2,9
5.	12,2	2,5	17.	44,2	2,9
6.	14,7	2,5	18.	47,3	2,9
7.	17,2	2,6	19.	50,0	3,0
8.	19,8	2,6	20.	53,0	3,0
9.	22,4	2,6	21.	56,0	3,1
10.	25,0	2,6	22.	59,1	3,1
11.	27,6	2,7	23.	62,2	-
12.	30,3	2,7	24.	-	-

4.5.3.3 Pengukuran kandungan sukrosa

Pengukuran kandungan sukrosa menggunakan Metode *Luff-Schoorl*. Adapun analisis yang dilakukan sebagai berikut.

- Filtrate bebas Pb dari larutan diambil sebanyak 50 ml (penentuan gula reduksi metode Luff Schoorl), kemudian dimasukkan ke dalam erlenmeyer dan ditambah dengn 25 ml aquades dan 10 ml HCl 30% (Berat jenis 1,15). Selanjutnya dipanaskan diatas penangas air pada suhu 67 – 70°C selama 10 menit. Kemudian didinginkan cepat-cepat sampai suhu 20°C dan dinetralkan dengan $NaOH$ 45%, kemudian diencerkan sampai volume tertentu sehingga 25 larutan mengandung 15 – 60 mg gula reduksi.
- Diambil 25 ml larutan dan dimasukkan ke dalam Erlenmeyer, ditambah 25 ml larutan Luff –Schoorl. Dibuat perlakuan blanko yaitu 25 ml larutan Luff-Schoorl ditambah 25 ml aquades.
- Setelah ditambah beberapa butir batu didih, Erlenmeyer dihubungkan dengan pendingin balik dan dididihkan selama 10 menit.
- Kemudian cepat-cepat didinginkan, selanjutnya ditambahkan 5 ml KI 20% dan dengan hati-hati ditambahkan 25 ml H_2SO_4 26,5%.
- Yodium yang dibebaskan dititrasi dengan larutan Na-Thiosulfat 0,1 N memakai indicator pati 1% sebanyak 2-3%. (Titrasi diahiri setelah timbul warna krem susu).

Perhitungan :

$$\frac{(\text{Titrasi Blanko} - \text{Titrasi sample}*)\ \text{X Fakt.Pengenceran}}{Mg\ Sampel} \text{ X } 100$$

Ket : * Masukkan dalam Tabel

Dengan mengetahui selisih antara titrasi blanko dan titrasi contoh kadar gula reduksi setelah inversi (setelah dihidrolisis dengan HCl 30%) dalam bahan dapat dicari dengan menggunakan Table 2. Selisih kadar gula reduksi setelah inversi dengan sebelum inversi (penentuan gula reduksi) dikalikan 0,95 merupakan kadar gula sakarosa dalam bahan.

4.5.3.4 Pengukuran kandungan asam bebas

Pengukuran kandungan asam bebas menggunakan metode titrasi Adapun tahapan analisis yang dilakukan sebagai berikut.

- Ditimbang bahan yang sudah dihaluskan atau bahan yang berupa cairan sebanyak 5-10 g. Kemudian dimasukkan kedalam labu ukur 100 ml dan ditambahkan aquades sampai tanda tera. Selanjutnya dilakukan penyaringan menggunakan kertas saring atau sentrifuge untuk mendapatkan filtratnya.
- Filtrat diambil sebanyak 5 – 25 ml menggunakan pipet dan dimasukkan ke dalam erlenmeyer 100 ml. (untuk sampel yang berwarna pekat boleh ditambahkan aquades

untuk mengurangi kepekatan warna) selanjutnya ditambahkan 2 -3 tetes indikator *Phenol Ptaline* (PP).

- Kemudian dititrasi dengan 0,1 N $NaOH$ standard hingga didapatkan warna pink seulas (tidak hilang selama 30 detik).
- Catat jumlah volume $NaOH$ yang dipakai untuk mentitrasi.

$$\frac{Vol\ NaOH\ x\ N.NaOH\ x\ FP}{Berat\ sampel\ (g)} \text{ x } 100$$

Keterangan :

Vol $NaOH$: Jumlah $NaOH$ pentitrasi

N. $NaOH$: Normalitas NaOH pentitrasi

FP : Faktor Pengenceran

4.5.3.5 Pengukuran kandungan glukosa

Pengukuran kandungan glukosa menggunakan metode *Luff-Schoorl* Adapun tahapan analisis yang dilakukan sebagai berikut.

- Bahan padat yang telah di haluskan ditimbang sebanyak 2,5 – 25 gr, kemudian dimasukkan ke dalam gelas piala 250 ml, ditambahkan 100 ml aquadest kemudian ditambahkan Pb asetat sebagai penjernih. Selanjutnya untuk menghilangkan kelebihan Pb ditambahkan Na_2CO_3 hingga tidak timbul reaksi sampai gelas piala menjadi 250 ml.
- Larutan diambil sebanyak 25 ml dan dimasukkan ke dalam Erlenmeyer, ditambah 25 ml larutan Luff –Schoorl. Dibuat perlakuan blanko yaitu 25 ml larutan Luff-Schoorl ditambah 25 ml aquades.
- Setelah ditambah beberapa butir batu didih, Erlenmeyer dihubungkan dengan pendingin balik dan didihkan selama 10 menit.
- Kemudian cepat-cepat dinginkan, tambahkan 5 ml KI 20% dan dengan hati-hati ditambahkan 25 ml H_2SO_4 26,5%.
- Yodium yang dibebaskan dititrasi dengan larutan Na-Thiosulfat 0,1 N memakai indicator pati 1% sebanyak 2-3%. (Titrasi diahiri setelah timbul warna krem susu)

Perhitungan :

$$\frac{(Titrasi\ blanko - Titrasi\ sampel)\ x\ Fakt.Pengenceran}{Mg\ sampel} \text{ X } 100$$

Ket : * Masukkan dalam Tabel

Dengan mengetahui selisih antara titrasi blanko dan titrasi contoh kadar gula reduksi dalam bahan dapat dicari dengan menggunakan Table 2.

4.6 Analisis dan Interpretasi Data

Hasil *thermal image* (TI) dan *Scanning electron microscope* (SEM) akan diolah menggunakan aplikasi Image J & MATLAB. Hasil pengatamatan mutu fisik dan kimia akan diolah menggunakan aplikasi Statistix 10 dan dicari korelasinya dengan hasil *thermal image* menggunakan koefisien korelasi (R^2).

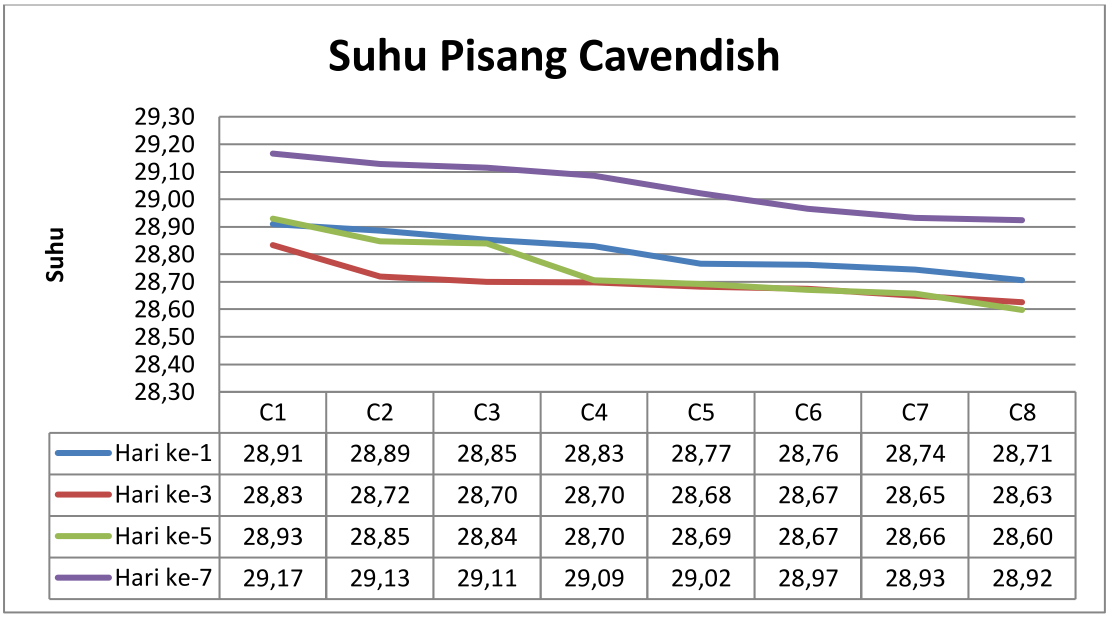
BAB V. HASIL DAN PEMBAHASAN

Penelitian ini dilakukan untuk mengetahui korelasi hasil *thermal image* dari berbagai tingkat kematangan buah (*fruit maturities*) terhadap mutu fisik dan kimia buah pisang ‘Cavendish’. Hasil penelitian menunjukkan bahwa terdapat perbedaan suhu pada masing-masing *finger* buah pisang Cavendish yang dapat dilihat pada Tabel 3. Pola penurunan/kenaikan suhu pada masing-masing sisir dari fase belum masak sampai fase masak dapat dilihat pada Gambar 6.

Table 3. *Thermal Image* (TI) *finger* buah pisang 'Cavendish' pada suhu ruang berdasarkan tingkat kematangan sisir buah pisang selama pemasakan*

*Maturity level***	Hari ke-1 (℃)		Hari ke-3 (℃)		Hari ke-5 (℃)		Hari ke-7 (℃)	
	5%	15%	5%	15%	5%	15%	5%	15%
C1	28.91 a	28.91 a	28.83 a	28.83 a	28.93 a	28.93 a	29.17 a	29.17 a
C2	28.89 a	28.89 ab	28.72 ab	28.72 ab	28.85 ab	28.85 a	29.13 a	29.13 ab
C3	28.85 a	28.85 abc	28.70 ab	28.70 b	28.84 ab	28.84 ab	29.11 a	29.11 ab
C4	28.83 a	28.83 abc	28.70 ab	28.70 b	28.70 bc	28.70 bc	29.09 a	29.09 ab
C5	28.77 a	28.77 abc	28.68 ab	28.68 b	28.69 bc	28.69 c	29.02 a	29.02 ab
C6	28.76 a	28.76 abc	28.67 ab	28.67 b	28.67 bc	28.67 c	28.97 a	28.97 ab
C7	28.74 a	28.74 bc	28.65 ab	28.65 b	28.66 bc	28.66 c	28.93 a	28.93 ab
C8	28.71 a	28.71 c	28.63 b	28.63 b	28.60 c	28.60 c	28.92 a	28.92 b

*Rata-rata nilai yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji BNT pada taraf 5% dan 15%; ** C1-8 = masing-masing sisir pertama hingga kedelapan, dari tandan teratas pisang 'Cavendish'.



Gambar 6. Pola kenaikan dan penurunan suhu buah pisang ‘Cavendish’

Pada Tabel 3, terlihat bahwa secara keseluruhan terdapat kecenderungan penurunan suhu dari C1 ke C8; semakin rendah urutan sisir maka semakin rendah suhunya. Namun kecenderungan ini tidak terdeteksi sebagai penurunan suhu yang signifikan hingga kadar BNT meningkat pada taraf 15%. Selain itu dapat diketahui bahwa hasil citra termal berpengaruh nyata pada semua taraf perlakuan (BNT: 15%) dan berpengaruh nyata pada hari ke-3 dan ke-5 (BNT:5%). Pada perlakuan hari ke-1 C1 memiliki suhu tertinggi, yaitu 28,91 ℃ dan C8 dengan suhu terendah, yaitu 28,71 ℃. Hal ini menunjukkan indikasi bahwa pisang 'Cavendish' di bagian atas memiliki suhu yang lebih tinggi daripada bagian bawah selama proses pematangan.

Pada Tabel 3 juga terlihat bahwa suhu C1 pada hari ke-7 (masak), yaitu 29,17 ℃ lebih tinggi dari suhu C1 pada hari ke-1 (mentah), yaitu 28,91 ℃. Peneliti lain [16] mencatat kecenderungan serupa bahwa terjadi peningkatan suhu buah secara bertahap dari waktu ke waktu, suhu buah pisang selama proses pemasakan adalah 19 ℃ pada hari ke-1 hingga 25 ℃ pada hari ke-5 yang terekam oleh citra termal. Penelitian lain [15] juga menyatakan bahwa buah yang masak memiliki kapasitas panas yang lebih tinggi dibandingkan dengan buah yang belum masak.

Pada Tabel 4, terlihat bahwa data citra termal memiliki korelasi yang erat dengan kualitas fisik buah, yaitu bobot buah, diameter, dan kekerasan buah berdasarkan koefisien korelasi (R^2). Selain itu dapat diketahui bahwa data citra termal berpengaruh signifikan terhadap semua variabel pengamatan, baik pada uji BNT taraf 5% maupun 15%. Pada umumnya pisang pada sisir atas memiliki bobot, diameter, dan suhu yang lebih tinggi daripada sisir di bawahnya.

Table 4. Bobot, diameter, dan kekerasan *finger* buah pisang 'Cavendish' pada stadium 1 sesuai dengan tingkat kematangan sisir pisang

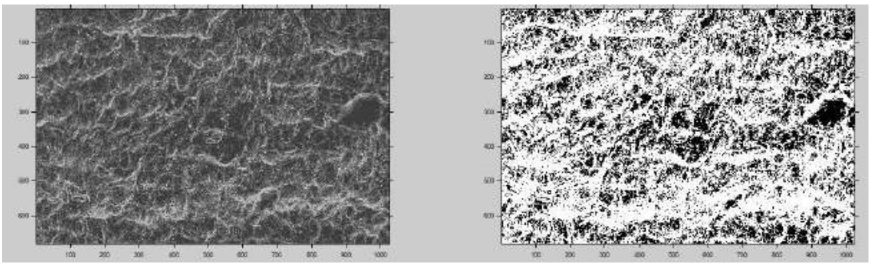
Maturity level	Bobot buah (g/finger)		Diameter buah (mm)		Kekerasan buah* (kg/cm^2)	
	5%	15%	5%	15%	5%	15%
C1	193.04 a	193.04 a	36.58 ab	36.58 abc	1.53 d	1.53 e
C2	193.64 a	193.64 a	36.98 ab	36.98 ab	1.95 cd	1.95 d
C3	179.94 ab	179.94 a	38.11 a	38.11 a	2.21 c	2.21 d
C4	161.70 bc	161.70 b	37.08 ab	37.08 ab	2.92 ab	2.92 bc
C5	148.62 cd	148.62 b	35.59 abc	35.59 bc	2.74 b	2.74 c
C6	126.42 de	126.42 c	34.98 bc	34.98 cd	3.05 ab	3.05 abc
C7	113.08 ef	113.08 c	33.12 cd	33.12 de	3.36 a	3.36 a
C8	89.22 f	89.22 d	32.30 d	32.30 e	3.20 a	3.20 ab
R^2 ke TI	0.9348	0.9348	0.7139	0.7139	0.8439	0.8439

* Nilai rerata yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji BNT pada taraf 5% atau 15%; ** C1-8 = masing-masing sisir pertama hingga kedelapan, dari tandan teratas pisang 'Cavendish'; R^2 to TI = Koefisien korelasi citra termal hari pertama pada Tabel 3.

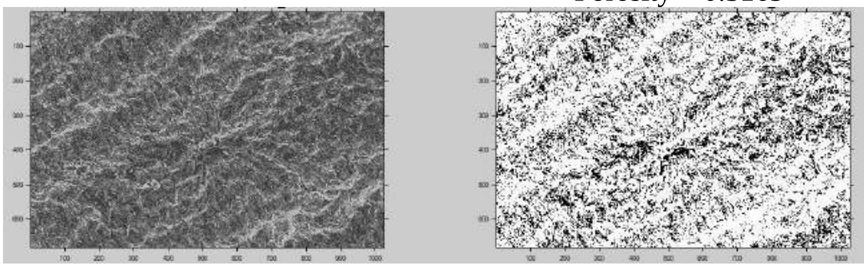
Tabel 4 juga menunjukkan bahwa terjadi peningkatan nilai kekerasan buah pisang 'Cavendish' dari sisir atas (C1) ke sisir bawah (C8). Hal ini karena pisang pada bagian atas lebih matang sehingga lebih lembut daripada bagian bawah. Jika dilihat pada Tabel 4, pisang 'Cavendish' pada sisir ke-8 memiliki nilai kekerasan yang lebih tinggi, yaitu 3,20 kg/cm^2 dibandingkan dengan sisir pertama dengan tingkat kekerasan, yaitu 1,53 kg/cm^2. Peneliti lain [17] menyatakan bahwa selama proses pematangan terjadi beberapa perubahan antara lain perubahan kekerasan buah, peningkatan tingkat kematangan buah yang umumnya diikuti dengan proses pelunakan kulit dan daging buah pisang. Kecenderungan sebaliknya terjadi pada suhu buah dimana buah pada sisir atas memiliki suhu yang lebih tinggi daripada sisir di bawah (Tabel 3). Hasil penelitian [18] menunjukkan bahwa sebagian besar komoditas buah dan sayuran memiliki koefisien suhu negatif yang menunjukkan bahwa kekerasan buah menurun dengan meningkatnya suhu.

Pengamatan kualitas fisik juga dilakukan pada permukaan buah dengan menggunakan *Scanning Electron Microscope* (SEM) (Gambar 7) yang menunjukkan bahwa pisang 'Cavendish' yang mendekati waktu panen memiliki sel epidermis yang pipih dan memanjang sejajar pada keliling buah, pada saat buah akan masak (*ripe*) maka terjadi pemisahan antar sel epidermis, besarnya pemisahan antar sel epidermis dapat dinyatakan dalam nilai porositas. Hasil SEM menunjukkan bahwa C1 memiliki nilai porositas yang lebih tinggi, yaitu sebesar

0,3165 dibandingkan dengan nilai porositas C8, yaitu sebesar 0,2300. Peneliti lain [19] menunjukkan bahwa buah masak memiliki keretakan lebih tinggi daripada buah belum masak (*unripe*), gejala pemisahan sel dan retakan antar sel muncul karena ketidakmampuan sel kutikula dan epidermis untuk berkembang pada tingkat yang sama dengan sel di bawahnya.



Porosity = 0.3165



Porosity = 0.2300

Gambar 7. Analisis kondisi permukaan kulit buah pisang ‘Cavendish’ pada sisir ke-1 & ke-8 dari tandan teratas dengan *Scanning Electron Microscope* (SEM; 5000 x)

Berdasarkan data pengamatan yang ditunjukkan pada Tabel 5, terlihat bahwa data citra termal memiliki korelasi yang erat dengan sukrosa, glukosa dan pati tetapi tidak berkorelasi dengan kadar asam bebas dan total padatan terlarut (ºBrix). Selain itu, hasil analisis kimia berpengaruh nyata terhadap semua taraf perlakuan pada BNT 15% dan berpengaruh nyata terhadap padatan terlarut, asam bebas, dan pati pada BNT 5%. Kandungan gula (glukosa dan sukrosa) sisir atas (C1) lebih tinggi, yaitu 0,81% dan 0,44% dibandingkan sisir ke-8 (C8), yaitu 0,64% dan 0,35% diikuti dengan penurunan suhu pisang 'Cavendish'. Hal ini sesuai dengan penelitian sebelumnya [20] yang menyatakan bahwa kandungan gula akan meningkat ketika buah menuju masak. Saat proses menuju pematangan terjadi perubahan warna pisang diikuti dengan perubahan tekstur menjadi lunak, kadar gula meningkat, sedangkan pati menurun. Kandungan pati menurun seiring dengan tingkat kematangan buah (Tabel 5), buah yang lebih matang pada sisir ke-1 (C1) memiliki kandungan pati yang lebih tinggi daripada sisir pada bagian bawah.

Tabel 5. Kandungan Brix, asam bebas, glukosa, sukrosa, dan pati *finger* pisang Cavendish pada stadium 1 menurut tingkat kematangan sisir pisang

Maturity level	ºBrix* (%)		Asam bebas (%)		Glukosa (%)		Sukrosa (%)		Pati (%)	
	5%	15%	5%	15%	5%	15%	5%	15%	5%	15%
H1	3.92 a	3.92 a	1.83 a	1.83 a	0.81 a	0.81 ab	0.44 a	0.44 ab	4.37 ab	4.37 a
H2	3.7 ab	3.7 ab	1.64 ab	1.64 a	1.00 a	1.00 a	0.27 a	0.27 b	2.45 b	2.45 b
H3	3.64 ab	3.64 abc	1.08 b	1.08 b	0.55 a	0.55 b	0.35 a	0.35 ab	5.07 a	5.07 a
H4	3.54 ab	3.54 abc	1.95 a	1.95 a	0.74 a	0.74 ab	0.53 a	0.53 ab	4.44 ab	4.44 a
H5	3.62 ab	3.62 abc	1.54 ab	1.54 a	0.79 a	0.79 ab	0.72 a	0.72 a	4.36 ab	4.36 a
H6	3.24 b	3.24 c	1.71 a	1.71 a	0.66 a	0.66 ab	0.45 a	0.45 ab	3.86 ab	3.86 ab
H7	3.32 ab	3.32 bc	1.57 ab	1.57 a	0.66 a	0.66 ab	0.39 a	0.39 ab	3.97 ab	3.97 ab
H8	3.58 ab	3.58 abc	1.50 ab	1.50 ab	0.64 a	0.64 ab	0.35 a	0.35 ab	3.53 ab	3.53 ab
R^2 to TI	0.4885	0.4885	0.0222	0.0222	0.8767	0.8767	0.8162	0.8162	0.8654	0.8654

*Rata-rata nilai yang diikuti oleh huruf yang sama tidak berbeda nyata menurut uji LSD pada taraf 5% atau 15%; ** H1-8 = masing-masing tangan pertama hingga kedelapan, dari tandan teratas pisang 'Cavendish'; R^2 to TI = Koefisien korelasi citra termal hari pertama pada Tabel 1.

Secara umum semakin rendah urutan sisir maka semakin rendah kandungan padatan terlarut (ºBrix) dan asam bebas. Pisang 'Cavendish' pada sisir pertama (C1) memiliki kandungan ºBrix dan asam bebas yang lebih tinggi, yaitu 3,92% dan 1,83%, dibandingkan dengan pisang sisir ke-8 (C8), yaitu 3,58% dan 1,50% yang diikuti oleh penurunan suhu pisang 'Cavendish' (Tabel 1). Hal ini sejalan dengan [21], yang menyatakan bahwa kandungan padatan terlarut total meningkat seiring dengan perkembangan buah dan kandungan asam total yang terkandung dalam buah termasuk asam askorbat cenderung meningkat selama proses pematangan buah akibat proses dekarboksilasi asam oksalat.

BAB V. KESIMPULAN DAN SARAN

5.1 Kesimpulan

Hasil penelitian menunjukkan bahwa citra termal dapat membedakan tingkat kematangan baik tingkat kematangan antara masing-masing sisir pada tandan pisang ‘Cavendish’ maupun pisang pada fase masak (*ripe*) dan belum masak (*unripe*). Hasil citra termal memiliki korelasi yang erat dengan kualitas fisik (bobot, diameter, dan kekerasan buah) dan kimia (glukosa, sukrosa, dan pati), tetapi tidak memiliki korelasi dengan kondisi permukaan buah (SEM), ºBrix, dan kandungan asam bebas berdasarkan nilai regresi (R^2). Sisir pada bagian atas tandan memiliki suhu yang lebih tinggi, yaitu 28,91℃ dibandingkan dengan sisir di bawah, yaitu 28,71℃. Pisang 'Cavendish' pada hari ke-7 (*ripe*) memiliki suhu yang lebih tinggi, yaitu 29,17 ℃ dibandingkan dengan pisang pada hari 1 (*unripe*), yaitu 28,92 ℃.

5.2 Saran

Pengukuran *thermal image* dilakukan setiap hari sampai buah pisang 'Cavendish' memasuki fase masak (*ripe*). Disamping itu, diperlukan penelitian lebih lanjut untuk mengetahui korelasi hasil *thermal image* terhadap mutu fisik dan kimia pada jenis buah yang berbeda.

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Detection of Fruit Maturity of 'Cavendish' Banana by Thermal Image Processing Technique

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Abstract. The level of fruit maturity for determining harvest time is an important factor that affects fruit qualities during ripening of 'Cavendish' banana. The quality resulting from that process can affect the level of consumer acceptance. During growth, fruit undergoes metabolism which produces energy and emit some kinds of infrared radiation. The thermal image processing technique was tried to detect fruit temperature at various levels of maturity of the fruits. Five bunches of 'Cavendish' bananas, with 8 hands each, from the top to the eighth hand were used for the experiment. Four fingers of each hand were analyzed for their thermal images, physical quality, chemical quality, and SEM. Each bunch was used as replications in the analysis. The standard method of determining the level of fruit ripeness was carried out to find the correlation with the thermal image. The results showed that the thermal image could distinguish the level of maturity and ripening, both the level of maturity between each hand on bunches of 'Cavendish' bananas and bananas in the ripe and mature phases. Thermal image results had a close correlation with physical (weight, diameter, fruit firmness) and chemical qualities (glucose, sucrose, starch) but had no correlation with fruit surface conditions (scanning electron microscope), ºBrix and free acid contents based on regression value. The hand at the top of the bunch had a higher temperature, which was 28.91℃ compared to the hand at the bottom, which was 28.71℃. Cavendish bananas on day 7 (ripe) had a higher temperature of 29.17℃ compared to bananas on day 1 (unripe) which was 28.92 ℃.

Keywords: Cavendish banana, harvest, maturity, thermal image

Introduction

As a climacteric fruit, 'Cavendish' banana fruit is harvested based on physical characteristics, namely based on the diameter of the banana finger fruit in the middle second hand as measured by a skimming tool with a minimum number of 38. This skimming number indicates that the fruit is ready to be harvested, aged 8-11 weeks after bagging, with a maturity level reaching 75-80% mature [1]. This level of maturity is estimated to be in the phase before the fruit reaches physiological maturity, so that theoretically the fruit will not ripen naturally. Therefore, during shipment for export in refrigerated containers, the 'Cavendish' bananas are expected not to ripen, and will only ripen if stimulated with ethylene after the fruit has arrived at its destination. Arriving at the export destination, the unripe bananas will be gassed with ethylene until they reach maturity stage III (greenish yellow fruit skin), and are ready to be marketed.

Based on data in the field (R. A. Wardhana, Great Giant Foods, Co. Ltd., Terbanggi Besar, Central Lampung, Indonesia; personal communication) incidents of ripe Cavendish bananas on the way during export (early ripening) often occur with varying volumes. Other researchers [2] refer to it as "mixed ripe", which is the term given to fruit that is sent to the market in a green condition but some of them have started to ripen (ripe) by the time they arrive at the market. This condition makes it difficult for artificial ripening and marketing and is detrimental to farmers or exporters. If this happens, the bananas will be rejected, causing significant material and non-material losses for exports. This happens because the harvest criteria are carried out physically, where fruits with the same physical criteria may have different levels of physiological maturity [2]. Climacteric fruit that has reached physiological maturity (full mature fruit) will naturally ripen perfectly. This occurrence is undesirable in 'Cavendish' banana exports. To overcome the problem of premature ripening of 'Cavendish' bananas as a result of harvesting based on physical properties, a more effective way is needed to distinguish the maturity level of 'Cavendish' bananas, one of which is using thermal image.

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 [3, 4]. This study, therefore, aimed to analyze the various levels of fruit maturity of 'Cavendish' banana fruit with the thermal image method and obtain a thermal image correlation with the physical and chemical qualities of the fruits.

Materials and Methods

This research was conducted by bringing in 10 bunches of 'Cavendish' banana fruit (stadium I; as a fresh harvest with standard maturity) from Great Giant Food, Co. Ltd. (GGF) in Terbanggi Besar, Central Lampung, Indonesia. From the 10 bunches, 5 bunches of the bananas with relatively uniform in size were selected. The banana hands were then separated from the bunches and coded the sample according to the order of the hands from the top of the bunches, for example, H1R1 (1^{st} hand, 1^{st} replication) to H8R5 (8^{th} hand, 5^{th} replication). Then, from each hand, 4 finger bananas were taken to be used for SEM (scanning electron microscope) analysis, thermal image, chemical (ºBrix, free acid, glucose, sucrose, starch), and physical (fruit weight, diameter, and firmness) qualities.

Thermal image (TI) observations were carried out by maintaining room temperature at 28 ℃, and there was no physical contact with the fruit when taking pictures to avoid local heat transfer to the fruit. TI was analyzed periodically every two days until the bananas were ripen. The data of physical and chemical fruit qualities were processed using the Statistix 10 with the Least significant difference test (LSD) at the level of 5% and 15%. The results of the TI and scanning electron microscope (SEM) were processed using the Image J & MATLAB. The physical and chemical quality observations were then correlated with the data of the TI and presented with the regression value (R^2).

Results and Discussion

This study was conducted to determine the correlation of thermal image data from various levels of fruit maturity to the physical and chemical quality of 'Cavendish' bananas. The results showed that there were differences in the temperature of each finger of the 'Cavendish' banana (Table 1).

Table 1. Thermal image (TI) of 'Cavendish' banana fingers in room temperature based on the maturity levels of banana hands during ripening*.

Maturity level**	1st Day (°C)		3rd Day (°C)		5th Day (°C)		7th Day (°C)	
	5%	15%	5%	15%	5%	15%	5%	15%
H1	28.91 a	28.91 a	28.83 a	28.83 a	28.93 a	28.93 a	29.17 a	29.17 a
H2	28.89 a	28.89 ab	28.72 ab	28.72 ab	28.85 ab	28.85 a	29.13 a	29.13 ab
H3	28.85 a	28.85 abc	28.70 ab	28.70 b	28.84 ab	28.84 ab	29.11 a	29.11 ab
H4	28.83 a	28.83 abc	28.70 ab	28.70 b	28.70 bc	28.70 bc	29.09 a	29.09 ab
H5	28.77 a	28.77 abc	28.68 ab	28.68 b	28.69 bc	28.69 c	29.02 a	29.02 ab
H6	28.76 a	28.76 abc	28.67 ab	28.67 b	28.67 bc	28.67 c	28.97 a	28.97 ab
H7	28.74 a	28.74 bc	28.65 ab	28.65 b	28.66 bc	28.66 c	28.93 a	28.93 ab
H8	28.71 a	28.71 c	28.63 b	28.63 b	28.60 c	28.60 c	28.92 a	28.92 b

*The mean values followed by the same letters are not significantly different according to the LSD test at the level of 5% and 15%; ** H1-8 = first to eighth hands, respectively, from the top bunch of 'Cavendish' bananas.

In Table 1, it appears that overall there was a tendency of decreasing in temperature from H1 to H8; the lower the hand order, the lower the temperature. However, this tendency was not detected as a significant decrease in temperature until the LSD level was increased up to 15%. In addition, it can be seen that the results of the thermal image have a significant effect on all treatment levels (BNT: 15%) and have a significant effect on the 3rd and 5th day (BNT: 5%). On the 1st day of treatment H1 had the highest temperature, which was 28.91°C and H8 with the lowest temperature, which was 28.71°C. This shows an indication that the 'Cavendish' bananas on the top hand had a higher temperature than the bottom hand during the ripening process. In Table 1, it also shows that the temperature of H1 on the 7th day (ripe), which was 29.17°C higher than the temperature of H1 on the 1st day (unripe), which is 28.91°C. Other researchers noted similar tendencies [3] that there was a gradual increase in fruit temperature over time, the temperature of bananas during the ripening process was 19°C on the 1st day to 25°C on the 5th day which was recorded by the thermal image. Other studies also stated that ripe fruit had a higher heat capacity than unripe fruit [5].

In Table 2, it appears that the data of the thermal image had a close correlation with frui physical qualities, namely fruit weight, diameter, and fruit hardness based on the regression value (R^2). In addition, it can be seen that the data of the thermal image had a significant effect on all observation variables, both in the LSD tests of 5% and 15% levels. In general, bananas on the top hand had a higher weight, diameter, and temperature than the hand below.

Table 2. Finger weight, diameter, and firmness of 'Cavendish' banana at 1st stadium according to maturity levels of banana hands.

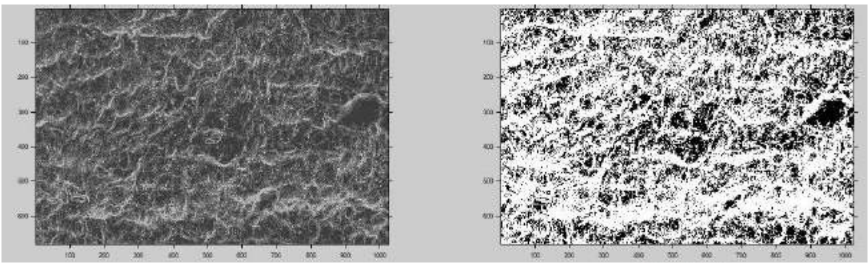
Maturity level	Fruit Weight (g/finger)		Fruit Diameter (mm)		Fruit Firmness* (kg/cm^2)	
	5%	15%	5%	15%	5%	15%
H1	193.04 a	193.04 a	36.58 ab	36.58 abc	1.53 d	1.53 e
H2	193.64 a	193.64 a	36.98 ab	36.98 ab	1.95 cd	1.95 d
H3	179.94 ab	179.94 a	38.11 a	38.11 a	2.21 c	2.21 d
H4	161.70 bc	161.70 b	37.08 ab	37.08 ab	2.92 ab	2.92 bc
H5	148.62 cd	148.62 b	35.59 abc	35.59 bc	2.74 b	2.74 c
H6	126.42 de	126.42 c	34.98 bc	34.98 cd	3.05 ab	3.05 abc
H7	113.08 ef	113.08 c	33.12 cd	33.12 de	3.36 a	3.36 a
H8	89.22 f	89.22 d	32.30 d	32.30 e	3.20 a	3.20 ab
R^2 to TI	0.9348	0.9348	0.7139	0.7139	0.8439	0.8439

*The mean values followed by the same letters are not significantly different according to the LSD test at the level of 5% or 15%; ** H1-8 = first to eighth hands, respectively, from the top bunch of 'Cavendish' bananas; R^2 to TI = Coefficient of correlation to 1st day thermal image in Table 1.

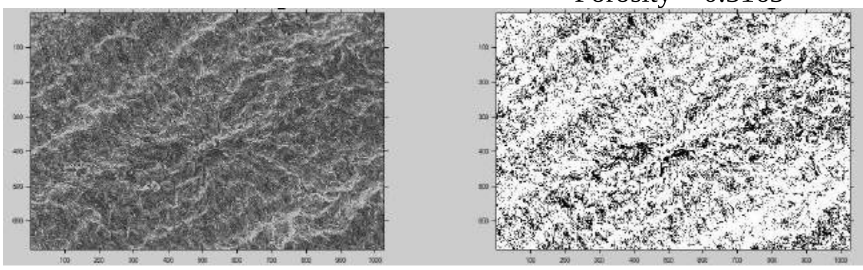
Table 2 also shows that there was an increase in the firmness values of bananas from the top hand (H1) to the bottom hand (H8). This was because the bananas on the top hand were more mature so they were softer than the hand underneath. When seen in Table 2, 'Cavendish' banana on the 8th hand had a higher firmness value, which was 3.20 (kg/cm^2) than the 1st hand with a firmness level of 1.53 (kg/cm^2). Working with 'Barangan' banana, other researchers [6] stated that during the ripening process, several changes occurred including changes in fruit tenderness, an increase in the level of fruit maturity which was generally followed by a process of softening the skin and flesh of bananas. The opposite tendencies occurred at fruit temperature where the fruit on the upper hand had a higher temperature than the hand below (Table 1). The results of other researcher's [7] showed that most of the fruit and vegetable commodities had a negative temperature coefficient indicating that the firmness decreased with increasing temperature.

Physical quality observations were also carried out on the fruit surface using a Scanning Electron Microscope (SEM) which can be seen in Figure 1. Figure 1 shows that 'Cavendish' bananas that were approaching harvest time have flat and elongated epidermal cells parallel to the circumference of the fruit, when the fruit is about to ripen (ripe) there will be a separation between the epidermal cells, the magnitude of the separation between epidermal cells can be expressed in terms of porosity. The SEM showed that H1 has a higher porosity value, which was 0.3165 compared to the porosity value of H8, which was 0.2300. Researchers [8] showed that ripe fruit cracked higher than that of mature fruit (unripe), symptoms of cell separation and cracks between cells arise due to the inability of cuticle and epidermal cells to develop at the same rate as cells underneath.

Based on the observational data shown in Table 3, it appears that the data of thermal image had a close correlation with sucrose, glucose and starch but did not correlate with the free acid content and total soluble solids (ºBrix). In addition, the results of chemical analysis had a significant effect on all treatment levels on LSD 15% and significantly affected soluble solids, free acids, and starch on LSD 5%. The sugar contents (glucose and sucrose) of the top hand (H1) was higher, namely 0.81% and 0.44%, compared to the 8th hand (H8), which was 0.64% and 0.35% followed by a decrease in the temperature of the 'Cavendish' bananas. This was in accordance with previous research [9] which states that the sugar content will increase when the fruit was ripe. When the process was leading to ripening, there was a change in the color of the banana followed by a change in texture to become soft, the sugar content increases, while the starch decreases [9]. The starch content decreased with the maturity level of the fruit (Table 3), the more ripe fruit on the 1st hand (H1) had a higher starch content than the lower hand.



Porosity = 0.3165



Porosity = 0.2300

Figure 1. Analyses on 'Cavendish' banana finger rind of 1st (two uppers) and 8th (two lowers) hands from the top bunch with scanning electron microscope (SEM; 5000 x).

Table 3. ºBrix, acidity, glucose, sucrose, and starch contents of 'Cavendish' banana fingers at 1st stadium according to maturity levels of banana hands.

Maturity level	ºBrix* (%)		Acidity (%)		Glucose (%)		Sucrose (%)		Starch (%)	
	5%	15%	5%	15%	5%	15%	5%	15%	5%	15%
H1	3.92 a	3.92 a	1.83 a	1.83 a	0.81 a	0.81 ab	0.44 a	0.44 ab	4.37 ab	4.37 a
H2	3.7 ab	3.7 ab	1.64 ab	1.64 a	1.00 a	1.00 a	0.27 a	0.27 b	2.45 b	2.45 b
H3	3.64 ab	3.64 abc	1.08 b	1.08 b	0.55 a	0.55 b	0.35 a	0.35 ab	5.07 a	5.07 a
H4	3.54 ab	3.54 abc	1.95 a	1.95 a	0.74 a	0.74 ab	0.53 a	0.53 ab	4.44 ab	4.44 a
H5	3.62 ab	3.62 abc	1.54 ab	1.54 a	0.79 a	0.79 ab	0.72 a	0.72 a	4.36 ab	4.36 a
H6	3.24 b	3.24 c	1.71 a	1.71 a	0.66 a	0.66 ab	0.45 a	0.45 ab	3.86 ab	3.86 ab
H7	3.32 ab	3.32 bc	1.57 ab	1.57 a	0.66 a	0.66 ab	0.39 a	0.39 ab	3.97 ab	3.97 ab
H8	3.58 ab	3.58 abc	1.50 ab	1.50 ab	0.64 a	0.64 ab	0.35 a	0.35 ab	3.53 ab	3.53 ab
R^2 to TI	0.4885	0.4885	0.0222	0.0222	0.8767	0.8767	0.8162	0.8162	0.8654	0.8654

*The mean values followed by the same letters are not significantly different according to the LSD test at the level of 5% or 15%; ** H1-8 = first to eighth hands, respectively, from the top bunch of 'Cavendish' bananas; R^2 to TI = Coefficient of correlation to 1st day thermal image in Table 1.

In general, the lower the hand order, the lower the soluble solid (ºBrix) and free acid contents. 'Cavendish' bananas on the 1st hand (H1) had higher ºBrix and free acids contents, namely 3.92% and 1.83%, compared to the 8th hand (H8) bananas, namely 3.58% and 1.50% (Table 3), followed by a decrease in the temperature of 'Cavendish' bananas (Table 1). This was in line with [10] stating that the total dissolved solids content increases with fruit development and the total acid content contained in the fruit including ascorbic acid tends to increase during the fruit ripening process due to the decarboxylation process of oxalic acid.

Conclusion

The results showed that the thermal image could distinguish the level of maturity and ripening, both the level of maturity between each hand on bunches of 'Cavendish' bananas and bananas in the ripe and mature phases. Thermal image results had a close correlation with physical (weight, diameter, fruit firmness) and chemical qualities (glucose, sucrose, starch) but had no correlation with fruit surface conditions (scanning electron microscope), ºBrix and free acid contents based on regression value. The hand at the top of the bunch had a higher temperature, which was 28.91℃ compared to the hand at the bottom, which was 28.71℃. Cavendish bananas on day 7 (ripe) had a higher temperature of 29.17℃ compared to bananas on day 1 (unripe) which was 28.92 ℃.

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MATURITY ASSESSMENT OF CAVENDISH BANANAS (*Musa paradisiaca* L.) USING THE THERMAL IMAGE METHOD

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ABSTRACT

Bananas (*Musa paradisiaca* L.) is a climacteric fruit having short storing period and fast fruit quality decrease. Maturity stage of banana fruit is an important factor that influences the fruit quality, so that the maturity level to determine proper harvesting time is required. Harvesting of banana fruit based on the fruit physical characteristics such as diameter and days after anthesis is considered to be less precise. The objective of this research was to find out the influence of banana fruit diameter to it's maturity level that was detected by thermal image method. This research was conducted using three fruit maturity levels based on their diameter; small diameter (<38), medium diameter (38-42), and large diameter (43-48) with skim scale at stage I. That scale was commonly used to determine quality standard size of Cavendish bananas, especially for international trade. The result showed that the increasing of fruit maturity level was followed by decreasing of firmness and increasing of fruit weight, °Brix, free acid, and sucrose. Thermal image method is potentially used to detect the fruit maturity level where increasing of fruit size was followed by rising of temperature.

Keywords: *fruit maturity, Cavendish banana, thermal image*

INTRODUCTION

Banana (*Musa paradisiaca* L.) is one of fruit commodities that is consumed many people since it contains fiber, vitamin, magnesium, and has a lower fat. In Indonesia, one of the superior banana cultivars for international trade is Cavendish banana. This type of banana is officially recognized by Ministry of Agriculture based on Decree of Minister of Agriculture No. 702/Kpts/SR.120/5/2008 (Ministry of Agriculture, 2008). Banana fruits is classified as a climacteric fruit with short storing period and fast fruit quality decrease because of their respiration and transpiration activities and high ethylene production during storage.

Banana fruit harvest timing based on the fruit physical characteristics such as diameter and days after anthesis is considered to be less precise, because the same fruit physical form may produce different possibilities of physiological maturity levels, and fruit physical form alone cannot describe all physiological effects to detect fruit maturity level in the very beginning. The banana fruit maturity level is an important factor that influences the fruit quality, so that a proper timing determination for harvesting is required. The fruit maturity level detection for determining Cavendish bananas harvest timing is done with thermal image method.

Thermal image is a non-contact technology that measures infrared wave emanated from an object to detect temperature distribution. It is also known as a non-destructive method to detect the maturity level of Cavendish bananas without damaging it. Salankar and Ansari (2017) suggested that thermal image method could be used to analyze banana fruit maturity condition. Thermal image could also be used to identify both natural and artificial banana fruit maturities with high accuracies (Karthika *et al*., 2017). These researches suggested the potential of thermal image used in identifying banana fruit maturity. However, banana fruit physiological maturity stages that are divided into three diameter size scales are not yet studied, despite of precise physiological maturity determination becoming an important criterion in determining banana fruit quality. The objective of this research was to find out the effect of banana fruit diameter to the maturity level of banana detected by thermal image method.

METHODS

This research was conducted at the Horticulture Postharvest Laboratory, The Department of Agrotechnology, Faculty of Agriculture, University of Lampung in April 2021. Materials used in this research were Stage I Cavendish bananas (green) obtained from PT Nusantara Tropical Farm (NTF Co.), East Lampung District, Lampung Province. The samples were classified into three diameter sizes; small (<38), medium (38-42), and large (43-48) with skim scale. Equipments used in this research were thermal image camera (FLIR F5–XT, ± 2 ^{0}C accuracy, resolution 160x120 pixels, thermal sensitivity < 0.10 ^{0}C), imaging chamber, computer, Matlab (R2014a), scale, penetrometer, 'Atago' hand refractrometer, and thermometer.

Cavendish bananas samples were prepared, weighed, and stored overnight at temperature of 26-28 ^{o}C to keep the fruit temperature stable. Prepared sample objects were taken for thermal image one by one in the chamber at 25 cm distance between the infrared camera and object. There were 10 samples for each diameter as repetition. Each sample unit was taken for image at three times. Thermal image analysis was done by using Matlab (R2014a) and by reading temperature displayed in the middle section of the fruit. Variables of fruit maturity level characteristics to be observed were temperature, weight, firmness, soluble solid

(°Brix), sucrose, free acid, and starch of the fruit. Results of physical and chemical quality observations were correlated with thermal image analysis results by using regression score (R^2). Data of temperature, weight, firmness and °Brix were analyzed by using analysis of variance (ANOVA) and followed with least significant difference test (LSD) at critical values for α 5% and 15% (Statistic 8).

RESULT AND DISCUSSION

Cavendish bananas analysis was conducted when the fruit was at stage I (green) by correlating fruit temperatures from difference fruit maturity levels to the fruit physical and chemical qualities. The applied thermal image method could show temperature differences. Fruit temperature increased from the small to large diameter of the fruits. This phenomenon indicated that the more mature of the fruit, the higher the fruit temperature. Cavendish banana with large diameter had temperature of 29.15 °C, while the medium diameter 28.88 °C and small diameter 28.85 °C (Table 1). The thermal image method indicated that the larger and the more mature of fruits, the more heat was accumulated (Stajnko *et al*., 2004).

Tabel 1. Fruit temperature and physical quality of Cavendish bananas at three levels of maturity

Maturity Levels	Fruit Temperature (°C)		Weight (gram)		Firmness (kg/cm^2)	
	(α=5%)	(α=15%)	(α=5%)	(α=15%)	(α=5%)	(α=15%)
Small diameter (< 38)	28.85 b	28.85 b	374.70 b	374.70 c	5.84 a	5.84 a
Medium diameter (38−42)	28.88 b	28.88 b	501.07 b	501.07 b	5.09 a	5.09 ab
Large diameter (43−48)	29.15 a	29.15 a	686.47 a	686.47 a	4.11 a	4.11 b
Regression coefficient (R^2) to the fruit temperature			0,8872		0,8661	

Notes: The numbers followed by different letters in the same column are significantly different at the 5% and 15% LSD tests

Based on the physical qualities, banana fruit with a higher level of maturity would be followed by increase of weight and decrease of fruit firmness. The fruit with larger diameter had higher fruit weight by 686.47 gram, while the fruits with medium diameter have a weight of 501.07 gram and small diameter 374.70 gram (Table 1). Maturity process was followed by decreasing firmness while the fruit flesh become softer. Cavendish bananas with large diameter had lowest firmness score by 4.11 kg/cm^2, compared to medium diameter (5.09 kg/cm^2), and small diameter size (5.84 kg/cm^2) (Table 1). Widodo *et.al* (2019) suggests that fruit maturity improvement is generally followed with fruit skin and flesh softening. The higher fruit skin and flesh softening level would indicate more mature fruit. Fruit firmness change is caused by soluble protopectin degradation, so that during fruit maturing many bio-chemical and structural changes occur (Praja *et al*., 2021).

Analysis of variance was done and followed by least significant difference test for each physical parameter and the result showed that the fruit maturity level classification was presented significantly by weight variable at significant value of α = 0.05 and α = 0.15. Meanwhile fruit firmness was presented significantly at significant value α = 0.15 (Table 1). Thermal image method application (sensoring) at fruit temperature could follow fruit maturity level changes. The correlation between emanated temperature and fruit weight and firmness showed a high correlation (R^2 > 0.86).

Table 2. Fruit temperature and chemical quality of Cavendish bananas at three levels of maturity

Maturity Levels	Fruit Temperature (℃)		°Brix (%)		Sucrose (%)	Free Acid (%)	Starch (%)
	(α=5%)	(α=15%)	(α=5%)	(α=15%)			
Small diameter (< 38)	28.85 b	28.85 b	8.76 a	8.76 b	1.57	0.71	4.30
Medium diameter (38−42)	28.88 b	28.88 b	9.11 a	9.11 ab	3.99	1.52	3.26
Large diameter (43−48)	29.15 a	29.15 a	10.50 a	10.50 a	6.93	2.19	4.23
Regression coefficient (R^2) to the fruit temperature			0.8872		0.8511	0.7661	0.1490

Notes: The numbers followed by different letters in the same column are significantly different at the 5% and 15% LSD tests

Fruit maturity level improvement was followed by increases of soluble solid content (°Brix), sucrose, and free acid. Meanwhile, starch content did not correlate to fruit maturity level (Table 2). Cavendish bananas with large diameter size had a highest soluble solid content (°Brix) by 10.50%, compared to medium diameter size (9.11%), and small diameter size (8.76%) (Table 2). The soluble solid content (°Brix) increase could be caused by increased respiration rate at maturity process, so that complex material degradation such as carbohydrate caused starch content decrease and sucrose increase (Praja *et al*., 2021). This was followed with sucrose increase along with more mature fruit condition. The banana fruit with large diameter size had higher sucrose content by 6.93%, compared to medium diameter size (3.99%), and small diameter size (1.57%) (Table 2). Research result by Zhu et. al (2021) shows starch conversion into sucrose during fruit maturity process. Banana maturity process is followed by fruit softening and fruit sweetness is mostly caused by starch degradation. At the green stage, bananas have very high starch content and a low amount of sugars, which changes dramatically to high sugars and low starch at the full-ripe stage (Evans *et al*., 2020).

The research result also showed free acid content increase at Cavendish bananas. The banana fruit with small diameter size had lowest free acid content by 0.71% compared to miedium diameter size (1.52%) and large diameter size (2.19%) (Table 2). Widodo et. al (2019) suggests that banana fruit undergoes free acid increase during fruit maturity process. Citric acid and malic acid are not affected by plant culturing technique, but they are affected by genotype and plant age to harvest (Etienne *et al.*, 2014).

The least significant difference test of Cavendish bananas chemical quality variable indicated no significant difference at significant level of α 5%, but it showed significant difference of fruit maturity level at significant level of α = 15%. The correlation of chemical quality variable (°Brix, sucrose, and free acid) to varying fruit maturity levels showed a high correlation value ($R^2 > 0.76$). Meanwhile, the correlation between fruit temperature and starch content was weak ($R^2 = 0.1490$). Therefore, infrared sensoring was potential to use for detecting Cavendish bananas maturity level.

CONCLUSION

The conclusion of this research was that thermal image method was able to detect different fruit maturity levels of stage I Cavendish bananas. The diameter size increase was followed by the fruit temperature level. The Cavendish bananas temperatures were 28.85 ^{o}C at small diameter size, 28.88 ^{o}C at medium diameter size, and 29.15 ^{o}C at large diameter size. The banana fruit maturity level was followed by increases of fruit weight, soluble solid content (°Brix), sucrose, and free acid. The banana fruit maturity level was followed by fruit firmness score decrease.

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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).

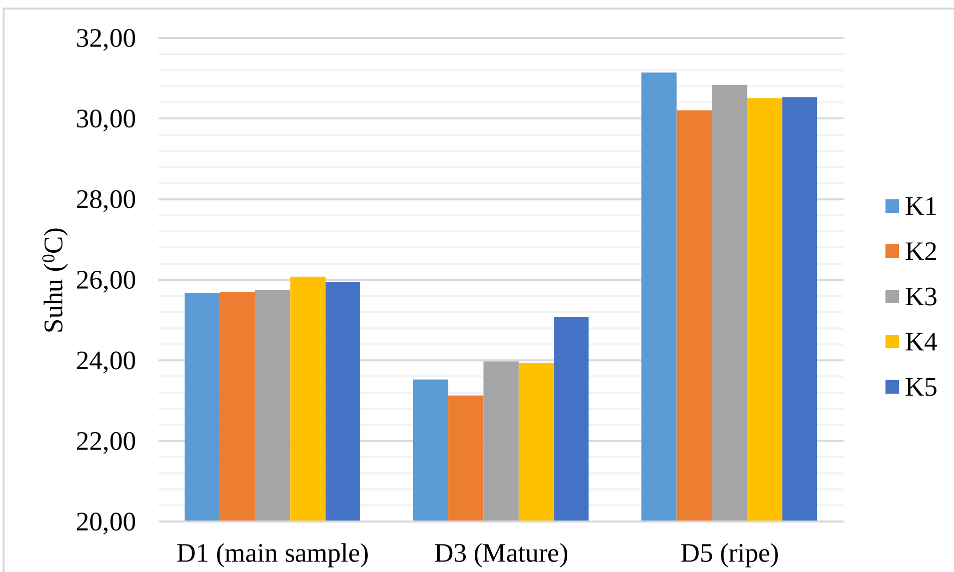

Figure 1. Average value of avocado fruit temperature

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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Thermal Image Method to Detect Fruit Maturity of 'Red' Guava (*Psidium Guajava L.*)

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Abstract. Guava 'Red' fruit is quite popular and favored by the wider community. Red guava is marketed in fresh or processed form such as fruit juice, jelly and jam. In the cultivation of 'Red' guava, the main obstacle faced by farmers is determining the right harvest time. In this study, the thermal image method was used to detect the maturity level of the 'Red' guava fruit. A total of 30 'Red' guava fruits at various levels of fruit maturity were used as samples. The research was arranged in a factorial design, with three level of fruit maturity: green, yellowish green, and greenish yellow and using 10 fruits each as a replication. The results showed that the level of fruit maturity correlated with fruit temperature, the higher the ripeness of the fruit (indicated by the increase in the content of °brix and sucrose and the decrease in the content of free acids and starch), the higher the temperature of the fruit. The thermal image analysis can then be potentially used to determine the cultivation time based on physiological fruit maturity.

Keywords:*'Red' Guava (Psidium guajava L.), stage of maturity, thermal image*

1. Introduction

Guava (Psidium guajava L.) 'Red' is a tropical fruit commodity that is favored by the wider community and has a fairly high economic value. Guava fruit 'Red' contains vitamins A, B1 (Thiamine), B2 (Riboflavin) and C (Ascorbic acid) are quite high [3]. 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 the right harvest time. The 'Red' guava fruit is harvested only based on physical, even though the same physique could be different levels of physiological maturity because the physical cannot describe the overall physiological impact that can be detected from the start [6].

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 level of maturity that is almost close to perfect so that the fruit is not damaged on the road.

To overcome these problems, a method is needed to detect the maturity level of 'Red' guava fruit by using a thermal image. Thermal Image is one method of detecting the level of fruit maturity. Thermal Image is an analytical tool without damaging the fruit (non-destructive) or that does not require direct physical contact with the fruit [4].Thermal Image can detect bruises on the 'Red' guava fruit [1].

This purpose of the research is 1). Apply the thermal image method to detect the maturity level of 'Red' guava fruit; 2). Determine maturity level of 'Red' guava fruit using the thermal image and correlate it to the physical and chemical parameters.

2. Materials and Method

The research was done at the Horticulture and Postharvest Laboratory, Faculty of Agriculture, University of Lampung. The research was done on March - April 2021. The research material was guava fruit 'Red' which have been classified based on the level of maturity, namely green, yellowish green, and greenish yellow. The tool used is a thermal image camera (FLIR F5 – XT, accuracy ± 2 ^{0}C, resolution 160 x 120 pixels, thermal sensitivity < 0, 10 ^{0}C), image capture box (chamber), digital scale, fruit penetrometer, and 'Atago' hand refractometer.

Impelementation of the research was done with a sample of 'Red' guava fruit that had been prepared and then placed the sample unit in the image box to take the thermal image. Prepare the image acquisition unit (image acquisition), check the completeness of the tools in the image capture box such as a camera, the basis for placing objects, and return programs to capture images. The distance between the object holder and the face of the camera lens is about 20-25 cm, during image data collection, the distance must be maintained so that the projection size of all objects is the same. The number of replicate samples for each maturity level was ten, and each sample unit was imaged three times.Taking pictures is done through a computer that has been connected to FIR. If the object of the image has appeared on the monitor screen in a fairly representative position (in the middle of the image field), click on the menu for capturing images taken in color. Then the captured image is saved with a specific file name or code in the form of a jpeg file.

The results of the thermal image are processed using the Image J & MATLAB application. The variables observed were fruit temperature, weight, firmness, dissolved solids content (°Brix), free acid, sucrose, and starch.The results of the physical and chemical quality observations will be correlated with the thermal image results using the regression value (R2) and analyzed by analysis of variance (ANARA) and continued with the Least Significant Difference (BNT) test at a significant level of 5% (Statistix 8).

3. Results and Discussion

Table 1. Fruit temperature and the physical parameters

Maturity Level	T (°C)		Weight (grams)		Firmness (kg/cm2)	
	(α=5%)	(α=15%)	(α=5%)	(α=15%)	(α=5%)	(α=15%)
Green	28.24 c	28.24 c	258.30 a	258.30 a	20.54 a	20.54 a
Yellowish green	28.45 b	28.45 b	262.20 a	262.20 a	13.24 b	13.24 b
Greenish Yellow	28.73 a	28.73 a	260.00 a	260.00 a	7.47 c	7.47 c
coef. of determination (R2)			0.150		0.985	

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. At the temperature of the guava fruit "Red" the level of green maturity has a lower temperature than the maturity level of yellowish green and greenish yellow, respectively 28.24 ^{0}C, 28.45 ^{0}C and 28.73^{0}C.The more ripe the 'Red' guava fruit, the higher the temperature of the 'Red' guava fruit (Table 1). The result is similar with the research of [8] stated that ripe fruit has a higher heat capacity than unripe fruit, resulting in an increase in the temperature of the fruit.

The maturity level treatment is influenced by the thermal image temperature variable. The treatment level of maturity and thermal image correlated to the firmness level of the 'Red' guava fruit, the higher the maturity level, and the higher the temperature, the lower the firmness level of the 'Red' guava fruit. Similar with the research results of [10] during the ripening process, several changes occur, including ripening the fruit, changing the composition of the cell wall and lowering cell turgor pressure, followed by the softening process of guava fruit. While the treatment level of maturity and thermal image is not correlated with the weight of the guava fruit 'Red' is presented in (Table 1).

The results of the analysis of variance followed by the Least Significant Difference (BNT) test for each physical parameter both at the significance level α = 0.05 and α= 0.15 had a significant effect on the fruit firmness variable while the fruit weight variable had no significant effect. Although the weight of the fruit represented by physical parameters was not statistically significant, however, the application of (sensoring) fruit temperature can follow changes in the level of fruit maturity. The relationship between fruit scatter temperature and fruit firmness shows a very strong correlation (R2 =0.985). The more ripe the fruit, followed by a decrease in hardness and an increase in fruit temperature. Meanwhile, the correlation between fruit temperature and fruit weight is very weak (R2 =0.150).

Table 2. Fruit temperature and the chemical parameters

Maturity Level	T (°C)		^{0}Brix (%)		Free Acid (%)	Sucrose (%)	Starch (%)
	(α=5%)	(α=15%)	(α=5%)	(α=15%)			
Green	28.24 c	28.24 c	7.20 c	7.20 c	4.50	0.76	1.14
Yellowish green	28.45 b	28.45 b	7.40 b	7.40 b	3.07	0.89	1.10
Greenish Yellow	28.73 a	28.73 a	8.00 a	8.00 a	2.11	0.99	0.98
coef. of determination (R2)			0.948		0.974	0.985	0.918

On the (Table 2). The treatment level of maturity and thermal image has a correlation with chemical parameters, namely the content of ^{0}brix, free acid, sucrose and starch. The content of ^{0}brix guava fruit "Red" at the level of green maturity has a value of 7.20%, yellowish green of 7.40% and greenish yellow of 8.00%, the higher the level of maturity, the temperature will increase, the content of ^{0}brix will increase. Ripe fruit is sweeter than unripe fruit. This is supported by research that the increase in pH and TSS values of guava can be explained by oxidation of organic acids and enzymatic hydrolysis of starch during fruit metabolism into simple sugars [5].

The free acid content of 'Red' guava fruit at the green maturity level initially has a value of 4.50% and decreases at the level of yellowish green by 3.07% and greenish yellow by 2.11%, the more ripe the temperature will increase and the free acid content will decrease. The more ripe the guava 'Red', the acidity of the fruit decreases. The results of the study [9] stated that at the beginning of maturity the acidity level was still high as the time of ripening the fruit the acidity of the fruit decreased over time due to the degradation of organic acids.

The sucrose content in the 'Red' guava fruit is ripe, the temperature will increase and the sucrose content will be high. The more ripe the guava 'Red' will taste sweet. This is in line with research that during fruit ripening the value of sucrose increases while glucose and fructose decreases during ripening of guava fruit [7].

The starch content of 'Red' guava fruit for the green maturity level has a value of 1.14%, yellowish green of 1.10 and greenish yellow of 0.98 this means that the more ripe the fruit, the lower the starch content because ripe fruit contains lower starch than fruit. immature. The result is similar with the research of [2] stated that initially the starch content increased and then decreased due to the ripening process of guava fruit.

4. Conclusion

The results showed that the thermal image can detect the maturity level of 'Red' guava fruit. At the level of greenish-yellow maturity, the temperature was higher at 28.73 ^{0}C compared to the yellowish-green level, which was 28.45 ^{0}C and green at 28.24 ^{0}C, the more ripe the fruit, the higher the temperature. The level of fruit maturity correlated with fruit temperature, the higher the ripeness of the fruit (indicated by the increase in the content of obrix and sucrose and the decrease in the content of free acids and starch) the higher the temperature of the fruit.

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Deteksi Tingkat Kematangan Buah Jambu Biji (*Psidium Guajava* L.) Kristal Secara Tak Merusak Dengan Metode *Thermal Image*

Detection of the Maturity Level of Guava (*Psidium Guajava* L.) 'Kristal' Non-Destructively Using Thermal Image Method

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ABSTRACT

Determination of the level of maturity of fruit at harvest is one of the critical factors that affects fruit quality during post-harvest handling. The thermal image method is a non-destructive technology used to detect the temperature radiated by an object without direct contact. This study aims to detect the level of maturity of guava fruit (*Psidium guajava* L.) Kristal by using the thermal image method. Three levels of fruit maturity were used in the research test, namely green, yellowish green, and greenish yellow. The results showed that the more mature the Guava 'Kristal' fruit, the higher the temperature of the fruit. This temperature increase was closely correlated with a decrease in fruit hardness (R^2 = 0.997), free acid (R^2 = 0.936), and starch content (R^2 = 0.903), and was strongly correlated with an increase in Brix (R^2 = 0.866), and sucrose (R^2 = 0.968). Although the fruit ripeness classification has very small differences in physical and chemical parameters (at significant level, α= 0.05, it does not show a significant difference), however, the temperature radiation of the fruit captured by the thermal camera is able to follow it very well. So that the thermal image method has the potential to be developed as a tool for detecting the level of fruit maturity.

Keywords : Guava (Psidium guajava L.*) crystals, fruit maturity, thermal image*

ABSTRAK

Penentuan tingkat kematangan (*maturity*) saat panen merupakan salah satu faktor kritis yang mempengaruhi kualitas buah selama penanganan pasca panen. Metode *thermal image* merupakan salah satu teknologi non destruktif yang digunakan untuk mendeteksi suhu yang diradiasikan oleh suatu objek tanpa kontak langsung. Penelitian ini bertujuan untuk mendeteksi tingkat kematangan buah jambu biji (*Psidium guajava* L.) Kristal dengan menggunakan metode *thermal image*. Tiga tingkatan kematangan buah digunakan pada pengujian penelitian, yakni hijau, hijau kekuningan, dan kuning kehijauan. Hasil penelitian menunjukkan bahwa semakin matang buah jambu biji Kristal, semakin meningkat suhu buah. Kenaikan suhu ini berkorelasi erat dengan penurunan kekerasan buah (R^2 = 0.997), asam bebas (R^2 = 0.936), dan pati (R^2 = 0.903), dan berkorelasi kuat dengan kenaikan Brix (R^2 = 0.866), dan sukrosa (R^2 = 0.968). Meskipun klasifikasi kematangan buah memiliki perbedaan parameter fisik dan kimia yang sangat kecil, namun demikian radiasi suhu buah yang ditangkap oleh kamera termal mampu mengikutinya dengan sangat baik. Sehingga metode *thermal image* potensial untuk dikembangkan sebagai alat deteksi tingkat kematangan buah.

Kata kunci : Jambu biji (Psidium guajava L.*) kristal, kematangan buah, thermal image*

PENDAHULUAN

Buah jambu biji (*Psidium guajava* L.) merupakan produk hortikultura penting di beberapa negara tropika. Salah satu jenis buah jambu biji yang diminati oleh konsumen yaitu buah jambu biji 'Kristal'. Konsumen menyukai jambu biji 'Kristal' karena bertekstur renyah, memiliki cita rasa manis, dan berbiji lebih sedikit atau bahkan tidak berbiji sehingga porsi buah yang dapat dikonsumsi lebih banyak (Ditbenih, 2007). Selain itu, buah jambu biji 'Kristal' mengandung vitamin C empat kali lebih banyak dari jumlah vitamin C pada buah jeruk (250,7 mg/100g) (Dina *et al*., 2014). Buah jambu biji 'Kristal' merupakan kultivar jambu biji yang telah resmi dilepas oleh Kementerian Pertanian berdasarkan SK Mentan No.540/Kpts/SR.120/9/2007 (Balitbu, 2007).

Buah jambu biji 'Kristal' selama ini dipanen hanya didasarkan pada kriteria fisik buah seperti dengan perhitungan hari setelah *antesis* dan melihat perubahan warna pada buah (Mitra, dkk., 2012; Raut and Bora, 2016). Padahal bentuk fisik buah yang sama dapat memunculkan kemungkinan tingkat kematangan fisiologis yang berbeda-beda pada buah jambu biji 'Kristal' (Gonzalez *et al*., 2004). Proses-proses fisiologis yang terjadi pada pascapanen sangat berpengaruh pada perubahan mutu buah jambu biji 'Kristal'. Untuk itu, perlu penanganan panen dan pascapanen dengan cara menentukan tingkat kematangan yang tepat. Pendeteksian tingkat kematangan buah sebagai penentu waktu panen buah jambu biji 'Kristal' pada penelitian ini didekati dengan metode *thermal image*. Metode *thermal image* merupakan salah satu teknologi inframerah yang digunakan untuk mendeteksi distribusi termal (suhu) yang diradiasikan yang ada pada suatu objek. Metode deteksi secara *non destruktif* untuk dapat mendeteksi bagian internal buah jambu biji 'Kristal' sehingga dapat diketahui tingkat kematangan buah jambu biji 'Kristal' tanpa merusak buah. Penelitian ini bertujuan untuk mempelajari efek metode *thermal image* sebagai faktor pendeteksi tingkat kematangan buah dan korelasinya terhadap mutu fisik kimia pada buah jambu biji 'Kristal'.

BAHAN DAN METODE

Penelitian ini dilaksanakan di Laboratorium Pascapanen Hortikultura, Jurusan Agroteknologi, Fakultas Pertanian, Universitas Lampung. Penelitian dilaksanakan pada bulan Februari 2021. Bahan yang digunakan pada penelitian ini adalah buah jambu biji 'Kristal' yang diperoleh dari PT Nusantara Tropical Fruits, Labuhan Ratu, Lampung Timur. Sampel buah jambu biji 'Kristal' ini telah diklasifikasi ke dalam tiga tingkatan kematangan oleh *expert* perusahaan sebagaimana pengklasifikasian tingkat kematangan yang dilakukan oleh perusahaan yakni hijau, hijau kekuningan, dan kuning kehijauan. Alat yang digunakan dalam pengujian adalah *thermal image camera* (FLIR F5 – XT, akurasi ± 2 ^{0}C, resolusi 160 x 120 *pixels*, sensitifitas *thermal* < 0, 10 ^{0}C), kotak pengambil citra (*chamber*), timbangan digital, penetrometer buah, dan refraktometer tangan '*Atago*'. Pelaksanaan penelitian yaitu sampel buah jambu biji 'Kristal' yang telah disiapkan kemudian diletakkan per unit sampel pada kotak pengambilan citra untuk diambil citra *thermal*-nya menggunakan kamera inframerah. Pengambilan citra dilakukan dengan jarak ketinggian 25cm dari sampel. Jumlah sampel ulangan untuk setiap tingkatan kematangan adalah sebanyak sepuluh buah, dan setiap unit sampel dilakukan pengambilan citra sebanyak tiga kali. Analisis citra *thermal* menggunakan program MATLAB 2009b. Peubah sebagai penciri tingkat kematangan buah yang diamati adalah suhu buah, bobot buah**,** tingkat kekerasan buah, kandungan padatan terlarut (^{o}Brix), asam bebas, sukrosa, dan pati. Hasil pengamatan mutu fisik dan kimia akan dicari korelasinya dengan hasil analisis *thermal image* menggunakan nilai regresi (R^2). Data suhu, bobot, kekerasan, dan brix dianalisis dengan analisis sidik ragam (ANARA) dan dilanjutkan dengan uji Beda Nyata Terkecil (BNT) pada taraf nyata 5% dan 15% (Statistix 8).

HASIL DAN PEMBAHASAN

Tabel 1 menampilkan hasil pengukuran suhu yang diradiasikan oleh buah jambu biji 'Kristal' dan parameter fisik buah: bobot dan kekerasan (*firmness*). Dari data ini dapat diperoleh informasi bahwa semakin matang (*mature*) buah, suhu yang dipencarkan semakin tinggi. Buah jambu biji 'Kristal' berwarna hijau memiliki suhu yang paling rendah (27.85 ^{0}C), sementara buah berwarna kuning kehijauan memiliki suhu paling tinggi (28.10 ^{0}C). Sedangkan secara fisik, semakin matang buah diikuti dengan penurunan kekerasan buah. Sementara itu, bobot buah tidak berkorelasi dengan tingkat kematangan buah. Buah jambu biji 'Kristal' berwarna kuning kehijauan merupakan buah dengan tingkat kematangan paling masak memiliki suhu dan kekerasan yang paling tinggi diantara buah berwarna hijau kekuningan dan hijau. Nilai tingkat kekerasan buah jambu biji kristal berwarna hijau memiliki nilai paling tinggi yaitu sebesar 15.61 kg/cm^2 dibandingkan buah berwarna hijau kekuningan sebesar 15.50 kg/cm^2 dan buah berwarna kuning kehijauan sebesar 14.60 kg/cm^2. Selama proses pematangan, kekerasan buah jambu biji akan mengalami pelunakan (Hong, *et al*., 2012). Proses penguraian pati menjadi gula, pemecahan dinding sel yang diakibatkan perombakan protopektin yang larut dalam air, dan perombakan selulosa menyebabkan buah menjadi lunak (Ali, *et al*., 2004).

Analisis sidik ragam yang dilanjutkan dengan uji Beda Nyata Terkecil (BNT) untuk setiap parameter fisik menyatakan bahwa klasifikasi tingkat kematangan buah tidak direpresentasikan secara nyata oleh peubah bobot dan kekerasan buah, baik pada taraf signifikansi α = 0.05 maupun α = 0.15. Hal ini menjadi penanda bahwa pengklasifikasian tingkat kematangan buah berdasarkan parameter fisik buah (warna, bobot, kekerasan buah) dapat kurang tepat. Meskipun tingkat kematangan buah yang direpresentasikan dengan parameter fisik tidak berbeda nyata secara statistik, namun demikian penerapan (*sensoring*) suhu buah dapat mengikuti perubahan tingkat kematangan buah. Hubungan antara suhu yang dipencarkan buah dengan kekerasan buah menunjukkan korelasi yang sangat kuat (R^2 = 0.997). Semakin masak buah, diikuti dengan penurunan kekerasan dan kenaikan suhu buah. Sementara itu, korelasi suhu buah dengan bobot buah sangat lemah (R^2 = 0.068).

Tabel 1. Hasil pengukuran suhu dan mutu fisik (bobot dan kekerasan) buah jambu biji ‘Kristal’ pada tiga tingkat kematangan

Tingkat kematangan	T (°C)		Bobot (gram)		Kekerasan (kg/cm2)	
	(α=5%)	(α=15%)	(α=5%)	(α=15%)	(α=5%)	(α=15%)
Hijau	27.85 a	27.85 b	252.37 b	252.37 b	15.61 a	15.61 a
Hijau kekuningan	27.89 a	27.89 ab	346.90 a	346.90 a	15.50 a	15.50 a
Kuning kehijauan	28.10 a	28.10 a	308.73 ab	308.73 ab	14.60 a	14.60 a
Koefisien regresi (R^2) terhadap suhu buah			0.068		0.997	

Keterangan : Angka-angka yang diikuti oleh huruf yang berbeda pada kolom yang sama adalah berbeda nyata pada uji BNT taraf 15%

Tabel 2. Hasil pengukuran mutu kimia buah jambu biji 'Kristal' pada tiga tingkat kematangan

Tingkat kematangan	T (°C)		Brix (%)		Asam bebas (%)	Sukrosa (%)	Pati (%)
	(α=5%)	(α=15%)	(α=5%)	(α=15%)			
Hijau	27.85 a	27.85 b	7.40 b	7.40 b	4.10	3.80	0.92
Hijau kekuningan	27.89 a	27.89 ab	7.94 ab	7.94 ab	4.02	4.16	0.82
Kuning kehijauan	28.10 a	28.10 a	8.53 a	8.53 a	3.90	4.88	0.70
Koefisien regresi (R^2) terhadap suhu buah			0.886		0.936	0.968	0.903

Keterangan : Angka-angka yang diikuti oleh huruf yang berbeda pada kolom yang sama adalah berbeda nyata pada uji BNT taraf 15%

Hasil pengujian tingkat kematangan buah jambu biji 'Kristal' yang dinyatakan dengan peubah kimia: Brix, asam bebas, sukrosa dan pati ditunjukkan pada Tabel 2. Berdasarkan Tabel 2, kenaikan tingkat kematangan buah diikuti dengan kenaikan Brix, penurunan asam bebas, kenaikan sukrosa, dan penurunan kandungan pati. Hasil kecenderungan ini sesuai dengan penelitian Killadi dkk. (2018) pada buah jambu 'shweta' dan 'lalit',

Dari Tabel 2 juga diperoleh informasi bahwa kandungan brix pada buah jambu biji 'Kristal' berwarna kuning kehijauan memiliki nilai tertinggi sebesar 8.53% dibandingkan buah berwarna hijau kekuningan sebesar 7.94% dan hijau sebesar 7.40%. Kandungan padatan terlarut buah jambu biji 'Kristal' meningkat dengan semakin bertambah masaknya buah karena terjadi perombakan pati menjadi gula (Widodo, 2009). Hal ini diikuti dengan penurunan kandungan asam bebas dari buah berwarna hijau memiliki nilai tertinggi sebesar 4.10% dibandingkan dengan buah berwarna hijau kekuningan sebesar 4.02% dan kuning kehijauan sebesar 3.90%.

Hasil penelitian juga menunjukkan nilai kandungan sukrosa pada buah jambu biji 'Kristal' mengalami peningkatan dengan naiknya tingkat kematangan buah. Buah berwarna hijau memiliki kandungan sukrosa terendah yaitu sebesar 3.80%, selanjutnya buah berwarna hijau kekuningan memiliki kandungan sukrosa 4.16% dan buah berwarna kuning kehijauan sebesar 4.88%. Jambu biji merupakan buah klimakterik dan dapat terjadi perubahan kadar gula yang cukup besar selama pematangan (Dube, *et al*., 2015). Kandungan gula antar tingkat kematangan bervariasi dikarenakan faktor genetik atau fenotip atau dikarenakan tahap dalam pematangan (Kumari, *et al*., 2020). Kandungan pati pada buah jambu biji 'Kristal' mengalami penurunan. Buah berwarna hijau memiliki kandungan pati tertinggi yaitu sebesar 0.92% dibandingkan buah berwana hijau kekuningan sebesar 0.82% dan kuning kehijauan sebesar 0.70%. Menurut Dumadi (2001), perubahan tekstur buah menjadi lunak akan diikuti dengan peningkatan gula sederhana dan penurunan kadar pati.

Sama halnya dengan peubah fisik, hasil uji BNT terhadap peubah mutu kimia buah jambu biji 'Kristal' belum dapat dibedakan pada taraf signifikansi 5%, namun mampu membedakan tingkat kematangan buah pada α = 15%. Hubungan antara peubah mutu kimia buah jambu biji Kristal dengan suhu buah pada berbagai tingkat kematangan menunjukkan nilai korelasi yang cukup tinggi (R^2 > 0.8). Dengan demikian, suhu buah yang disensor dengan kamera inframerah, secara potensial dapat digunakan sebagai detektor tingkat kematangan buah jambu biji 'Kristal'.

KESIMPULAN

Dari hasil penelitian dapat dinyatakan bahwa kenaikan tingkat kematangan buah jambu biji 'Kristal' diikuti dengan penurunan kekerasan, kandungan asam bebas dan pati serta diikuti dengan kenaikan Brix dan sukrosa. Suhu buah yang disensor dengan *thermal camera* berkorelasi sangat kuat (koefisien regresi R^2 ~ 0.9) dengan parameter kematangan tersebut. Kenaikan kematangan buah diikuti dengan kenaikan suhu buah. Suhu buah berkorelasi terhadap mutu fisik yaitu kekerasan dan mutu kimia yaitu Brix, asam bebas, sukrosa, dan pati pada buah jambu biji 'Kristal'. Metode *thermal image* potensial untuk digunakan sebagai pendeteksi tingkat kematangan buah jambu biji 'Kristal'.

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