UNIVERSITI PUTRA MALAYSIA

DEGREEING CHARACTERISTIC OF MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' BANANAS

PHEBE DING.

FP 2004 22
DEGREEING CHARACTERISTICS OF MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' BANANAS

PHEBE DING

DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA
2004
DEGREEING CHARACTERISTICS OF MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' BANANAS

By

PHEBE DING

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

March 2004
A study was conducted on the changes in cellular structure, physiology and physio-
chemical of *Musa* AAA ‘Berangan’ and ‘Cavendish’ as the ripening progressed at
18±2 and 27±2 °C. Mature green (ripening stage (RS) 1) bananas were initiated to
ripen using 0.02% acetylene from calcium carbide (CaC$_2$) source (with an equivalent
of 1 g CaC$_2$ kg$^{-1}$ fruit) for 24 h. A hand of Berangan and Cavendish fruit was split
into 2 clusters. One of the clusters was initiated and ripened at 18±2 °C RH 90-
94%, while the other was initiated and ripened at 27±2 °C RH 75-80%. The
experiment was conducted using randomized complete block design with four
replications. Five fruits per replicate were used. The various ripening stages were
evaluated with the aid of FAMA visual colour score until the fruit turned into full
*yellow at RS 6. For the Cavendish ripened at 27±2 °C (C27) where the fruit failed
to degreen, the evaluation was done daily until senescence, when brown specks
appeared on the peel. Data from measurements of ripening duration, L*, C* and h°
values, chlorophyll *a, b* and total chlorophylls, water loss, stomatal density, stomatal
length and opening, peel thickness, peel and pulp fresh and dry weight, cell length and width of photosynthetic, epidermal, crystalliferous, tanniferous and starch granules, pulp firmness, soluble solids concentration (SSC), titratable acidity and pH were analysed using analysis of variance and differences between means were determined by Duncan Multiple Range Test. Data from starch iodine test, cellular structure and ultrastructure were documented as photographs or micrographs. Berangan degreened naturally under tropical ripening temperature of 27±2 °C, and a golden yellow fruit of RS 6 was obtained within 4 d of ripening. In contrast, Cavendish failed to degreen at 27±2 °C even though the pulp had softened. By day 5 after the acetylene treatment brown specks started to appear on the fruit surface indicating senescence had commenced. Cavendish could only degreen when ripened at 18±2 °C, and a yellow fruit of RS 6 was obtained after 9 d of ripening. On the contrary, Berangan could not degreen and ripen under 18±2 °C thus the fruit was discarded. TEM revealed that at RS 6 the grana-thylakoid membrane of chromoplast Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 °C (C18) had lysed. Besides, plastoglobuli increased in number, and types of staining density and vesicles increased in number and size. However at day 5 of C27, the grana-thylakoid membrane retained and this was in concurrent with the high retention of chlorophyll content in fruit peel. The total chlorophyll retained in C27 was 57%, while only 25 and 40% of total chlorophyll was retained in B27 and C18 respectively. The high retention of chlorophyll content in C27 had caused it to correlate significantly with L*, C* and h° values. Among B27, C18 and C27, C27 encountered the most water loss. However, there was no correlation between water loss and stomatal density and opening. The existence of cracks and pores on the banana peel surface could be the
passage for water loss. The severe water loss caused the peel thickness of C27 to be the thinnest among the bananas studied although initially its peel was thicker than B27. The fruit pulp and peel behaved differently towards ripening temperature. The moisture content in pulp increased, while no moisture content in peel decreased as ripening progressed. This led to increase of pulp to peel fresh weight ratio and C27 had the highest ratio as compared to C18 and B27. The softening of the banana fruit was due to starch degradation and dissolution of middle lamellae. SEM revealed that the pulp starch granules decreased in size and density as ripening progressed. The blue-black stained area of starch-iodine complex cleared from the central core of fruit towards the periphery of peel in all the bananas studied. The clearing pattern was most rapid in C27. The hydrolysed starch increased the SSC of all the bananas studied but the most significant increase was in C27. The titratable acidity of the three bananas studied increased then decreased as ripening progressed. In contrast, the pH decreased then increased as contrary to the trend of titratable acidity. The tropical temperature of 27±2 °C, besides failing to degreen, had caused poor keeping and eating quality of Cavendish.
Abstrak tesis yang dikenakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN PENYAHHIJAUAN PADA PISANG, MUSA AAA 'BERANGAN' DAN 'WILLIAM CAVENDISH'

Oleh

PHEBE DING

Mac 2004

Pengerusi: Profesor Madya Siti Hajar Ahmad, Ph.D.

Fakulti: Pertanian

Suatu kajian dijalankan ke atas perubahan struktur sel, fisiologi dan fiziko-kimia semasa proses kemasakan pada Musa AAA 'Berangan' dan 'Cavendish' yang diranumkan pada suhu 18±2 dan 27±2 °C. Pisang yang hijau matang (Peringkat Kematangan (PK) 1) diperam dengan menggunakan 0.02% asetilena yang dibebaskan dari sumber kalsium karbida (CaC₂) (bersamaan dengan 1 g CaC₂.kg⁻¹ buah) selama 24 j. Sesikat Berangan dan Cavendish dipisahkan kepada dua bahagian. Salah satu bahagian diperam dan diranum pada suhu 18±2 °C dengan kelembapan relatif (RH) 90-94%. Manakala bahagian yang lain diperam dan diranum pada suhu 27±2 °C RH 75-80%. Ujikaji dijalankan dengan menggunakan rekabentuk blok rawak lengkap dengan empat replikasi. Sebanyak lima biji buah/replikasi digunakan. Penilaian dibuat berdasarkan peringkat kemasakan dengan Panduan Carta Warna FAMA sehingga buah mencapai kuning sepenuhnya pada PK 6. Untuk buah Cavendish yang diranum pada suhu 27±2 °C (C27) di mana buah gagal menyahhijau, penilaian dijalankan setiap hari sehingga senesens di mana...
bintik perang kelihatan pada kulit buah. Data-data masa peranuman, nilai-nilai L*, C* dan h°, klorofil a, b dan jumlah klorofil, kehilangan air, ketumpatan stomata, panjang dan lebar stomata, ketebalan kulit, jisim segar dan kering kulit dan isi, panjang dan lebar untuk sel-sel fotosintetik, epidermis, 'crystalliferous' dan 'tanniferous' dan butiran kanji, kekerasan isi, jumlah kandungan pepejal terlarut, asid tertitrat dan pH dianalisa dengan menggunakan kaedah analisis varian dan perbezaan antara setiap min ditentukan dengan menggunakan kaedah 'Duncan Multiple Range Test'. Data ujian iodin terhadap kanji, struktur dan ultrastruktur sel dicatatkan sebagai gambar foto atau mikro. Berangan dapat menyahhijau secara semula jadi di bawah suhu tropikal pada 27±2 °C dan buah kuning keemasan diperolehi selepas 4 hari peranuman. Sebaliknya Cavendish tidak dapat menyahhijau pada suhu 27±2 °C sungguhpun isinya sudah lembut. Pada hari ke-5 selepas dirawat dengan dengan asetilena, bintik perang mulai kelihatan pada kulit buah yang menandakan bermulanya senesens. Cavendish hanya boleh dinyahhijau apabila diranum pada suhu 18±2 °C dan buah berwarna kuning penuh pada PK 6 selepas 9 hari diranum Sebaliknya Berangan tidak dapat dinyahhijau dan masak pada suhu 18±2 °C. Penemuan melalui TEM mendapati pada PK 6, membran grana-tilakoid pada kromoplast Berangan yang diranum pada 27±2 °C (B27) dan Cavendish yang diranum pada suhu 18±2 °C (C18) sudah lisis. Selain itu, bilangan dan jenis darjah kepekatan pewarnaan elektron plastoglobuli bertambah dan bilangan dan saiz vesikel juga bertambah. Tetapi, pada hari ke-5, membran grana-tilakoid C27 masih kelihatan dan ini adalah sejajar dengan pengekalan kandungan klorofil yang tinggi pada kulit buah. Jumlah klorofil yang masih wujud pada C27 adalah 57% sementara hanya 25 dan 40% jumlah klorofil yang tinggal pada B27 dan
tropikal pada 27±2 ℃ selain menyebabkan kegagalan menyahhijau, ia juga telah menurunkan kualiti penyimpanan dan nilai pemakanan pada Cavendish.
I wish to express my sincere thanks and gratitude to my supervisors, Associate Professor Dr. Siti Hajar Ahmad, a Postharvest Physiologist, Professor Dr. Abdul Rahman Abdul Razak, a Cellular Developmental Biologist, Associate Professor Dr. Nazamid Saari, an Enzymologist and Associate Professor Dr. Tengku Mahmud Tengku Mohamed, a Postharvest Physiologist for their invaluable advice, guidance, ideas, encouragement and patience throughout the course of this study.

Thanks are also due to the staff and friends of the Postharvest Laboratory, Electron Microscopy Unit, Histology Laboratory and Enzyme Laboratory who had helped me in completing this experiment successfully.

Finally, my sincere appreciation to my dearest dad, step-mother, sister, brother and friends for their understanding, patience and moral support throughout my study.
I certify that the Examination Committee have met on 25th March, 2004 to conduct the final examination of Phebe Ding on her Doctor of Philosophy thesis entitled “Degreening Characteristics of Musa AAA ‘Berangan’ and ‘William Cavendish’ Bananas” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommended that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

**Gulam Rusul Rahmat Ali, Ph.D.**  
Professor  
Faculty of Food Science and Biotechnology  
Universiti Putra Malaysia  
(Chairman)

**Siti Hajar Ahmad, Ph.D.**  
Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Abdul Rahman Abdul Razak, Ph.D.**  
Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Nazamid Saari, Ph.D.**  
Associate Professor  
Faculty of Food Science and Biotechnology  
Universiti Putra Malaysia  
(Member)

**Mahmud Tengku Muda Tengku Mohamed, Ph.D.**  
Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

GULAM RUSUL RAHMAT ALI, Ph.D.  
Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia  
Date: 30 JUN 2004
This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

**Siti Hajar Ahmad, Ph.D.**
Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Abdul Rahman Abdul Razak, Ph.D.**
Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

**Nazamid Saari, Ph.D.**
Associate Professor  
Faculty of Food Science and Biotechnology  
Universiti Putra Malaysia  
(Member)

**Mahmud Tengku Muda Tengku Mohamed, Ph.D.**
Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, Ph.D.**  
Professor/Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 09 JUL 2004
DECLARATION

I hereby declare that the dissertation based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been submitted for any other degree at UPM or other institutions.

Date: 22/6/04

PHEBE DING
TABLE OF CONTENTS

ABSTRACT \hspace{13cm} ii
ABSTRAK \hspace{13cm} v
ACKNOWLEDGEMENTS \hspace{13cm} ix
APPROVAL \hspace{13cm} x
DECLARATION \hspace{13cm} xii
LIST OF TABLES \hspace{13cm} xvi
LIST OF FIGURES \hspace{13cm} xix

CHAPTER

1 \hspace{1cm} INTRODUCTION \hspace{1cm} 1.1

2 \hspace{1cm} LITERATURE REVIEW \hspace{1cm} 2.1
2.1 Banana \hspace{1cm} 2.1
2.2 Fruit Ripening \hspace{1cm} 2.5
2.3 Peel Degreening of Banana \hspace{1cm} 2.14
\hspace{1cm} 2.3.1 Structure of Chloroplast \hspace{1cm} 2.15
\hspace{1cm} 2.3.2 Ultrastructural Changes of Chloroplast during Degreening \hspace{1cm} 2.15
\hspace{1cm} 2.3.3 Chlorophyll \hspace{1cm} 2.17
2.4 Water Loss and Peel Surface Morphology \hspace{1cm} 2.20

3 \hspace{1cm} CHANGES IN PEEL COLOUR OF MUSA AAA ‘BERANGAN’ AND ‘WILLIAM CAVENDISH’ DURING RIPENING \hspace{1cm} 3.1
3.1 Introduction \hspace{1cm} 3.1
3.2 Materials and Methods \hspace{1cm} 3.3
\hspace{1cm} 3.2.1 Plant Materials \hspace{1cm} 3.2
\hspace{1cm} 3.2.2 Ripening Duration Determination \hspace{1cm} 3.3
\hspace{1cm} 3.2.3 Peel Colour Determination \hspace{1cm} 3.4
\hspace{1cm} 3.2.4 Chlorophyll Determination \hspace{1cm} 3.5
\hspace{1cm} 3.2.5 Statistical Analysis \hspace{1cm} 3.6
3.3 Results and Discussion \hspace{1cm} 3.6
\hspace{1cm} 3.3.1 Ripening Duration \hspace{1cm} 3.6
\hspace{1cm} 3.3.2 Peel Colour \hspace{1cm} 3.9
\hspace{1cm} 3.3.3 Chlorophyll Content \hspace{1cm} 3.13
3.4 Conclusion \hspace{1cm} 3.30

4 \hspace{1cm} CHANGES IN PEEL PLASTID OF MUSA AAA ‘BERANGAN’ AND ‘WILLIAM CAVENDISH’ DURING DEGREEENING \hspace{1cm} 4.1
4.1 Introduction \hspace{1cm} 4.1
4.2 Materials and Methods \hspace{1cm} 4.3
4.2.1 Plant Materials 4.3
4.2.2 Plastid Ultrastructural Studies 4.3
4.2.3 Statistical Analysis 4.4
4.3 Results and Discussion 4.4
4.3.1 Plastid Structural Changes 4.4
4.3.2 Granal-thylakoid Lamellae Changes 4.14
4.3.3 Plastoglobuli Number and Density and Vesicle Number Changes 4.19
4.4 Conclusion 4.24

5 FRUIT WATER LOSS IN RELATION TO PEEL SURFACE MORPHOLOGY AND PHYSICAL PROPERTIES OF MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' DURING DEGREEING 5.1
5.1 Introduction 5.1
5.2 Materials and Methods 5.2
5.2.1 Plant Materials 5.2
5.2.2 Water Loss Determination 5.2
5.2.3 Peel Surface Area to Fruit Volume Ratio Determination 5.3
5.2.4 Stomatal Density Determination 5.3
5.2.5 Stomatal Length and Opening Determination 5.4
5.2.6 Photosynthetic Cells Size Determination 5.5
5.2.7 Peel Thickness Determination 5.5
5.2.8 Statistical Analysis 5.5
5.3 Results and Discussion 5.6
5.3.1 Water Loss 5.6
5.3.2 Stomatal Density 5.11
5.3.3 Stomatal Length and Opening 5.21
5.3.4 Peel Thickness 5.26
5.3.5 Photosynthetic Cells Length and Width 5.29
5.4 Conclusion 5.34

6 RELATION BETWEEN PULP AND PEEL OF MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' DURING RIPENING 6.1
6.1 Introduction 6.1
6.2 Materials and Methods 6.3
6.2.1 Plant Materials 6.3
6.2.2 Pulp and Peel Content Determination 6.3
6.2.3 Pulp to Peel Fresh Weight Ratio Determination 6.3
6.2.4 Pulp and Peel Moisture Content Determination 6.4
6.2.5 Pulp and Peel Dry Matter Determination 6.4
6.2.6 Cell Macrostructural Studies 6.4
6.2.6.1 Tissue Preparation for SEM Studies 6.4
6.2.6.2 Tissue Preparation for Light Microscopic Studies 6.5
6.2.7 Statistical Analysis

6.3 Results and Discussion

6.3.1 Pulp and Peel Content

6.3.2 Pulp to Peel Fresh Weight Ratio

6.3.3 Pulp and Peel Moisture Content

6.3.4 Pulp and Peel Dry Matter

6.3.5 Cell Macrostructural Changes

6.3.5.1 Epidermal Layer of Peel Region

6.3.5.2 Peel-pulp Transition Region

6.3.5.3 Pulp Region

6.4 Conclusion

7 PHYSICO-CHEMICAL CHANGES IN MUSA AAA 'BERANGAN' AND 'WILLIAM CAVENDISH' DURING RIPENING

7.1 Introduction

7.2 Materials and Methods

7.2.1 Plant Materials

7.2.2 Pulp Firmness Determination

7.2.3 Peel Ultrastructural Studies

7.2.4 Starch Iodine Test

7.2.5 Pulp Starch Granules Size Determination

7.2.6 Soluble Solids Concentration Determination

7.2.7 Titratable Acidity Determination

7.2.8 pH Determination

7.2.9 Statistical Analysis

7.3 Results and Discussion

7.3.1 Pulp Firmness

7.3.2 Peel Ultrastructural Changes During Ripening

7.3.2.1 Peel Ultrastructural Changes of Berangan Ripened at 27±2 °C

7.3.2.2 Peel Ultrastructural Changes of Cavendish Ripened at 18±2 °C

7.3.2.3 Peel Ultrastructural Changes of Cavendish Ripened at 27±2 °C

7.3.3 Pulp Starch Granules

7.3.4 Starch Pattern

7.3.5 Soluble Solids Concentration

7.3.6 Titratable Acidity

7.3.7 pH

7.4 Conclusion

8 CONCLUSION

BIBLIOGRAPHY

BIO_DATA OF THE AUTHOR
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Duration for each stage of ripening of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 °C.</td>
</tr>
<tr>
<td>2</td>
<td>Effects of ripening stage or days after acetylene treatment on peel colours (L*, C* and h*) of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>3</td>
<td>Effects of ripening stage or days after acetylene treatment on chlorophyll a (Chl a) and b (Chl b), total chlorophyll (Total chl) and chlorophyll a/b ratio (Chl a/b ratio) of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>4</td>
<td>Correlation coefficients (r) for chlorophyll a (Chl a) and b (Chl b), total chlorophyll (T chl), chlorophyll a/b ratio (Chl a/b), L*, C* and h° of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>5</td>
<td>Effects of ripening stage (RS) or days after acetylene treatment (DAAT) on length and width ± SD in ten chloroplasts of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>6</td>
<td>Effects of ripening stage (RS) or days after acetylene treatment (DAAT) on granum length and number of thylakoid per stack of granum in ten chloroplasts of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>7</td>
<td>Effects of ripening stage (RS) or days after acetylene treatment (DAAT) on diameter ± SD of five differential electron staining densities of plastoglobuli and vesicles of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>8</td>
<td>Effects of ripening stage or days after acetylene treatment on water loss and water loss rate of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.</td>
</tr>
<tr>
<td>9</td>
<td>Main and interaction effects of six ripening stages (RS) or days after acetylene treatment (D), five faces (F) and three regions (R) of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C on stomatal density per mm².</td>
</tr>
<tr>
<td>10</td>
<td>Correlation coefficients (r) for water loss (WL), stomatal density (SD), stomatal opening (SO), peel thickness (Thick) and photosynthetic cell width (Width) of the first five-layer peel cells in Berangan and Cavendish during ripening.</td>
</tr>
</tbody>
</table>
Effects of ripening stage or days after acetylene treatment on stomatal length and opening of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Effects of ripening stage or days after acetylene treatment on peel thickness of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Effects of ripening stage or days after acetylene treatment on photosynthetic cell length and width of the first five layers of cells in peel of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Effects of ripening stage or days after acetylene treatment on the percentage of pulp and peel content and pulp:peel fresh weight (P/p) of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Effects of ripening stage or days after acetylene treatment on the percentage of pulp and peel moisture content of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Effects of ripening stage or days after acetylene treatment on the percentage of pulp and peel dry matter of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C.

Correlation coefficients (r) for pulp to peel fresh weight ratio (p/p), pulp content, peel content, pulp moisture content (Pulp MC), peel moisture content (Peel MC), pulp dry matter (Pulp DM), peel dry matter (Peel DM), peel thickness and water loss of Berangan ripened at 27±2 °C.

Correlation coefficients (r) for pulp to peel fresh weight ratio (p/p), pulp content, peel content, pulp moisture content (pulp MC), peel moisture content (peel MC), pulp dry matter (pulp DM), peel dry matter (peel DM), peel thickness (Thick), and water loss of Cavendish ripened at 18±2 °C.

Correlation coefficients (r) for pulp to peel fresh weight ratio (p/p), pulp content, peel content, pulp moisture content (pulp MC), peel moisture content (peel MC), pulp dry matter (pulp DM), peel dry matter (peel DM), peel thickness (Thick), and water loss of Cavendish ripened at 27±2 °C.

Effects of ripening stage or days after acetylene treatment (DAAT)² on epidermal cell length and width of Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 (C18) and 27±2 °C (C27).

xvii
| 21 | Effects of ripening stage or days after acetylene treatment (DAAT) on crystalliferous idioblast cell length, width and frequency at peel region of Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 °C (C18) and 27±2 °C (C27). | 6.38 |
| 22 | Effects of ripening stage or days after acetylene treatment (DAAT) on tanniferous cells length, width and frequency at peel region of Berangan ripened at 27±2 °C (B27), Cavendish ripened at 18±2 (C18) and 27±2 °C (C27). | 6.42 |
| 23 | Effects of ripening stage or days after acetylene treatment (DAAT) on crystalliferous idioblast cell number, length and width at peel-pulp transition region of Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 (C18) and 27±2 °C (C27). | 6.56 |
| 24 | Effects of ripening stage or days after acetylene treatment (DAAT) on bead-like structure of coagulated latex cell length and width at peel-pulp transition region of Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 (C18) and 27±2 °C (C27). | 6.57 |
| 25 | Effects of ripening stage or days after acetylene treatment (DAAT) on tanniferous cell frequency, length and width at peel-pulp transition region of Berangan ripened at 27±2 °C (B27) and Cavendish ripened at 18±2 (C18) and 27±2 °C (C27). | 6.59 |
| 26 | Effects of ripening stage or days after acetylene treatment on pulp firmness, SSC, titratable acidity and pH of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C. | 7.7 |
| 27 | Correlation coefficients (r) for pulp firmness (Firm), soluble solids concentration (SSC), titratable acidity (TA), pH and peel colours (L*, C* and h°) of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C. | 7.13 |
| 28 | Effects of ripening stage or days after acetylene treatment on pulp starch granules length and width of Berangan ripened at 27±2 °C and Cavendish ripened at 18±2 and 27±2 °C. | 7.35 |
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structure of chlorophyll a. Chlorophyll b differs from chlorophyll a by having an aldehyde group (-CHO).</td>
<td>2.18</td>
</tr>
<tr>
<td>2</td>
<td>TEM micrograph of a Berangan chloroplast at ripening stage 1, ripened at 27±2 °C. (A) The plasma membrane (pm), rough endoplasmic reticulum (rer), mitochondria (mc) and chloroplast with grana (g), thylakoid (th) and plastoglobuli (pg) were near to cell wall (cw). Peripheral reticulum could be seen in this plastid (dashed arrow). x 20,000; bar = 0.47 μm (B) The chloroplast, near to cell wall (cw) was full of plastoglobuli (pg) and perforated grana-thylakoid membranes (arrow). x 50,000; bar = 197 nm.</td>
<td>4.5</td>
</tr>
<tr>
<td>3</td>
<td>TEM micrograph of a Berangan chloroplast at ripening stage 3, ripened at 27±2 °C. (A) The disc shape of chloroplast with plastoglobuli (pg), grana (g) and thylakoid (th) networks and peripheral reticulum (arrowhead). t = tonoplast; cw = cell wall. x 20,000; bar = 0.47 μm (B) Some portion of the grana (arrow) became diffuse (dashed arrow) as lysis had taken place. The peripheral reticulum (arrowhead) and plastoglobuli (pg) sandwiched the grana-thylakoid network. x 100,000; bar = 97 nm.</td>
<td>4.5</td>
</tr>
<tr>
<td>4</td>
<td>TEM micrograph of a Berangan chromoplast at ripening stage 6, ripened at 27±2 °C. The peripheral reticulum (arrow) and electron non-dense area (circle) are seen in these four chromoplasts. The granal-thylakoid membranes are hardly seen. (A) The oval shape of chromoplast containing electron dense plastoglobuli (<em>). x 25,000; bar = 245 nm (B) Another oval shape of chromoplast contains starch grains (s), electron dense (</em>) and core electron dense (dashed circle) plastoglobuli. The electron dense deposits (**) scattered mainly in the middle lamella region of cell wall (cw). mc = mitochondria; x 16,000; bar = 0.64 μm (C) The swollen elongated shape of chromoplast with large vesicles (v) contains fibrilar material. mc = mitochondria; x 20,000; bar = 0.47 μm (D) The elongated shape of chromoplast composes of spiral vesicles with fibrilar material (v), crystal (cr) and starch grain (s). The quantity of plastoglobuli is much less than those at Fig. 3A. x 20,000; bar = 0.5 μm.</td>
<td>4.6</td>
</tr>
<tr>
<td>5</td>
<td>TEM micrograph of a Cavendish chloroplast at ripening stage 1, ripened at 18 ± 2 °C. (A) A chloroplast near the cell wall (cw) and plastoglobuli (pg) distributed randomly in it. pm = plasma membrane, va = vacuole, t = tonoplast. x 12500; bar = 0.6 μm (B) The disc shaped chloroplast (chr) near the cell wall (cw). The plasma membrane (pm) is invaginated into cytoplasm as a</td>
<td>xix</td>
</tr>
</tbody>
</table>
concentric ring (i). Plastoglobuli (pg) are distributed randomly in stroma. The tripartite structure of thylakoid (thy) and granum (g) membranes are seen. x 63,000; bar = 170 nm (C). The invaginations (large solid arrowhead) of the inner envelope membranes form a peripheral reticulum (single arrow) in the chloroplast (chr). The invaginations lead into dilated sacs, pierced by many perforations through which the stroma penetrates (dashed arrow). x 63,000; bar = 170 nm.

TEM micrograph of a Cavendish chloroplast at ripening stage 3, ripened at 18±2 °C. (A) The disc shaped of chloroplast with a peripheral reticulum (arrow). The non-electron dense (*), core electron dense (**), and electron dense (***), plastoglobuli are seen. Notice the thin band of cytoplasm surrounding the chloroplast. x 20,000; bar = 0.5 μm (B) The perforation in thylakoids is large (single arrow), while the perforation in grana is tiny (dashed arrow). x 50,000; bar = 200 nm (C) The chloroplast with crystals (cr) and vesicles (v). X 20,000; bar = 0.5 μm.

TEM micrograph of a Cavendish chromoplast at ripening stage 6, ripened at 18±2 °C. (A) The shape of the plastid has transformed into oval and it is called a chromoplast (chm). x 12,500; bar = 0.88 μm (B) The thylakoid-granal system has disintegrated. The granum stack is hardly seen and only short perforated thylakoids (dashed arrow) are noticed. The large vesicles (v) occupied much space of the chromoplast, surrounded by mitochondria (mc). x 40,000; bar = 249 nm (C) Crystal (cr) is found in the chromoplast. Three vesicles (v) are also seen in the chromoplast. x 25,000; bar = 439 nm.

TEM micrograph of a Cavendish chloroplast at day 2, ripened at 27±2 °C after an acetylene treatment. (A) The elongated and swollen shape of the chloroplast with randomly scattered plastoglobuli (*). x 20,000; bar = 0.55 μm (B) The grana (g) are pushed to the peripheral, and the thylakoid (th) membranes are short and perforated (dashed arrow). The grana start to lysis and diffuse at the partition (arrow). Plastoglobuli with different electron staining densities and vesicles (v) can be noticed. The non-electron dense region (circle) is found. x 50,000; bar = 220 nm (C) The peripheral reticulum is obvious (arrow) and some part of the envelopes form an opening to the cytoplasm. A protuberance is observed at the opening (dashed arrow). x 50,000; bar = 220 nm.

TEM micrograph of a Cavendish chloroplast at day 5, ripened at 27±2 °C after an acetylene treatment. (A) and (B) The chloroplast is elongated in shape with different electron staining densities of plastoglobuli (*). Some of the non-dense region (circle) and grana
membranes are pushed to the peripheral as plastoglobuli filled the central region of the stroma. (C) The higher magnification of (A). Grana membranes (arrow) are pushed to the peripheral as plastoglobuli filled the central region of stroma (D) Vesicles (v), non-dense region (circle), perforated thylakoids (dashed arrow) and crystal (cr) are found. (A) x 25,000; bar = 439 nm (B) x 12,5000; bar = 0.65 μm (C) x 50,000; bar = 197 nm (D) x 31,500; bar = 250 nm.

TEM micrograph of a Cavendish chloroplast at day 5, ripened at 27±2 °C after an acetylene treatment. (E) The grana (g) lysis at the partitions and locules, and are less sharply defined (g1), while at g2 the membranous structure is essentially lost. x 200,000; bar = 30 nm (F) The single lamellae of the thylakoid encircle plastoglobuli (pg). The peripheral reticulum (dashed arrow) can be seen. x 100,000; bar = 100 nm.

The five faces of a banana at transverse section.

Interreaction effects of face x region on stomatal density per mm² of peel of Berangan ripened at 27±2 °C. Mean separation within each face is by DMRT, $P \leq 0.05$.

Interaction effects of face x region on stomatal density per mm² of peel of Cavendish ripened at 18±2 °C. Mean separation within each face is by DMRT, $P \leq 0.05$.

Interaction effects of face x region on stomatal density per mm² of peel of Cavendish ripened at 27±2 °C. Mean separation within each face is by DMRT, $P \leq 0.05$.

Longitudinal section of ripening stage 1 Berangan ripened at 27±2 °C. (A) Camera lucida drawing. x 30; bar = 1 mm (B) SEM micrograph. x 23; bar = 1 mm.

SEM micrograph of longitudinal section of ripening stage 1 Berangan ripened at 27±2 °C at peel region. x 430.

SEM micrograph of papillae topography of ripening stage 1 Berangan ripened at 27±2 °C with stomatal complex. x 1,600.

SEM micrograph of stomatal complex with guard cells (gc) and subsidiary cells (sc) of ripening stage 1 Berangan ripened at 27±2 °C. The stomata were slightly opened. x 1,300.
SEM micrograph of stomatal complex with large opening of Cavendish ripened at 27±2 °C of ripening day 2. x 1,000. 6.24

SEM micrograph of papillae topography of ripening stage 6 of Cavendish ripened at 18±2 °C with three stomatal complexes. x 230. 6.25

SEM micrograph of well-defined epicuticular wax, that appeared like lamellae-strands, of ripening stage 1 Berangan ripened at 27±2 °C. x 2,700. 6.25

SEM micrograph of degenerated epicuticular wax of ripening stage 6 Cavendish ripened at 18±2 °C but was not as serious as those occurred in ripening stage 6 Berangan ripened at 27±2 °C. x 3,300. 6.27

SEM micrograph of completely degenerated wax and sunken stomata of ripening stage 6 Berangan ripened at 27±2 °C. x 1,200. 6.27

SEM micrograph of depressed epicuticular tips (arrow) of ripening day 2 Cavendish ripened at 27±2 °C. x 400. 6.28

SEM micrograph of distinct outline of epidermal cells and formation of gaps appearing as an opening (circle) at ripening stage 6 of Cavendish ripened at 18±2 °C. x 750. 6.28

SEM micrograph of cavity between epidermal cells (circle) of ripening stage 6 Cavendish ripened at 18±2 °C. x 1,300. 6.30

LM photograph of longitudinal section of ripening stage 1 Berangan ripened at 27±2 °C at peel region. Chloroplast (chr) was stained green with TBO. cu = cuticle, ep = epidermal cell, n = nucleus. x 500. 6.30

LM photograph of longitudinal section at ripening stage 3 of Berangan ripened at 27±2 °C at peel region. Tanniferous cell (tc) with coarse round bodies is stained green with TBO. Crystalliferous idioblast cell (cic) is not stained by TBO. cu = cuticle, ep = epidermal cell. x 400. 6.33

LM photograph of transverse section at ripening stage 1 of Berangan ripened at 27±2 °C at peel region. Laticifer (lc) with coagulated latex forms a ring to surround vascular bundle at bottom left of the photograph. cic = crystalliferous idioblast cell, tc = tanniferous cell, If = lignified fibre, xy = xylem, ph = phloem. 6.33
29. LM photograph of starch granule at peel-pulp transition region at ripening stage 1 of Berangan ripened at 27±2 °C. The hilum (arrowhead) of starch granule appear as refractive points under polarized light. x 1,000; bar = 50 μm.

30. SEM micrograph of longitudinal section at ripening stage 3 of Berangan ripened at 27±2 °C at peel region. The integrity of cells are as strong as those in ripening stage 1. cil = crystalliferous cell, lf = lignified fibre. x 300.

31. SEM micrograph of longitudinal section at ripening stage 6 of Berangan ripened at 27±2 °C at peel region. The cells are seen to loss integrity. x 430.

32. SEM micrograph of crystalliferous idioblast cell at ripening stage 2 of Cavendish ripened at 18±2 °C at peel region. The cell orientates horizontally along the axis of fruit. The bundle is composed by needle-like end points of calcium oxalate. x 1,200.

33. LM photograph of longitudinal section at ripening stage 3 of Berangan ripened at 27±2 °C at peel-pulp transition region. The fine amorphous polyphenol bodies (apb) appear in vessel. lc = laticifer, cl = coagulated latex. x 80.

34. SEM micrograph of transverse section at ripening stage 1 of Cavendish ripened at 18±2 °C at peel-pulp transition region. The vascular bundle tissues are formed by large metaxylem (mx), protoxylem (px) and phloem (ph). The starch granules (sg) are found in parenchymatous cells enclosing vascular bundle tissue. x 250.

35. SEM micrograph of scalariform perforation plates with membrane remnants at ripening stage 5 of Cavendish ripened at 18±2 °C in peel region. The perforation shows porous strands. x 1,300.

36. LM photograph of longitudinal section at ripening stage 1 of Berangan ripened at 27±2 °C at peel region. The fibres are elongated cell, slender with end tip (arrow head) lignified and narrow lumen. x 250; bar = 50 μm.

37. LM photograph of longitudinal section at ripening stage 1 of Cavendish ripened at 18±2 °C at peel region. The laticifer contains