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CHARACTERIZATION OF PHYSICO-CHEMICAL FEATURES OF TERUNG ASAM SARAWAK (Solanum lasiocarpum Dunal*) FRUIT DURING GROWTH, MATURATION AND RIPENING*

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By

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CHARACTERIZATION OF PHYSICO-CHEMICAL FEATURES OF TERUNG ASAM SARAWAK (*Solanum lasiocarpum* Dunal) FRUIT DURING GROWTH, MATURATION AND RIPENING

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Faculty : Agriculture

A study on characterizing the changes in physico-chemical, antioxidant activities and cellular structure of “terung asam Sarawak” fruit was conducted on weekly intervals from anthesis until fruit senescence. In this study, fully bloomed flowers of “terung asam” plant were tagged and the fruits were thinned to allow only one per cluster. The experiment was conducted by using a completely randomized design with twelve fruit replications for each week after anthesis (WAA). Logistic regression analysis was used to analyse morphological traits (fruit length, diameter, fresh weight and volume). Data from measurements of respiration rate and ethylene production, colour, moisture content, firmness, soluble solids concentration (SSC), pH, titratable acidity (TA), total phenolic content, total carotenoid content and antioxidant activities were analysed by using analysis of variance whereas means were separated by Duncan’s multiple range test (DMRT). Light microscopy (LM) and scanning electron microscopy (SEM) were utilized to document “terung asam” fruit’s growth at the cellular level. Results illustrated that “terung asam” fruit took about 115 days or 16 weeks from anthesis until ripening. The fruit exhibits a single sigmoid growth pattern where three physiological stages (S1, S2 and S3) were identified. At S1, cells of “terung asam” fruit went through rapid division, followed by cell expansion at S2 before reaching physiological maturity at S3. These changes were in accordance with cellular structure as observed under LM and SEM. “Terung asam” fruit appeared green in colour at the initial growth stage before it became yellow then orange at later weeks. The visual colour changes of “terung asam” fruit were tally with L^*, a^* and b^* values as fruit matured and ripened. Fruit firmness increased initially and then decreased during ripening whereas SSC and TA increased gradually as WAA progressed. In contrast, fruit pH decreased gradually as WAA progressed. As “terung asam” fruit matured and ripened, citric acid increased but succinic acid decreased. On the other hand, malic acid increased as fruit matured but

decreased when fruit ripened. Respiration and ethylene production rate of "terung asam" fruit were high at the initial stage of growth then reduced and remained constant at later stages. As for total carotenoid content, it was initially low in concentration and the carotenoid pigments started to accumulate as the fruit reached maturity and achieved the highest amount when fruit reached 16 WAA. Total phenolic content decreased at the early growth stage then started to increase as the fruit reached maturation and dropped again as the fruit reached 16 WAA. "Terung asam" fruit at 13 until 15 WAA displayed the highest amount of antioxidant activities, total phenolic content and vitamin C. "Terung asam" fruit's vitamin C at ripening stage can reach about 3 to 4 folds more than that of guava (*Psidium guajava* L.) fruit. Results from the current study concluded that "terung asam" fruit harvested at 14 WAA could be determined as optimum harvest maturity when the fruit has developed good organoleptic (firmness, moisture, SSC, TA, organic acids, etc.) and quality attributes (vitamin C, carotenoid content, phenolic content and antioxidant activities) during ripening. Since "terung asam" fruit is a promising fruit by having a high amount of vitamin C and total phenolic content (TPC), this fruit need to be intensively commercialized for fruit and food industries to explore and utilize "terung asam" fruit to its full potential. All in all, the physico-chemical, antioxidant activities and cellular structure of "terung asam" fruit changed as it grew, matured and ripened.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENCIRIAN FIZIKO-KIMIA BUAH TERUNG ASAM SARAWAK (*Solanum lasiocarpum* Dunal*)* SEMASA PERTUMBUHAN, KEMATANGAN DAN PERANUMAN

Oleh

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Suatu kajian tentang pencirian perubahan fiziko-kimia, aktiviti antioksida dan struktur sel buah terung asam Sarawak telah dijalankan pada selang seminggu dari antesis sehingga penuaan buah. Dalam penelitian ini, bunga terung asam yang mekar sepenuhnya telah ditandakan dan proses penjarangan dilakukan selepas berputik untuk memastikan hanya satu buah yang membesar di setiap jambak. Eksperimen ini dijalankan dengan menggunakan reka bentuk rawak lengkap dengan dua belas replikasi buah untuk setiap minggu selepas antesis (WAA). Ciri-ciri morfologi buah (panjang, diameter, berat dan isipadu) tertakluk kepada analisis regresi logistik. Data dari ukuran kadar pernafasan dan penghasilan etilena, warna, kandungan kelembapan, kekerasan, kepekatan pepejal terlarut (SSC), pH, keasidan titrat (TA), kandungan fenolik, kandungan karotenoid dan aktiviti antioksida telah dianalisa dengan menggunakan kaedah analisis varians manakala min dibezakan dengan menggunakan kaedah ujian pelbagai jarak Duncan (DMRT). Pertumbuhan buah terung asam di peringkat sel telah direkod dengan menggunakan mikroskop cahaya (LM) dan mikroskop pengimbas elektron (SEM). Keputusan kajian ini menunjukkan bahawa buah terung asam mengambil masa kira-kira 115 hari atau 16 minggu dari antesis sehingga ranum. Buah ini telah mempamerkan jenis pola pertumbuhan sigmoid di mana terdapat tiga peringkat fisiologi iaitu S1, S2 dan S3 telah dikenalpasti. Pada peringkat S1, pertumbuhan secara perlahan diperhatikan di mana pembahagian sel-sel giat berlaku. Apabila buah memasuki peringkat S2, pengembangan sel banyak berlaku sebelum buah tersebut mencapai kematangan fisiologi di peringkat S3. Perubahan ini adalah sejajar dengan perubahan struktur selular yang diperhatikan di bawah LM dan SEM. Pada peringkat pertumbuhan yang awal, buah terung asam adalah berwarna hijau sebelum ia berubah menjadi kuning pada peringkat matang dan oren pada

peringkat akhir pertumbuhan. Di sepanjang pertumbuhan, perubahan warna visual buah terung asam adalah sejajar dengan nilai-nilai *L**, *a** dan *b**. Kekerasan buah meningkat pada awal penilaian, kemudian ia menurun di sepanjang proses kematangan manakala SSC dan TA meningkat secara beransur-ansur ketika WAA berkembang. Sebaliknya, pH buah telah menurun secara beransur-ansur ketika WAA berkembang. Asid-asid organik seperti asid askorbik dan asid sitrik telah meningkat secara beransur-ansur ketika kematangan buah meningkat tetapi asid sukinik telah menurun secara beransur-ansur ketika buah matang dan ranum. Sebaliknya, asid malik telah meningkat semasa buah memcapai kematangan tetapi menurun sedikit ketika buah ranum. Peningkatan kedua-dua asid-asid organik dan SSC dalam buah ketika buah mencapai kematangan dan ranum telah membantu buah "terung asam" memiliki rasa masam yang unik. Kadar respirasi dan pengeluaran etilena buah terung asam adalah tinggi pada peringkat awal pertumbuhan sebelum kedua-duanya menurun kekal stabil pada peringkat akhir pertumbuhan. Untuk kandungan karotenoid dalam buah terung asam, ianya didapati hanya pada kadar yang rendah pada peringkat awal pertumbuhan dan pigmen karotenoid mula terkumpul ketika buah semakin matang dan berada pada jumlah yang tertinggi ketika buah mencapai 16 WAA. Jumlah kandungan fenolik menurun pada peringkat awal pertumbuhan dan kemudian meningkat ketika buah telah mencapai kematangan dan turun lagi ketika buah mencapai 16 WAA. Oleh itu, buah terung asam pada 13 WAA hingga 15 WAA telah menunjukkan jumlah aktiviti antioksidan, kandungan fenolik total dan vitamin C yang tertinggi. Kandungan vitamin C dalam buah terung asam apabila mencapai tahap keranuman adalah sekitar 3 hingga 4 kali lebih tinggi daripada buah jambu (*Psidium guajava* L.). Hasil dari kajian ini juga menunjukkan bahawa buah terung asam yang dituai pada 14 WAA dapat dianggap sebagai kematangan penuaian yang optimum disebabkan buah tersebut telah mempunyai perkembangan organoleptik yang baik (ketegasan, kelembapan, SSC, TA, asid-asid organik dan lain-lain) serta sifat-sifat kualiti (vitamin C, kandungan karotenoid, kandungan fenolik dan aktiviti antioksidan) semasa buah tersebut ranum. Memandangkan buah terung asam mempunyai potensi jumlah vitamin C dan kandungan fenolik (TPC) yang tinggi, buah ini perlu dikomersialkan secara intensif untuk industri buah dan makanan untuk meneroka dan memanfaatkan buah terung asam semaksimum yang mungkin. Secara keseluruhannya, adalah jelas bahawa kualiti buah terung asam berubah- ubah sepanjang ia berkembang, matang dan ranum.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

$(C_2H_3)NaO_2.3H_2O$	Sodium acetate
A	Absorbance
$A_{1\ cm}^{1\%}$	Absorption coefficient
ABTS	2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
$ABTS^{\cdot +}$	ABTS radical cation
ACC	1-Aminocyclopropane-1-carboxylic acid
ACO	ACC oxidase
ACS	ACC synthase
ANOVA	Analysis of variance
C_2H_4	Ethylene
$C_2H_4O_2$	Glacial acetic acid
CO_2	Carbon dioxide
CRD	Completely randomized design
DPPH	Diphenyl-2-picrylhydrazyl
DPX	Dibutylphthalate polystyrene xylene
ΔE_{ab}	Total colour differences
$FeCl_3.6H_2O$	Ferric chloride solution
$FeSO_4.7H_2O$	Ferrous sulphate
FRAP	Ferric ion reducing antioxidant power
GAE	Gallic acid equivalent
H_2SO_4	Sulphuric acid
*L**	Lightness
LM	Light microscopy
DMRT	Duncan's Multiple Ranged Test

N	Newton
NaCl	Sodium chloride
NaOH	Sodium hydroxide
$O\bullet^{2-}$	Superoxide anions
ORAC	Oxygen radical absorbance capacity
PE	Pectinesterase
PG	Polygalacturonase
PL	Pectate lyase
PPO	Polyphenol oxidases
RI	Refractive index
ROO•	Peroxyl radicals
ROS	Reactive oxygen species
SAM	S-adenosyl-L-methionine
SEM	Scanning electron microscope
SSC	Soluble solids concentration
TA	Titratable acidity
TE	Trolox equivalent
TPC	Total phenolic content
TPTZ	2,4,6-Tris (1-pyridyl)-5-triazine
USDA	United State Department of Agriculture
UV	Ultraviolet
WAA	Week after anthesis
β-GAL	β-Glactosidase

CHAPTER 1

INTRODUCTION

Terung Asam Sarawak (*Solanum lasiocarpum*) is one of the indigenous plant or wild fruit vegetable in the state of Sarawak, Malaysia, that belongs to the Solanaceae family of eggplant. It has a unique sour taste and is served as vegetables and flavouring in local dishes which is popular among locals (Dayod and Lim, 2015). Most eggplant, especially this indigenous “terung asam” Sarawak fruit contains a high amount of vitamin C with ample concentration of calcium, fiber, phosphorus and potassium (Jansen et al., 1996). However, it can be considered as underutilized crops due to insufficient genetic materials, germplasm collection, traditional knowledge, knowledge on uses as well as research and development activities (Dienngngan and Hasan, 2015). Up to date, there are only a number of “terung asam” accessions in Sarawak where they were assigned by the collector at different origin. For example, “Terung Mas” was collected in Semongok, Hairy in Rampangi, AC. No. 148 in Miri, AC. No. 155 in Mamdi and AC. No. 167 in Ensebang, Balai Ringin (Missnan, 2004). According to Shariah et al. (2013), growing of “terung asam” on intensively used land has been almost impossible due to the presence of bacterial wilt disease.

Nowadays, with the upsurge in demand, high market size and price especially in Sarawak state, “terung asam” plant has been planted as one of the local specialty fruit vegetables throughout the Sarawak. Shariah (2013) stated that the production of “terung asam” fruit was about 16 to 20 tonnes per hectare on average and with market price of about USD 1.43 - 2.39 per kilogram depending on quality and size. The “terung asam” fruit price is on par with other fruit and vegetables such as tomato (USD 2.06) and eggplant (USD 2.11) as reported in the latest average prices of daily commodity at the retail level by the Federal Agriculture Marketing Authority (FAMA, 2021). Hence, fruit growth which refers to a change in fruit physical measurements (weight, length, width, and volume) is of great importance (Valero and Serrano, 2010). According to Opara (2000), fruit growth also involves various physico-chemical and phytochemical changes that take place at both physical and cellular aspects which can be utilized as indices of fruit growth. These changes are associated with the chronological fruit development starting from flowering to maturity and senescence. The obtained cumulative data of the increment in physical measurements can then be used to show a simple or double-sigmoid curve depending on fruit species (Valero and Serrano, 2010).

On the other hand, fruit growth and development are also closely associated with increased cell number, cell size and intercellular air spaces at the cellular level (Valero and Serrano, 2010). Thus, fruit cellular characteristics can also provide additional information to support fruit growth and development. Tadesse et al. (2002) stated that understanding these changes is crucial in determining optimum harvest time which directly affects fruit postharvest life and quality. The authors further clarified that fruits harvested immature are more susceptible to mechanical damage, sagging and probably lose the ability to ripen properly. On the other hand, harvesting overripe fruits are often not applicable for commercial use due to their shorter shelf life. Therefore, there is a need to understand the process of fruit development and their maturity stages to help growers cope with fruit quality standards of market demand for further exploitation (Fawole and Opara, 2013a).

As to consumer acceptability, consumers tend to choose a better quality of fruit in term of fruit colour, taste and visual aspect (Fawole and Opara, 2013a). Fruit imports and accumulates water, minerals, sugar, amino acids, organic acids during growth and at the same time initiate production of flavour and aroma compounds (Conde et al., 2007). These changes are also closely related to fruit ripening, which can be defined as a process where fruits reach their final maturity and then undergo numerous physical and chemical changes (Thompson, 2003). Therefore, the physico-chemical changes in fruit during growth, such as firmness and colour (physical qualities); sugar, pH and organic acids (chemical qualities); respiration rate and ethylene gas production (physiological qualities) are indeed very essential in deciding the optimum fruit stage for consumer consumption or utilization (Fawole and Opara, 2013a). The group of phytochemicals such as phenolic compounds, flavonoids and vitamin C can also be used as indices of fruit growth since the amount of these phytochemicals is very much associated with fruit growth (Fawole and Opara, 2013b).

Various growth prediction and physico-chemical profiles have been created for crops, including brinjal (*Solanum melongena* L.) (Singh and Sharma, 1990) and tomato (*Lycopersicon esculentum*) (Kaur et al., 2006) vegetable fruit, but there is no such work being done on “terung asam” fruit yet. Most of the researchers working on “terung asam” only focus on cultural practices, fruit chemical composition and potential applications or importance without clearly describing which fruit growth stages that they used in their studies (Voon and Kueh, 1999; Shariah et al., 2013). Therefore, a comprehensive study including physico-chemical, cellular structure and phytochemical changes in “terung asam” fruit from fruit set until senescence was carried out. Understanding these changes will lead to appropriate identification of harvest time in order to maintain fruit quality and finally improve their productivity and profitability. Hence, the objectives of this study were:

1. To characterize the growth and development of “terung asam” fruit from fruit set to ripening

2. To investigate physico-chemical and phytochemical changes as well as cellular structure from fruit set to ripening.

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