UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF AQUEOUS EXTRACT OF MANGOSTEEN (Garcinia mangostana L.) PERICARP AND ITS APPLICATION IN THE FOOD SYSTEM

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By

TAN POH LEE

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Faculty : Food Science and Technology

Garcinia mangostana or generally known as mangosteen is one of the abundant plants utilized in numerous applications. Mangosteen pericarp which is supposedly become fruit waste is the predominantly part of plants being reviewed. These agro-food residues are worth to study because it can be one of the attractive sources of polyphenols and to replace the usage of the synthetic food antioxidants. Once the usage of mangosteen pericarp has becoming more popular to be investigated, it may bring positive impact in reducing the environmental pollution. Nevertheless, most of the earlier research on the extraction of mangosteen pericarp were studied by using solvent extraction methods but aqueous extraction of the mangosteen pericarp is still scarce. Thus, in this study, aqueous extraction of mangosteen pericarp was explored with the assisted of enzymes to obtain the bioactive compounds which can be used in food applications. Firstly, water extraction of mangosteen pericarp with the assistance of Celluclast® 1.5l and Pectinex Ultra SPL enzymes was optimized with fractional factorial design by response surface methodology. Optimized conditions obtained were 1.50% w/w of enzymes concentration, 18.75 liquid-solid ratio, reaction temperature at 30˚C, pH 3 and reaction time of 30 min and resulted 86.51% of DPPH, 86.77% of ABTS and 21.222 mg GAE/g of total phenolic content. Optimized mangosteen pericarp extract tentatively being identified to contain smeaxanthone *m/z* 395, apigenin-6-C-glucoside *m/z* 431, garcimangosone-C *m/z* 411, α-mangostin *m/z* 409, gartanin *m/z* 395, 1,5-dihydroxy-3-methoxy-2-(3-methyl-2-buten-1-yl)-9H-xanthen-9-one *m/z* 325, 8-desoxygartanin *m/z* 379 and γ-mangostin *m/z* 395 based on different retention times, *m/z* ratios and fragment ions identified by LC-MS/MS. Secondly, mangosteen pericarp extract possessed inhibition activity on four strains of bacteria, *Streptococcus pyogenes*, *Staphylococcus aureus*, *Streptococcus mutans* and *Porphyromonas gingivalis* with same MIC and MBC values at 15.63 µg/mL, 62.50 µg/mL, 125 µg/mL and 125 µg/mL. MTT assay was performed to evaluate the cytotoxicity level of the mangosteen pericarp extract and the result obtained showed that the optimized extract was nontoxic to the human embryonic kidney cell line, HEK293. Thirdly, two types of functional foods were developed, one was mangosteen pastilles (solid) and another one was mangosteen ready-to-drink

beverage (liquid). Three different formulations of functional foods for each category were developed and physicochemical stability and sensory evaluation were performed for storage period of 8 weeks. Moisture content, water activity, color, texture profile analysis and microbiological analysis for the mangosteen pastilles were determined. The moisture content and water activity of the mangosteen pastilles were decreased during storage and the color lightness of the mangosteen pastilles was significantly reduced ($p<0.05$) during storage stability study. Three formulations of mangosteen pastilles were proven to be shelf life stable. Formulation A with the highest amount of optimized mangosteen pericarp extract, gelatin and carrageenan gum has the highest scores for the aroma, texture, color and overall acceptability. Lastly, pH, total soluble solid, viscosity, color, microbiological analysis and antioxidant capacity (DPPH, ABTS and total phenolic content) of the mangosteen ready-to-drink beverage were performed and observed. A minimal increase in the total soluble solid content and significantly increase ($p<0.05$) of pH for the three formulations of mangosteen ready-to-drink beverage was observed during 8 weeks of storage stability study. For the first 4 weeks of storage, no microbial count, yeast and mold were detected, however, microbial growth was visible after storage for 4 weeks. Antioxidant capacities and total phenolic content of the mangosteen ready-to-drink beverage decreased during storage study. From the result obtained through the sensory evaluation, there's no significant difference was seen among the three formulations of mangosteen ready-to-drink beverage; however, the most acceptable formulation of the mangosteen ready-to-drink beverage is formulation A which has the highest amount of optimized mangosteen pericarp extract, mangosteen puree and apple juice concentrate. Enzyme-assisted water extraction of mangosteen pericarp is a green technique that is worth to explore especially for food manufacturer.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN EKSTRAK AKUEUS KULIT BUAH MANGGIS (*Garcinia mangostana* L.) DAN APLIKASINYA DALAM SISTEM MAKANAN

Oleh

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Garcinia mangostana atau umumnya dikenali sebagai manggis merupakan salah satu tanaman yang digunakan dalam banyak aplikasi. Kulit manggis yang sepatutnya menjadi sisa buah-buahan adalah bahagian pokok yang paling kerap dikaji. Sisa agro-makanan tersebut berbaloi untuk dikaji kerana ia akan menjadi salah satu sumber polifenol yang menarik dan dapat menggantikan pengunaan antioksidan makanan yang sintetik. Apabila penggunaan kulit manggis semakin popular untuk dikaji, ia mungkin akan membawa impak positif dalam pengurangan pencemaran alam sekitar. Namun demikian, kebanyakkan kajian terdahulu mengenai pengekstrakan kulit manggis adalah menggunakan kaedah pengekstrakan pelarut tetapi pengekstrakan akueus kulit manggis masih jarang dikaji. Justeru itu, dalam kajian ini, pengekstrakan akueus kulit manggis dengan bantuan enzim telah dikaji untuk menghasilkan sebatian bioaktif yang boleh digunakan dalam aplikasi makanan. Pertama sekali, kulit manggis diekstrak dengan cara pengekstrakan akueus dengan bantuan enzim Celluclast® 1.5l dan Pectinex Ultra SPL dan dioptimumkan dengan reka bentuk faktorial pecahan dengan metodologi respons permukaan. Keadaan optimum yang diperolehi adalah kepekatan enzim 1.46% w/w, nisbah cecair-pepejal 22.80, suhu tindak balas pada 30˚C, pH 3 dan masa reaksi 30 minit dan menghasilkan 86.51% DPPH, 86.77% ABTS dan 21.222 mg GAE/g jumlah kandungan fenolik. Ekstrak kulit manggis sementara dikenal pasti mengandungi smeaxanthone *m/z* 395, apigenin-6-C-glucoside *m/z* 431, garcimangosone-C *m/z* 411, α-mangostin *m/z* 409, gartanin *m/z* 395, 1,5-dihydroxy-3-methoxy-2- (3-metil-2-buten-1-yl) -9H-xanthan-9-one *m/z* 325, 8-desoxygartanin *m/z* 379 dan γ-mangostin *m/z* 395 berdasarkan masa pengekalan yang berbeza , nisbah *m/z* dan ion pecahan yang dikenal pasti oleh LC-MS/MS. Seterusnya, ekstrak kulit manggis didapati mempunyai aktiviti perencatan pada empat jenis bakteria, *Streptococcus pyogenes*, *Staphylococcus aureus*, *Streptococcus mutans* dan *Porphyromonas gingivalis* dengan nilai MIC dan MBC yang sama pada 15.63 µg/mL, 62.50 µg/mL, 125 µg/mL dan 125 µg/mL. Ujian MTT dilakukan untuk menilai tahap sitotoksisiti ekstrak kulit manggis dan hasil yang diperoleh menunjukkan bahawa ekstrak yang dioptimumkan tidak beracun pada sel ginjal embrio manusia, HEK293. Ketiga, dua jenis makanan berfungsi telah diformulasikan, satu adalah manggis pastil (pepejal) dan satu lagi minuman manggis siap

diminum (cecair). Tiga formulasi makanan berfungsi yang berbeza untuk setiap kategori dikembangkan dan kestabilan fizikokimia dan penilaian deria dilakukan dalam tempoh penyimpanan selama 8 minggu. Kandungan kelembapan, aktiviti air, warna, analisis profil tekstur dan analisis mikrobiologi untuk pastil manggis telah ditentukan. Kandungan kelembapan dan aktiviti air manggis pastil didapati menurun semasa penyimpanan dan keterangan warna manggis pastil juga berkurang dengan ketara ($p<0.05$) semasa kajian kestabilan penyimpana. Tiga formulasi manggis pastil telah terbukti adalah stabil dalam tempoh jangka hayat. Formulasi A dengan jumlah ekstrak kulit manggis yang dioptimumkan, gelatin dan gam karragenan mempunyai skor tertinggi untuk aroma, tekstur, warna dan penerimaan secara keseluruhan. Akhir sekali, pH, jumlah pepejal larut, kelikatan, warna, analisis mikrobiologi dan kapasiti antipengoksidaan (DPPH, ABTS dan kandungan fenolik total) manggis siap diminum dilakukan dan diperhatikan. Peningkatan minimum dalam keseluruhan kandungan pepejal larut dan peningkatan pH adalah ketara ($p<0.05$) untuk ketiga-tiga formulasi minuman manggis siap diminum selama 8 minggu kajian kestabilan penyimpanan. Pada penyimpanan 4 minggu pertama, tidak ada kiraan mikrob, yis dan kulat dikesan, namun setelah 4 minggu penyimpanan, terdapat pertumbuhan mikrob dalam minuman manggis siap diminum. Kapasiti antioksidan dan jumlah kandungan fenolik minuman manggis siap diminum telah menurun semasa kajian penyimpanan. Daripada keputusan yang diperolehi melalui penilaian deria, tiada perbezaan yang signifikan antara ketiga-tiga formulasi minuman manggis siap diminum; walau bagaimanapun, formulasi minuman manggis siap diminum yang paling diminati adalah formulasi A yang mempunyai jumlah ekstrak kulit manggis yang dioptimumkan, puri manggis dan jus epal pekat. Pengekstrakan akueus dengan bantuan enzim ke atas kulit manggis merupakan sejenis teknik hijau yang patut diterokai terutamanya bagi kilang pengeluar makanan.

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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 Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

LCMS/MS	Liquid chromatography with tandem mass spectrometry
SCUC	Southampton Centre for Underutilised Crops
MARDI	Malaysian Agricultural Research & Development Institute
MOA	Ministry of Agriculture
PHP	Philippine Peso
SFE	Supercritical fluid extraction
RSM	Response surface methodology
CCD	Central composite design
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
DPPH	2,2-Diphenyl-2-picrylhydrazyl
ABTS	2,2-Azinobis (3-ethylbenzothia-zoline-6-sulfonic acid) diammonium salt
RP-HPLC	Reversed phase high performance liquid chromatography
LC	Liquid chromatography
MS	Mass spectrometry
DAD	Diode array detection
ESI	Electrospray ionization
QTOF	Quadrupole Time of Flight
MT	Metric ton
OFAT	One-factor-at-a-time
FFD	Fractional factorial design
TPC	Total phenolic content
GAE	Gallic acid equivalent
UHPLC	Ultra-high performance liquid chromatography

RP	Reversed phase
ANOVA	Analysis of variance
STD	Standard
CV	Coefficient of the variation
CPS	Count per second
DMSO	Dimethylsulfoxide
WHO	World Health Organization
SPP	Species
MRSA	Methicillin-resistant *Staphylococcus aureus*
ATCC	American Type Culture Collection
NCBI	National Center for Biotechnology Information
HEK	Human embryonic kidney
CAMHB	Cation-adjusted Mueller Hinton broth
LHB	Lysed horse blood
D-PBS	Dulbecco's phosphate-buffered saline
MEM	Modified Eagle's Medium
DMEM	Dulbecco's Modified Eagle's Medium
FBS	Fetal bovine serum
EDTA	Ethylenediamine tetraacetic acid
MIC	Minimum inhibitory concentration
MBC	Minimum bactericidal concentration
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide
H_2O_2	Hydrogen peroxide
TSA	Tryptone soya agar
SDA	Sabouraud dextrose agar
AOAC	Association of official agricultural chemists

TPA	Texture profile analyzer
TVAC	Total Viable Aerobic Count
TAMC	Total Aerobic Microbial Count
TYMC	Total Yeast and Mould Count
USFDA	United States Food & Drug Administration
LDL	Low-density lipoprotein
ROPP	Roll-on-pilfer-proof
TSS	Total soluble solid
$^{\circ}$Bx	Degree Brix
ΔE	Total colour difference
CAC	Codex Alimentarius Commission
SD	Standard deviation
NMR	Nuclear magnetic resonance

CHAPTER 1

INTRODUCTION

1.1 Research background

Mangosteen (*Garcinia mangostana*) is widely known as "the queen of fruits" not only because it is a delicious tropical fruit, but also for its medicinal properties where Southeast Asians have used it for centuries in the treatment of diarrhea, inflammation, trauma, chronic ulcer, skin infections and wounds. Mangosteen belongs to the family of *Guttiferae* and is cultivated throughout Malaysia, India, Thailand, Myanmar, Philippines and Sri Lanka. Mangosteen has edible whitish, sweet and juicy flesh with a dark purple or reddish thick, leathery pericarp.

Mangosteen application has been studied not only in medicinal areas, but it also has been utilized and diverged in other fields, such as food science, engineering, material sciences and postharvest. Mangosteen fruits have been developed into various kinds of food and functional food products, mostly using the unique sweet-sour taste of the mangosteen flesh to formulate fruit jams, yogurts, ice cream, chocolates and fruit drinks. Furthermore, mangosteen rind juice has been evaluated as a natural colorant in a sugar palm fruit jam to improve its color, texture and flavor (Sayuti et al., 2017).

Besides its usage as a natural colorant in food products, mangosteen pericarp extract has been utilized natively as an inexpensive and environmentally friendly natural dye in the textile industry due to anthocyanins found in mangosteen pericarp. In contrast, mangosteen peel was evaluated for efficiency as a dye removal agent through its characteristic as an adsorbent (Phawachalotorn et al., 2021). Anthocyanins have been shown to decrease polyphenol oxidase (PPO) activity and control enzymatic browning thus prolonging the shelf life of fresh-cut apples (Hemachandran et al., 2017).

Various parts of the mangosteen fruit, including pericarp, aril, seeds, leaves, saps and barks have been evaluated for their bioactive compounds and found to contain phenolics and flavonoids (Aizat et al., 2019). Table 1.1 summarizes the bioactive compounds discovered in numerous parts of mangosteen fruit.

Table 1.1: Summary of bioactive compounds found in various parts of mangosteen fruit

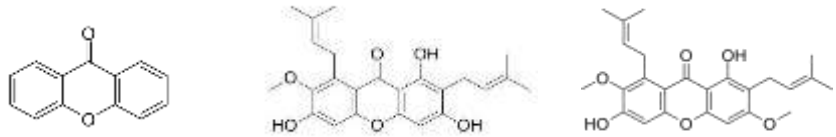
Parts of mangosteen	Bioactive compounds	Reference
Seed	Tannins, saponins, terpenoids, flavonoids, reducing compounds & alkanoids	Ajayi et al., 2011
Sap	α-mangostin & γ-mangostin	Sukatta et al., 2013
Leaves	Flavonoids, alkaloids, Tannin & saponin	Suhartati et al., 2019
Bark	Xanthones	See et al., 2014
Pericarp	Xanthones, flavonoids, tannins & phenolic acids	Suttirak & Manurakchinakorn, 2014

Mangosteen seed extract was screened and found to contain tannins, saponins, terpenoids, flavonoids, reducing sugars and alkaloids (Ajayi et al., 2011). Mangosteen seed was shown to have a high amount of carbohydrate and oil but low in protein content. Mangosteen seed oil was also evaluated for its preliminary toxicology on albino rats and no toxicological effects were detected (Ajayi et al., 2007).

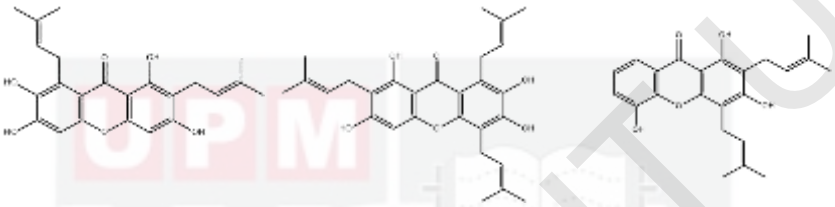
The yellow sap on the mangosteen fruit was reported to contain higher amounts of xanthones whereby the concentration of α-mangostin and γ-mangostin was 6-fold and 7-fold, respectively higher than the one in the mangosteen pericarp (Sukatta et al., 2013). Ethanolic extract of *Garcinia mangostana* Linn leaves has been evaluated for its antibacterial activity against *Pseudomonas aeruginosa* due to its active compounds, flavonoids, tannins, alkaloids and saponins (Suhartati et al., 2019). From various studies conducted so far, it was found that almost every part of mangosteen fruit contains xanthones but in different amounts. Mangosteen tree bark was reported to contain the well-known secondary metabolites, xanthones (See et al., 2014).

The pericarp of the mangosteen fruit is a source of complex phenolic compounds, such as xanthones, flavonoids, tannins and other bioactive substances (Suttirak & Manurakchinakorn, 2014). Xanthones, a biologically active antioxidant phytonutrient with the molecular formula $C_{13}H_8O_2$, is the secondary metabolite of the principal class of *Garcinia mangostana*. α-, β- and γ-mangostins, garcinone E, 8-deoxygartanin and gartanin, which is isolated from the pericarp of the mangosteen fruit, are the most studied xanthones. The chemical structure of xanthones, α-, β- and γ-mangostins, garcinone E, 8-deoxygartanin and gartanin were displayed in Fig. 1.1.

(a) Xanthone (b) α-Mangostin (c) β-Mangostin



(d) γ-Mangostin (e) Garcinone E (f) 8-Deoxygartanin



(g) Gartanin

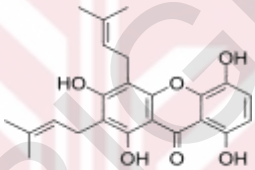


Figure 1.1: Chemical structure of various xanthones (a-g) isolated from mangosteen pericarp.

Herbaceous plants, such as mangosteen have, from time to time, been recognized for its economic importance as it contains biologically active compounds and therapeutic effects. Nevertheless, mangosteen, despite having such a high functional value and exquisite flavor has not been exploited commercially due to lack of thorough knowledge of the fruit.

The most common method used in the extraction of mangosteen fruits during phytochemical analysis is solvent-based extraction, such as using ethanol, methanol, chloroform and ethyl acetate (Mulia et al., 2019). Some new approaches like microwave-assisted and ultrasound technique on the solvent-based extraction have been applied to optimize the extraction of mangosteen. However, due to the toxicity and volatility of the conventional organic solvents used for mangosteen extraction reduced its prospective for food and pharmaceutical product application.

Thus, the main aim of this study was to explore the bioactive compounds of mangosteen pericarp by using a greener method. To date, this is the first study using water extraction with the enzyme-assisted method on the pericarp of *Garcinia mangostana*. Enzyme-

assisted water extraction of mangosteen pericarp was optimized through a statistical tool, response surface methodology.

Furthermore, the antioxidative compound of the optimized mangosteen pericarp extract was evaluated and a preliminary profiling of the mangosteen pericarp extract was screened by performing liquid chromatography with tandem mass spectrometry (LCMS/MS) analysis. This study was followed by an evaluation of antibacterial activity and cytotoxicity levels on the optimized mangosteen pericarp extract before being developed into functional products. Physicochemical stability for the developed functional products was analyzed. Sensory tests were performed to determine the acceptance level of the functional food products.

1.2 Research objectives

The main objective of this study was:

1) To develop a green extraction method to evaluate the role of the extracts in stability performance in food system and sensory evaluation.

The specific objectives for this study were as follows:

a) To optimize the enzyme-assisted water extraction from pericarp of mangosteen fruit to obtain the high antioxidative compounds.
b) To characterize the optimized mangosteen extract.
c) To evaluate antibacterial activity and cytotoxicity of optimized mangosteen extract.
d) To evaluate the stability performance of the optimized mangosteen extract in solid and liquid food systems.
e) To determine the sensory acceptance of the optimized mangosteen extracts in solid and liquid food systems.

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