EXTRACTION OF XANTHONE DERIVATIVES FROM MANGOSTEEN (*Garcinia mangostana* L.) PERICARP WITH VIRGIN COCONUT OIL BY SUPERCRITICAL CARBON DIOXIDE

By

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Chairman : Associate Professor Chong Gun Hean, PhD
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Mangosteen (*Garcinia mangostana* L.) pericarp (MP), a by-product from mangosteen products is known to be loaded with xanthone, a popular phenolic compound with various functional benefits such as antioxidant and antimicrobial. Hence, the purpose of this research was to investigate the separation of xanthone from mangosteen pericarp with virgin coconut oil (VCO) by supercritical carbon dioxide ($scCO_2$). The research began with optimising the yield of mangosteen pericarp extract (MPE), xanthone concentration, xanthone recovery and total phenolic content (TPC) where $scCO_2$ extraction were done under fixed CO_2 mass flowrate (18 g/min) and dynamic extraction (420 min) by varying the pressure (230 to 430) bar, temperature (50 to 70) °C and concentration of VCO (20 to 40) % as co-extractant using Box-Behnken design. The extract obtained from optimised conditions was characterised for α-mangostin and γ-mangostin with ultra-performance liquid chromatography (UPLC). It was found that %VCO had the most profound positive impact on the MPE yield and TPC, while pressure was the most significant factor affecting xanthone recovery. The best conditions (430 bar, 70°C, 40% VCO) predicted by response surface methodology (RSM) produced MPE yield (31.0%), xanthone concentration (28.2 mg/g), recovery (20.9%), TPC (1,473 mg GAE/ 100 g MP), α-mangostin (32.2 mg/g), and γ-mangostin (7.2 mg/g). VCO was seen to promote the mass transfer of xanthone from solid matrix into VCO phase, and subsequently $scCO_2$ phase as elucidated by Pardo-Castaño model I (PC-I). Following that, ANOVA and broken intact cell (BIC) model differentiated the overall extraction curve (OEC) into three zones based on the extraction rate and suggested 100 min as the most efficient extraction time. The extraction performances and the quality of MPEs were reproduced when the process with the best conditions was scaled up based on the similarity of solvent mass to feed mass ratio (S/F) at different scales factors (1.0, 1.6, and 2.2), indicating that simultaneous increase of targeted compound and extraction solvent; similar OEC and product could be obtained. Meanwhile, the

partial carbon footprint (PCF) was determined with Soxhlet (2.41 kg CO_2 e/ g xanthone) being the most CF efficient in xanthone extraction process followed by maximised scCO_2 (scale 1.6, 120 min extraction) process (3.43 kg CO_2 e/ g xanthone). Therefore, it is suggested that scCO_2 extraction with VCO could be used in extracting bioactive compounds from other plant matrices.

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

PENGEKSTRAKAN DERIVATIF XANTHONE DARI KULIT MANGGIS (*Garcinia mangostana* L.) DENGAN MINYAK KELAPA DARA MELALUI KAEDAH KARBON DIOXIDA SUPERKRITIK

Oleh

KOK SIEW LEE

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Kulit manggis (*Garcinia mangostana* L.) (MP) merupakan produk sampingan daripada penghasilan produk manggis. Ia didapati mangandungi xanthone, sejenis kompaun fenolik yang mempunyai pelbagai fungsi berfaedah seperti, antioksidan dan antimikrob. Dengan itu, tujuan kajian ini adalah untuk mengkaji pemisahan xanthone dari kulit manggis dengan minyak kelapa dara (VCO) melaui kaedah karbon dioksida superkritik (scCO_2). Kajian ini bermula dengan pengoptimuman pemulihan xanthone di mana pengekstrakan scCO_2 dijalankan pada kadar aliran jisim CO_2 (18 g/min) dan pengekstrakan dinamik (420 min) yang tetap dengan perubahan tiga faktor, iaitu tekanan (230 hingga 430) bar, suhu (50 hingga 70) °C and konsentrasi VCO (20 hingga 40) % melalui reka bentuk Box-Behnken. Ekstrak yang diperoleh daripada keadaan yang dioptimumkan telah dicirikan untuk α-mangostin dan γ-mangostin dengan kromatografi cecair ultra-prestasi (UPLC). Ia didapati bahawa %VCO mempunyai kesan positif yang paling besar terhadap hasil ekstrak kulit manggis (MPE) dan jumlah kandungan fenolik (TPC), manakala tekanan merupakan faktor paling penting dalam mempengaruhi pemulihan xanthone. Keadaan yang paling baik (430 bar, 70°C, 40% VCO) seperti yang diramalkan oleh gerak balas permukaan (RSM) menghasilkan MPE (31.0%), berkonsentrasi xanthone (28.2 mg/g), pemulihan xanthone (20.9%), TPC (1,473 mg GAE/ 100 g MP), α-mangostin (32.2 mg/g), dan γ-mangostin (7.2 mg/g). VCO didapati mampu menggalakkan pemindahan jisim xanthone dari matriks pepejal ke fasa cecair VCO dan seterusnya ke fasa scCO_2 sepertimana dijelaskan oleh analisis model Pardo-Castaño I (PC-I). Seterusnya, ANOVA dan model sel patah utuh (BIC) telah membezakan lengkung pengekstrakan keseluruhan (OEC) kepada tiga zon berdasarkan kadar pengekstrakan dan telah mencadangkan 100 min sebagai masa pengekstrakan paling cekap. Prestasi pengekstrakan dan kualiti MPE dapat dihasilkan semula apabila proses dengan kondisi yang disyorkan dinaikkan skala dengan mengikuti kriteria kesamaan nisbah jisim pelarut dengan jisim suapan (S/F) pada faktor

skala berlainan (1.0, 1.6 dan 2.2). Ini menunjukkan bahawa dengan peningkatan serentak pelarut pengekstrakan dan kompaun yang disasarkan, produk dan OEC yang serupa dapat diperoleh. Sementara itu, jejak karbon separa (PCF) teleh dikenal pasti bagi kaedah Soxhlet (2.41 kg CO_2 e/ g xanthone) sebagai kaedah yang mempunyai CF yang paling cekap dalam proses pengekstrakan xanthone dan diikuti oleh kaedah $scCO_2$ (skala 1.6, 120 min extraction) yang telah dimaksimumkan (3.43 kg CO_2 e/ g xanthone). Oleh itu, adalah dicadangkan bahawa pengekstrakan $scCO_2$ dengan VCO boleh digunakan untuk memisahkan kompaun bioaktif dari matriks tumbuhan yang lain.

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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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CHAPTER 1

INTRODUCTION

1.1 Background

Mangosteen (*Garcinia mangostana* L.) is a fruit naturally grown in tropical climate such as Malaysia and Thailand. Various parts of the plant have been used as herbs by the local communities in folk medicine to treat illnesses and wounds. The mangosteen fruit on the other hand has dark red pericarp, seeds as well as an edible white aril which is sweet and usually being consumed raw. The edible part of the mangosteen fruits are also being processed into wine, jam and puree (Sungpud et al., 2020). According to a report, the annual fruit productions of mangosteen for year 2019 of the aforementioned countries are 81 Gg and 1600 Gg, respectively (Tridge, 2020). However, a large portion of the crop is considered as an agriculture waste because the nonedible pericarp is twice the composition of consumable part of the fruit (Fu et al., 2007).

Interestingly, the mangosteen pericarp is discovered to be packed with biologically active compounds, such as xanthone (Zarena and Udaya Sankar, 2009). Xanthone from mangosteen pericarp is mainly constituted of α-mangostin and γ- mangostin (Jung et al., 2006). This compound is gaining popularity rapidly as an antioxidant. Mangosteen extract has been found to inhibit colon tumor (Aisha et al., 2012), stabilise sunflower oil under accelerated storage (Chong et al., 2015) and increase oxygen radical absorbance capacity within healthy human volunteers (Kondo et al., 2009). However, majority of the xanthone recovery process studied involves the use of polar organic solvents, for example aqueous micellar biphasic system (AMBS) (Tan el at., 2017), liquefied dimethyl ether extraction (Nerome et al., 2016), maceration (Sungpud et al., 2019), and microwave assisted extraction (MAE) with ethyl acetate (Ghasemzadeh et al., 2018).

The interest to recovery bioactive compounds without organic solvents has gained popularity over the years, hence extraction of xanthone from MP with supercritical carbon dioxide (scCO_2) is attractive from the point of view of food processing since scCO_2 does not leave harmful residues in foods and scCO_2 can be used to further process extracts into particles or food ingredients (Temelli et al., 2018). The extraction of xanthone with scCO_2 has been demonstrated to be feasible by Zarena et al. (2011, 2012). Modified extraction with ethanol and virgin coconut oil (VCO) has also been done by Zarena and Udaya (2009) and Lee et al. (2019), respectively. Extraction with VCO as co-extractant showed to improve the α-mangostin content (17.34%) as compared to conventional Soxhlet extraction method (5.41%). This may be due to the high (60%) medium chain triacylglycerides (MCT) content in the oil; a unique character of VCO which can bind with xanthone, a polar compound more readily and allow to be extracted with scCO_2 (Lee et al., 2019). However, the role of VCO was not clear, since there was lacking of study on investigating the kinetics of $scCO_2$ in co-extraction of xanthone and VCO. Though research projects that utilize $scCO_2$ has been increasing over the past few years due to the reputation of $scCO_2$ as a green technology for extraction operations which can be applied in food, cosmetics, and pharmaceuticals industry. It is still a question as to what criteria were being measured to confirm the operation as a green technology since there are no previous data that shows the carbon footprint (CF) from this technology.

This work hypothesized that VCO plays a crucial role in improving the extraction of xanthone from MP by $scCO_2$ and that models can help with the understanding of the extraction process. Therefore, separation of xanthone from MP with $scCO_2$ using VCO as co-extractant was studied with the focus being to effectively extract xanthone with $scCO_2$-VCO co-extraction technique. Experimental conditions were chosen to explore xanthone mass transfer in CO_2-saturated VCO and results were analysed with theoretical, statistical and empirical models. Extraction processes were maximised to enhance its efficiency and lowering CF. This work contributes by introducing $scCO_2$ extraction with VCO as an alternative method in extracting xanthone from MP which could also be applied in extracting bioactive compounds from other plant matrices.

1.2 Objectives

The main objective of this research was to assess the efficiency of $scCO_2$ extraction process with VCO as co-extractant in the recovery of xanthone from MP.

The specific objectives to achieve the main goal were:

1. To determine the effects of $scCO_2$ conditions (pressure and temperature) and %VCO on the extraction yield, xanthone recovery, and TPC of the MPE.
2. To identify effective extraction conditions for xanthone by using $scCO_2$ with VCO empirically.
3. To investigate the efficiency of $scCO_2$ extraction process from the view point of carbon footprint (CF).

1.3 Scope and significance of study

The research focused on the $scCO_2$ extraction process with VCO as co-extractant in the recovery of xanthone from MP. The scope covered the characterization of raw materials and MPE, optimization of the $scCO_2$ with VCO extraction process, modelling of the extraction kinetics, upscaling of the process and the CF efficiency of the $scCO_2$ with VCO extraction process.

The results may be useful to few parties, mainly academicians and industrial players, as well as the government and policy makers. This is because Malaysia and Thailand are some of the many countries that have signed the Paris Agreement 2015 and agreed in working towards reducing the world carbon footprint.

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