OPTIMIZATION OF CHARANTIN RICH POWDER FROM *MOMORDICA CHARANTIA* USING EXTRACTION AND SPRAY DRYING PROCESSES

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...Special Dedication to my late father, ***Zaini bin Mohd Yasin****...*

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ABSTRACT

Momordica charantia (*M. charantia*) fruits have a lot of health benefits through its antitumor, antimicrobial, antiviral, immunotoxin, antifertility and antimutagenic properties. Besides, *M. charantia* has the potential of controlling glucose levels in hyperglycemic states in Asian countries. The target compound in this fruits is charantin. Thus, a research on the production of charantin rich powder from *M. charantia* was carried out using a water-based extraction and spray dryer. The objectives of this research are to determine the optimum conditions for the extraction of charantin from *M. charantia,* to investigate the optimum condition of total solid content of maltodextrin for the feedstock of the spray drying process, and to optimize the parameters of the *M. charantia* powder spray drying process to produce higher quality charantin encapsulation. The process conditions of this study were particle size (250 ≤ particle diameter ≤ 300) μm, extraction time (6 hours) and ratio sample:solvent (1:20). The optimum temperature for maximum extraction was 80 ^{o}C which yielded 8.238 mg/mL of charantin. The optimum feedstock solution level was 10^{o} brix of total solid content of maltodextrin which yielded 6.948 mg/mL of charantin. The spray drying was run at an inlet temperature ranging from 150 ^{o}C to 190 ^{o}C and a feed flow rate ranging from 2 to 4 mL/min. The maximum charantin concentration during spray drying process condition was achieved at 170 ^{o}C and 3 mL/min with the concentration of 2.400 mg/mL, powder yield of 2.9 g, encapsulation efficiency of 29.1% and moisture content of 2.3%. The optimization of spray drying conditions were evaluated in term of inlet temperature and feed flow rate with respect to responses of powder yield, concentration of charantin and moisture content. The results showed that a temperature of 175.96^{o}C and feed flow rate of 2.41 mL/min produced the highest powder yield, moisture content and concentration of charantin with 3.51 g, 2.5% and 1.563 mg/mL, respectively. The regression coefficient, R^2 for powder yield, concentration of charantin and moisture content were 0.8741, 0.7579 and 0.7651, respectively. This shows that the higher value of R^2 is consistent with the data predicted using an experimental data model. The results of this study have a potential for commercialization as the powder contains rich encapsulation of charantin.

ABSTRAK

Buah peria katak memberi banyak kesan yang baik kepada kesihatan menerusi antitumor, antimikrob, antivirus, imunotoksin, antikesuburan dan antimutagenik. Selain itu, peria katak juga berpotensi dalam mengawal paras glukosa pada keadaan hiperglisemik di negara-negara Asian. Sasaran komponen dalam buah peria katak ialah charantina. Oleh itu, satu kajian tentang pengeluaran serbuk charantina daripada peria katak telah dijalankan dengan menggunakan kaedah penyarian berasaskan air dan pengering sembur. Objektif dalam kajian ini termasuklah menentukan keadaan optimum bagi proses penyarian charantina daripada peria katak, mengkaji tahap keadaan optimum terhadap jumlah kandungan pepejal maltodekstrin bagi suapan proses pengeringan sembur dan menentukan keadaan optimum parameter bagi proses pengeringan sembur buah peria katak dalam menghasilkan pengkapsulan charantina yang berkualiti tinggi. Keadaan proses yang digunakan dalam kajian ini adalah saiz zarah (250 $\leq$ diameter zarah $\leq$ 300) µm, masa penyarian (6 jam) dan nisbah sampel:pelarut (1:20). Suhu optimum bagi penyarian maksimum ialah 80 ^{o}C yang menghasilkan 8.238 mg/mL charantina. Paras larutan suapan optimum ialah 10^{o} brix jumlah kandungan pepejal maltodekstrin yang menghasilkan 6.948 mg/mLcharantina. Pengeringan sembur dijalankan pada suhu masukan dalam julat 150 ^{o}C hingga 190 ^{o}C dan kadar aliran suapan dalam julat 2 mL/min hingga 4 mL/min. Kepekatan charantina maksimum yang dicapai ketika proses pengeringan sembur pada keadaan 170 ^{o}C dan 3 mL/min dengan kepekatan 2.400 mg/mL, hasil berat serbuk 2.9 g, kecekapan pengkapsulan 29.1% dan kandungan kelembapan 2.3%. Pengoptimuman keadaan pengeringan sembur dinilai berdasarkan kepada suhu masukan dan kadar aliran suapan terhadap gerak balas hasil berat serbuk, kepekatan charantina dan kandungan kelembapan. Hasil keputusan menunjukkan bahawa suhu 175.95^{o}C dan kadar aliran suapan 2.41 mL/min menghasilkan berat serbuk yang tinggi, kepekatan charantina dan kandungan kelembapan masing-masing adalah 3.51g, 2.457% dan 1.563 mg/mL. Pekali regresi, R^2 untuk hasil berat serbuk, kepekatan charantin dan kandungan kelembapan masing masing adalah 0.8741, 0.7579 dan 0.7651. Ini menunjukkan nilai R^2 yang tinggi adalah konsisten dengan data ramalan menggunakan model data eksperimen. Keputusan kajian ini berpotensi untuk dikomersialkan sebagai serbuk yang kaya kandungan pengkapsulan charantina.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DE	Dextrose Equivalent
RSM	Response Surface Methodology
HPLC	High Performance Liquid Chromatography
PLE	Pressurize Liquid Extraction
SD	Spray Drying
CTD	Cast Tape Drying
$SC\text{-}SO_2$	Supercritical Carbon Dioxide
E-PVC	Emulsion Polymerization
S-PVC	Suspension Polymerization
ANOVA	Analysis of Variance
SSR	Sum of Squares Regression
SSE	Sum of Square Error
SST	Sum of Square Total
QSRR	Quantitative Structure-Retention Relationship
ADMI	American Dry Milk Institute
IDF	International Dairy Federation
PY	Powder Yield (g)
EE	Encapsulation Efficiency (%)
TCE	Total concentration of charantin in extraction process (mg/mL)
TCS	Total concentration of charantin in powder after spray dried (mg/mL)
MC	Moisture Content (%)

LIST OF SYMBOLS

Mt	Metric Tons
R^2	Regression Coefficient
W_{after}	Mass of the bottle after spray drying (g)
W_{before}	Mass of the bottle before spray drying (g)
M_a	Mass crucible after drying (g)
M_b	Mass crucible before drying (g)
W1	Mass of extracted oil (g)
W2	Mass of sample used (g)
Y	Peak area (mAU*S)
m	Slope of the equation line
x	Concentration of β-sitosterol glucoside/stigmasterol glucoside
c	Intercept line
Y	Predicted responses
β_0	Intercept regression coefficient
β_1, β_2	Linear regression coefficient
β_{12}	Interaction regression coefficient
β_{11}, β_{22}	Quadratic regression coefficient
Y_u	Experimental data
$\bar{Y}$	Mean for experimental data
$\hat{Y}_u$	Predicted data
p	Number of terms in model/equation
N	Number of experiment

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The study of natural products like plants can be a very thought-provoking subject for scientists to explore further. For decades, plants have been inevitably powerful sources of vast amount of compounds such as vitamins, phenolics, and metabolites that are rich in bio-activities like antioxidant, anticarcinogenic, antibacterial, and antiinflammatory properties. Hence, plants have become a major source for researchers in identifying and developing natural colorants, biodiesel, new drugs and so forth with no or less side effect. With this intention, the demand and requirement of plant studies have increased among natural product researchers.

Momordica charantia (*M. charantia*), a plant commonly known as bitter melon, bitter gourd, kugua, karela or balsam pear which belongs to the Cucurbitaceae family was selected in this study. Physically, *M. charantia* looks like a climber and bears oblong fruits similar in shape to the cucumber (Raina *et al.*, 2016). *M. charantia* is a plant with great nutritional value and has been commonly used as medicine. Traditionally, *M. charantia* is famous as a method for controlling glucose levels in hyperglycemic people in Asian countries who consume this fruit's juice in the early morning on an empty stomach (Raina *et al.*, 2016; Zhang *et al.*, 2016). Besides being antidiabetic, others medicinal properties such as antitumor, antimicrobial, antiviral, immunotoxin, antifertility and antimutagenic, have been clarified for *M. charantia*.

Researchers from United Kingdom found that *M. charantia* fruits contain biologically active chemicals such as steroids, protein, saponins, alkaloids, triterpenes and fixed oils (Raman and Lau, 1996). *M. charantia* contains several phytochemicals that have been isolated which include charantin, charine, cryptoxanthin, goyasaponins, gypsogenin, gentisic acid, momordicilin, momodicins, momordenol and so forth (Grover and Yadav, 2004).

Basically, *M. charantia* extracts in concentrated and powder form is the main commercial source of charantin. Charantin consists of a mixture of two compounds which are stigmasteryl glucoside and sitosteryl glucoside (Pitipanapong *et al.*, 2007). According to Belinda (2000), aside from its usage to treat diabetes, charantin can also be used as a substitute for existing insulin injection treatments that are used to treat diabetes patients by stimulating their pancreas to reduce sugar content in the blood. As they are free from side effects, this compound is now broadly accepted as a surrogate medicine for diabetes mellitus (Sharma *et al.*, 1996).

In the food and pharmaceutical industries, the microencapsulation technique has been widely used to protect food ingredients against volatile losses, deterioration, or premature interaction with other ingredients (Fang and Bhandari, 2011). Research by Jafari *et al.* (2016) defined microencapsulation as a process of seizing active substances within other materials to produce particles with dimensions of a few micrometers to a few nanometers. Besides the encapsulation technique, another factor that plays an important role in feed and powder characteristics is the selection of carrier agent. There are several types of encapsulation agents that are commonly used by researchers, including maltodextrin (Fongin *et al.*, 2017; Matsuura *et al.*, 2015; Oberoi and Sogi, 2015), the combination of maltodextrin and gum arabic (Idham *et al.*, 2012; Nguyen *et al.*, 2017; Premi and Sharma, 2017), sucrose and glucose (Bayram *et al.*, 2005), and skim milk powder (Shamaei *et al.*, 2017). Maltodextrin is low cost, has low viscosity at higher temperatures according to level of dextrose equivalent (DE) (Matsuura *et al.*, 2015; Wangsakan *et al.*, 2003) and can protect active compounds from oxidization. Thus, maltodextrin was used in this research as an encapsulation agent followed by spray drying which is used as an encapsulation technique for charantin.

Many studies have been conducted by previous researchers on the extraction of active compounds from *M. charantia* fruits. The most common methodologies used for the extraction of active compound include solvent extraction (Horax *et al.*, 2010; Virdi *et al.*, 2003), pressurized liquid extraction (Pitipanapong *et al.*, 2007; Syahariza *et al.*, 2017), heat reflux extraction (Budrat and Shotipruk, 2008; Shan *et al.*, 2012) and water-based extraction (Jain and De, 2016; Wang *et al.*, 2014). The hindrance of using solvent extraction is that it contains high toxicity of extracted yield and is costing when pressurized liquid extraction is applied. Thus, the feedstock of *M. charantia* for spray drying was prepared using water-based extraction method.

Spray drying is a method used to dehydrate fluids such as milk, coffee, and eggs, and it is also used widely in the pharmaceutical and chemical industries (Thirugnanasambandham and Sivakumar, 2015). This is the most important technology used to change the physical properties and remove water content in food. Spray drying is also a method of producing dry powder from a slurry or liquid by rapidly drying it with hot gas. The hot drying gas can be passed as a counter-current or co-current flow to the atomizer direction. The particle separator is typically a cyclone device that operates competently as the co-current flow allows particles to have a lesser residence time within the system. The particles in the chamber which are usually paired with a fluidized bed system enable for greater residence time if the counter-current flow method is used (Møller *et al.*, 2009).

All spray dryers use a spray nozzle or atomizer to disperse the slurry or liquid into a controlled drop size spray. The most common nozzles used are the single fluid pressure swirl nozzle and the rotary nozzle, while the two-fluid or ultrasonic nozzles are used in some applications too. The drying process is core, very rapid and is generally heated to temperatures lower than 100 ^{o}C, thus, spray drying is recommended for the encapsulation of heat-sensitive food ingredients. (Fang and Bhandari, 2011).

The optimization and assessment of the extraction process using mathematical and intelligent modeling seem to be essential for industrial applications (Sodeifian *et al.*, 2016). An experimental design has been used to optimize the number of experiments. To support the interpretation of experimental design result which is discussed mainly in terms of powder yield, concentration of charantin and moisture content, response surface methodology (RSM) was used in this present study. RSM is an effective statistical tool for optimization as it consists of multiple variables that influences powder yield. Study by Sablania and Bosco (2018) state that, the equation and statistical analysis showed an effect on all the responses while the optimized conditions of spray drying validated the model.

1.2 Problem Statement

There are a lot of studies regarding the encapsulation of potential herbs using the spray drying process. However, there are some limitations on the spray drying methodology itself. For example, the drying process takes place without knowing the concentration of the active compound before and after process, as well as the active compound loss. In addition, feedstock preparation for the spray drying process is one of its weaknesses as the preparation take places without the extraction process and with unknown concentrations of the active compound. Besides that, proximate analysis is more appropriate to be used to determine the physical characteristics on a powder, for example its particle size, moisture content, bulk density and ash.

Thus, to overcome this limitation, the extraction of *M. charantia* fruits using water based extraction was implemented in order to quantify its active compounds such as charantin so to prepare the feedstock for the spray drying process. In addition, the powder produced was analyzed in terms of physical (moisture content) and chemical (concentration charantin) characteristic in order to confirm that the product contains antidiabetic properties.

1.3 Objectives of Research

The objectives of the research are:

i. To determine the optimum condition for the extraction of charantin from *M. charantia*.
ii. To investigate the optimum condition of total solid content of maltodextrin for the feedstock of the spray drying process.
iii. To optimize the parameters of the *M. charantia* powder spray drying process to produce high quality charantin encapsulation.

1.4 Scopes of Research

The scopes of this research include:

i. Water based extraction

Feedstock preparation was performed with a particle size $250 \leq dp \leq 300$ µm and run using a water-based extraction for 6 hours at 60 ^{o}C, 80 ^{o}C, and 95 ^{o}C with ratio sample: solvent (1:20).

ii. Encapsulation process of charantin

Total solid content of maltodextrin which ranged from 5^{o} – 20^{o} Brix was determined according to the suitable amount of carrier agent and later was set as a constant parameter along with the best condition of extraction temperature. Suitable nozzle sizes in the range of 0.5 – 1.5 mm was set as a constant parameter before the encapsulation studies were conducted at inlet temperature in ranging from 150 ^{o}C to 190 ^{o}C and a feed flow rate ranging from 2 to 4 mL/min.

iii. Optimization of Spray Drying Process

The operating conditions of the spray drying process such as the inlet temperature, X_1 (150 – 190) ^{o}C and feed flow rate, X_2 (2 -4) mL/min with respect to responses such as powder yield, concentration of charantin and moisture content were optimized using respond surface methodology and contour plot.

iv. Analysis of *M. charantia* extracts and powder

The concentrations of charantin in the Soxhlet extraction, water-based extraction and spray dried powder were quantified using High Performance Liquid Chromatography (HPLC) analysis and the physiochemical characteristic of the dried powder was studied in terms of moisture content.

1.5 Significance of Research

M. charantia can be commercialized as it is rich in bioactive compounds especially charantin as charantin is one of the sources for the treatment of the diabetic mellitus disease. Using this treatment, the number of diabetic patients can be reduced in the future. Furthermore, the use of the spray dry method provides a promising alternative in the pharmaceutical industry as an encapsulation technique as it distribute the particles with control shelf life.

Lastly, the experimental procedures of this research may be used by third parties and also give benefits for future study. Besides that, other parties can decide on a suitable parameter based on this research's experimental data and adopt it according to their uses.

1.6 Limitation of Study

The limitation of this study is the water-based extractor which is, a shaking water bath equipment used in the laboratory. The maximum operating temperature of the equipment is only up to 95^oC. In addition, the up-scaling of the feed flow rate pump to spray drying was 1mL/min and not in decimal places.

1.7 Thesis Outline

Overall, this thesis consists of 5 chapters. Chapter 1 began with an introduction to the research project. This chapter included the background of the research, problem statement, objective of research, scope of research, significant of research and limitation of research. Three research objectives were stated within the scope of research.

In Chapter 2, the literature review describes the fundamental theory and application used in this study. This includes previous studies on the extraction process and spray drying process on a wide range of samples. In addition, it also provides an overview on the characteristics of the material which is the *M. charantia* fruit and the factors affecting the Soxhlet extraction. Besides that, the chapter also describes an overview on optimization using Response Surface Methodology (RSM).

Chapter 3 discusses in detail the research methodology used for the extraction process and spray drying process. The flow of this research includes the pretreatment of sample, preparation of feedstock using the water-based extraction, determination of the total solid content of maltodextrin and extraction temperature, encapsulation using the spray drying technique, and optimization of the drying process. The method for the quantification of charantin which is High Performance Liquid Chromatography and the moisture content analysis are also discussed in this chapter.

In Chapter 4, the results and discussion obtained from the process conducted in Chapter 3 are described briefly. The results from the Soxhlet extraction are presented first in order to determine the exact amount contained in the *M. charantia* fruits. Next, the extraction and pre-encapsulation processes are discussed further in terms of both extract yield and powder yield concentration of charantin. Then, the spray drying results are illustrated and conversed in terms of the effect of spray drying conditions towards powder yield, concentration of charantin and moisture content. Lastly, the optimization of data is computed using response surface methodology (RSM).

The conclusion in Chapter 5 answers all the objectives stated in Chapter 1. Recommendations are also provided for future work and improvement.

REFERENCES

Aghbashlo, M., Mobli, H., Madadlou, A., and Rafiee, S. (2012). Integrated optimization of fish oil microencapsulation process by spray drying. *Journal of Microencapsulation, 29*(8), 790-804

Ahmadi, M., Vahabzadeh, F., Bonakdarpour, B., Mofarrah, E., and Mehranian, M. (2005). Application of the central composite design and response surface methodology to the advanced treatment of olive oil processing wastewater using Fenton's peroxidation. *Journal of Hazardous Materials, 123*(1-3), 187-195

Ahmed, I., Adeghate, E., Sharma, A., Pallot, D., and Singh, J. (1998). Effects of Momordica charantia fruit juice on islet morphology in the pancreas of the streptozotocin-diabetic rat. *Diabetes research and clinical practice, 40*(3), 145-151

Ahmed, M., Akter, M. S., Chin, K. B., and Eun, J. B. (2009). Effect of Maltodextrin Concentration and Drying Temperature on Quality Properties of Purple Sweet Potato Flour. *Food Science and Biotechnology, 18*(6), 1487-1494

Ardestani, S. B., Sahari, M. A., and Barzegar, M. (2016). Effect of Extraction and Processing Conditions on Anthocyanins of Barberry. *Journal of Food Processing and Preservation, 40*(6), 1407-1420

Aris., N. A., Yunus., M. A. C., Yian., L. N., Idham., Z., Ramli., W. N. D., and Aziz., A. H. A. (2016). Effect of Particle Size on Bitter Gourd (Momordica charantia) Extract Yield by Supercritical Carbon Dioxide Extraction. *Symposium of Malaysian Chemical Engineers (SOMChE), 29*, 1-6

Arsad, N. H., Yunus, M. A. C., Zaini, M. A. A., Rahman, Z. A., and Idham, Z. (2016). Effect of Operating Conditions of Supercritical Carbon Dioxide on Piper Betle Leave Oil Yield and Antioxidant Activity. *International Journal of Applied Chemistry*, *12*(4), 741-751

Azmir, J., Zaidul, I. S. M., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., . . . Omar, A. K. M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *Journal of Food Engineering, 117*(4), 426-436

Bayram, Ö. A., Bayram, M., and Tekin, A. R. (2005). Spray drying of sumac flavour using sodium chloride, sucrose, glucose and starch as carriers. *Journal of Food Engineering, 69*(2), 253-260

Belinda, O. (2000). Diabetes self-management. *Herbal Supplements in Diabetes Management*

Belwal, T., Dhyani, P., Bhatt, I. D., Rawal, R. S., and Pande, V. (2016). Optimization extraction conditions for improving phenolic content and antioxidant activity in Berberis asiatica fruits using response surface methodology (RSM). *Food Chem, 207,* 115-124

Bezerra, M. A., Santelli, R. E., Oliveira, E. P., Villar, L. S., and Escaleira, L. A. (2008). Response surface methodology (RSM) as a tool for optimization in analytical chemistry. *Talanta, 76*(5), 965-977

Budrat, P., and Shotipruk, A. (2008). Extraction of phenolic compounds from fruits of bitter melon (Momordica charantia) with subcritical water extraction and antioxidant activities of these extracts. *Chiang Mai Journal of Science, 35*(1), 123-130

Can Karaca, A., Guzel, O., and Ak, M. M. (2016). Effects of processing conditions and formulation on spray drying of sour cherry juice concentrate. *Journal of the Science of Food and Agriculture, 96*(2), 449-455

Chatterjee, S., Jain, A., and De, S. (2017). Effect of different operating conditions in cloud point assisted extraction of thymol from Ajwain (Trachyspermum Ammi L.) seeds and recovery using solvent. *Journal of Food Science and Technology-Mysore, 54*(13), 4353-4361

Chegini, G., and Ghobadian, B. (2007). Spray dryer parameters for fruit juice drying. *World Journal of Agricultural Sciences, 3*(2), 230-236

Cowan, M. M. (1999). Plant products as antimicrobial agents. *Clinical microbiology reviews, 12*(4), 564-582

Desai, S., and Tatke, P. (2015). Charantin: An important lead compound from Momordica charantia for the treatment of diabetes. *Journal of Pharmacognosy and Phytochemistry, 3*(6), 163-166

Eggers, R. (1996). Supercritical fluid extraction (SFE) of oilseeds/lipids in natural products. *Supercritical fluid technology in oil and lipid chemistry*, 35-64

El-Said, S., and Al-Barak, A. (2011). Extraction of insulin like compounds from bitter melon plants. *Am. J. Drug Discovery Dev, 1*, 1-7

Fang, Z., and Bhandari, B. (2011). Effect of spray drying and storage on the stability of bayberry polyphenols. *Food Chem, 129*(3), 1139-1147

Fazaeli, M., Emam-Djomeh, Z., Ashtari, A. K., and Omid, M. (2012). Effect of spray drying conditions and feed composition on the physical properties of black mulberry juice powder. *Food and Bioproducts Processing, 90*(4), 667-675

Fongin, S., Kawai, K., Harnkarnsujarit, N., and Hagura, Y. (2017). Effects of water and maltodextrin on the glass transition temperature of freeze-dried mango pulp and an empirical model to predict plasticizing effect of water on dried fruits. *Journal of Food Engineering, 210*, 91-97

Gallo, L., Ramirez-Rigo, M. V., Pina, J., and Bucala, V. (2015). A comparative study of spray-dried medicinal plant aqueous extracts. Drying performance and product quality. *Chemical Engineering Research & Design, 104*, 681-694

Geankoplis, C. (2003). *Transport processes and separation process principles (includes unit operations)*: Prentice Hall Press.

Grover, J. K., and Yadav, S. P. (2004). Pharmacological actions and potential uses of Momordica charantia: a review. *J Ethnopharmacol, 93*(1), 123-132

Harinantenaina, L., Tanaka, M., Takaoka, S., Oda, M., Mogami, O., Uchida, M., and Asakawa, Y. (2006). Momordica charantia constituents and antidiabetic screening of the isolated major compounds. *Chemical and Pharmaceutical Bulletin, 54*(7), 1017-1021

Hawthorne, S. B., Yang, Y., and Miller, D. J. (1994). Extraction of Organic Pollutants from Environmental Solids with Subcritical and Supercritical Water. *Analytical Chemistry, 66*(18), 2912-2920

Horax, R., Hettiarachchy, N., and Chen, P. Y. (2010). Extraction, Quantification, and Antioxidant Activities of Phenolics from Pericarp and Seeds of Bitter Melons (Momordica charantia) Harvested at Three Maturity Stages (Immature, Mature, and Ripe). *Journal of Agricultural and Food Chemistry, 58*(7), 4428-4433

Hu, L., Zhang, J., Hu, Q., Gao, N., Wang, S., Sun, Y., and Yang, X. (2016). Microencapsulation of brucea javanica oil: Characterization, stability and optimization of spray drying conditions. *Journal of Drug Delivery Science and Technology, 36*, 46-54

Idham, Z., Muhamad, I. I., and Sarmidi, M. R. (2012). Degradation Kinetics and Color Stability of Spray‐dried Encapsulated Anthocyanins from Hibiscus Sabdariffa L. *Journal of Food Process Engineering, 35*(4), 522-542

Jafari, S. M., Mahdavi-Khazaei, K., and Hemmati-Kakhki, A. (2016). Microencapsulation of saffron petal anthocyanins with cress seed gum compared with Arabic gum through freeze drying. *Carbohydr Polym, 140*, 20-25

Jain, A., and De, S. (2016). Aqueous extraction of bitter gourd (Momordica charantia L.) juice and optimization of operating conditions. *Fruits, 71*(6), 379-387

Jittanit, W., Niti-Att, S., and Techanuntachaikul, O. (2010). Study of spray drying of pineapple juice using maltodextrin as an adjunct. *Chiang Mai Journal of Science, 37*(3), 498-506

Joseph, B., and Jini, D. (2013). Antidiabetic effects of Momordica charantia (bitter melon) and its medicinal potency. *Asian Pacific Journal of Tropical Disease, 3*(2), 93-102

Latip, L. D., Zzaman, W., Abedin, M. Z., and Yang, T. A. (2015). Optimization of Spray Drying Process in Commercial Hydrolyzed Fish Scale Collagen and Characterization by Scanning Electron Microscope and Fourier Transform Infrared Spectroscopy. *Journal of Food Processing and Preservation, 39*(6), 1754-1761

Lee, K. C., Yoon, Y. S., Li, F. Z., and Eun, J. B. (2017). Effects of inlet air temperature and concentration of carrier agents on physicochemical properties, sensory evaluation of spray-dried mandarin (Citrus unshiu) beverage powder. *Applied Biological Chemistry, 60*(1), 33-40

Lee, N. Y., Setapar, S. H. M., Sharif, N. S. M., Ahmad, A., Khatoon, A., Yunus, M. A. C., and Muhamad, I. I. (2013). Extraction of rubber (Hevea brasiliensis) seed oil using supercritical carbon dioxide and soxhlet extraction. *Research Journal of Chemistry and Environment, 17*, 1-7

Lin, Y. W., Liu, Y. H., Wang, L., Xie, Y. K., Gao, Z. J., and Wang, S. J. (2018). Optimization of drying conditions and components to reduce wall sticking during spray drying of infant formula milk. *International Journal of Agricultural and Biological Engineering, 11*(2), 214-218

Liu, Y. J., Chen, F. X., and Guo, H. H. (2017). Optimization of bayberry juice spray drying process using response surface methodology. *Food Science and Biotechnology, 26*(5), 1235-1244

Lucas., E. A., Dumancas., G. G., Smith, B. J., and Clarke, S. L. (2010). Health Benefits of Bitter Melon (Momordica Charantia). *Bioactive Foods in Promoting Health: Fruits and Vegetables*, 525-549

Masters, K. (1985). Spray Drying Handbook George Godwin. *London, England*, 67

Matsuura, T., Ogawa, A., Tomabechi, M., Matsushita, R., Gohtani, S., Neoh, T. L., and Yoshii, H. (2015). Effect of dextrose equivalent of maltodextrin on the stability of emulsified coconut-oil in spray-dried powder. *Journal of Food Engineering, 163*, 54-59

McEachran, A. D., Mansouri, K., Newton, S. R., Beverly, B. E., Sobus, J. R., and Williams, A. J. (2018). A Comparison of Three Liquid Chromatography (LC) Retention Time Prediction Models. *Talanta*, *182*, 371-379

Mohammed, N. K., Tan, C. P., Manap, Y. A., Alhelli, A. M., and Hussin, A. S. M. (2017). Process conditions of spray drying microencapsulation of Nigella sativa oil. *Powder Technology, 315*, 1-14

Møller, J. T., Fredsted, S., and Niro, G. (2009). A primer on spray drying. *Chemical Engineering*, *116*(12), 34-40

Montgomery, D. C., Runger, G. C., and Hubele, N. F. (2009). *Engineering statistics*: John Wiley & Sons.

Muzaffar, K., and Kumar, P. (2015). Parameter optimization for spray drying of tamarind pulp using response surface methodology. *Powder Technology*, *279,* 179-184

Nerurkar, P. V., Lee, Y. K., Motosue, M., Adeli, K., and Nerurkar, V. R. (2008). Momordica charantia (bitter melon) reduces plasma apolipoprotein B-100 and increases hepatic insulin receptor substrate and phosphoinositide-3 kinase interactions. *Br J Nutr*, *100*(4), 751-759

Nguyen, D. Q., Mounir, S., and Allaf, K. (2017). Optimization of the Spray Drying Operating Conditions for Producing the Powder Mixture of Gum Arabic and Maltodextrin. *International Journal of Food Engineering*, *13*(8)

Oberoi, D. P. S., and Sogi, D. S. (2015). Effect of drying methods and maltodextrin concentration on pigment content of watermelon juice powder. *Journal of Food Engineering, 165*, 172-178

Ojewole, J., Adewole, S. O., and Olayiwola, G. (2005). Hypoglycaemic and hypotensive effects of Momordica charantia Linn (Cucurbitaceae) whole-plant aqueous extract in rats. *Cardiovascular journal of South Africa: official journal for Southern Africa Cardiac Society [and] South African Society of Cardiac Practitioners, 17*(5), 227-232

Phisut, N. (2012). Spray drying technique of fruit juice powder: some factors influencing the properties of product. *International Food Research Journal, 19*(4), 1297-1306

Pitipanapong, J., Chitprasert, S., Goto, M., Jiratchariyakul, W., Sasaki, M., and Shotipruk, A. (2007). New approach for extraction of charantin from Momordica charantia with pressurized liquid extraction. *Separation and Purification Technology, 52*(3), 416-422

Premi, M., and Sharma, H. (2017). Effect of different combinations of maltodextrin, gum arabic and whey protein concentrate on the encapsulation behavior and oxidative stability of spray dried drumstick (Moringa oleifera) oil. *Int J Biol Macromol, 105*, 1232-1240

Quek, S. Y., Chok, N. K., and Swedlund, P. (2007). The physicochemical properties of spray-dried watermelon powders. *Chemical Engineering and Processing, 46*(5), 386-392

Raina, K., Kumar, D., and Agarwal, R. (2016). Promise of bitter melon (Momordica charantia) bioactives in cancer prevention and therapy. *Semin Cancer Biol, 40-41*, 116-129

Raman, A., and Lau, C. (1996). Anti-diabetic properties and phytochemistry of Momordica charantia L. (Cucurbitaceae). *Phytomedicine, 2*(4), 349-362

Sablania, V., and Bosco, S. J. D. (2018). Optimization of spray drying parameters for Murraya koenigii (Linn) leaves extract using response surface methodology. *Powder Technology, 335*, 35-41

Saxena, D. K., Sharma, S., and Sambi, S. (2011). Comparative extraction of cottonseed oil.

Shamaei, S., Seiiedlou, S. S., Aghbashlo, M., Tsotsas, E., and Kharaghani, A. (2017). Microencapsulation of walnut oil by spray drying: Effects of wall material and drying conditions on physicochemical properties of microcapsules. *Innovative Food Science & Emerging Technologies, 39*, 101-112

Shan, B., Xie, J.-H., Zhu, J.-H., and Peng, Y. (2012). Ethanol modified supercritical carbon dioxide extraction of flavonoids from Momordica charantia L. and its antioxidant activity. *Food and Bioproducts Processing, 90*(3), 579-587

Sharma, S., Dwivedi, S., Varshney, V., and Swarup, D. (1996). Antihyperglycaemic and Insulin Release Effects of Aegle marmelos Leaves in Streptozotocin–Diabetic Rats. *Phytotherapy Research, 10*(5), 426-428

Shishir, M. R. I., Taip, F. S., Ab Aziz, N., Talib, R. A., and Sarker, M. S. H. (2016). Optimization of Spray Drying Parameters for Pink Guava Powder Using RSM. *Food Science and Biotechnology, 25*(2), 461-468

Silva, P. I., Stringheta, P. C., Teófilo, R. F., and de Oliveira, I. R. N. (2013). Parameter optimization for spray-drying microencapsulation of jaboticaba (Myrciaria jaboticaba) peel extracts using simultaneous analysis of responses. *Journal of Food Engineering, 117*(4), 538-544

Sodeifian, G., Sajadian, S. A., and Saadati Ardestani, N. (2016). Optimization of essential oil extraction from Launaea acanthodes Boiss: Utilization of supercritical carbon dioxide and cosolvent. *The Journal of Supercritical Fluids, 116*, 46-56

Sollohub, K., and Cal, K. (2010). Spray Drying Technique: II. Current Applications in Pharmaceutical Technology. *Journal of Pharmaceutical Sciences, 99*(2), 587-597

Syahariza, Z. A., Torkamani, A. E., Norziah, H. M., Mahmood, W. A. K., and Juliano, P. (2017). Optimisation of pressurised liquid extraction for antioxidative polyphenolic compound from Momordica charantia using response surface methodology. *International Journal of Food Science and Technology, 52*(2), 480-493

Tan, S. P., Kha, T. C., Parks, S., Stathopoulos, C., and Roach, P. D. (2015). Optimising the Encapsulation of an Aqueous Bitter Melon Extract by Spray-Drying. *Foods, 4*(3), 400-419

Tan, S. P., Tuyen, C. K., Parks, S. E., Stathopoulos, C. E., and Roach, P. D. (2015). Effects of the spray-drying temperatures on the physiochemical properties of an encapsulated bitter melon aqueous extract powder. *Powder Technology, 281*, 65-75

Tan, S. W., Jiang, T. T., Ebrahimi, A., and Langrish, T. (2018). Effect of spray-drying temperature on the formation of flower-like lactose for griseofulvin loading. *European Journal of Pharmaceutical Sciences, 111*, 534-539

Thirugnanasambandham, K., and Sivakumar, V. (2015). Influence of process conditions on the physicochemical properties of pomegranate juice in spray drying process: Modelling and optimization. *Journal of the Saudi Society of Agricultural Sciences, 16*, 358-366

Tonon, R. V., Brabet, C., and Hubinger, M. D. (2008). Influence of process conditions on the physicochemical properties of açai (Euterpe oleraceae Mart.) powder produced by spray drying. *Journal of Food Engineering, 88*(3), 411-418

Tontul, I., and Topuz, A. (2017). Spray-drying of fruit and vegetable juices: Effect of drying conditions on the product yield and physical properties. *Trends in Food Science & Technology, 63*, 91-102

Vinatoru, M., Toma, M., Radu, O., Filip, P., Lazurca, D., and Mason, T. (1997). The use of ultrasound for the extraction of bioactive principles from plant materials. *Ultrasonics Sonochemistry, 4*(2), 135-139

Virdi, J., Sivakami, S., Shahani, S., Suthar, A. C., Banavalikar, M. M., and Biyani, M. K. (2003). Antihyperglycemic effects of three extracts from Momordica charantia. *J Ethnopharmacol, 88*(1), 107-111

Wang, H. Y., Kan, W. C., Cheng, T. J., Yu, S. H., Chang, L. H., and Chuu, J. J. (2014). Differential anti-diabetic effects and mechanism of action of charantin-rich extract of Taiwanese Momordica charantia between type 1 and type 2 diabetic mice. *Food Chem Toxicol, 69*, 347-356

Wangsakan, A., Chinachoti, P., and McClements, D. J. (2003). Effect of different dextrose equivalent of maltodextrin on the interactions with anionic surfactant in an isothermal titration calorimetry study. *Journal of Agricultural and Food Chemistry, 51*(26), 7810-7814

Wong, C. W., Teoh, C. Y., and Putri, C. E. (2018). Effect of enzymatic processing, inlet temperature, and maltodextrin concentration on the rheological and physicochemical properties of spray-dried banana (Musa acuminata) powder. *Journal of Food Processing and Preservation, 42*(2)

Yunus, M. (2007). Extraction, Identification, and Separation of Vitamin E and Djenkolic Acid from Pithecellobium jiringan (Jack) Prain Seeds using

Supercritical Carbon Dioxide. *Doctor Philosophy, Universiti Sains Malaysia, Penang*

Yunus, M., Lee, C., and Idham, Z. (2011). Effects of variables on the production of red-fleshed pitaya powder using response surface methodology. *Jurnal Teknologi*, *56*, 15-29

Yunus, M. A. C., and Ripin, A. (2001). Optimization of processing parameter for enhancing good quality of mango powder using response surface methodology. *Symposium of Malaysian Chemical Engineers (SOMChE), 15*, 427-434

Yuwai, K. E., Rao, K. S., Kaluwin, C., Jones, G. P., and Rivett, D. E. (1991). Chemical composition of Momordica charantia L. fruits. *Journal of Agricultural and Food Chemistry, 39*(10), 1762-1763

Zhang, F., Lin, L., and Xie, J. (2016). A mini-review of chemical and biological properties of polysaccharides from Momordica charantia. *Int J Biol Macromol, 92*, 246-253

Zotarelli, M. F., da Silva, V. M., Durigon, A., Hubinger, M. D., and Laurindo, J. B. (2017). Production of mango powder by spray drying and cast-tape drying. *Powder Technology, 305*, 447-454