UNIVERSITI PUTRA MALAYSIA

OPTIMIZATION OF TANNIN EXTRACTION FROM CAVENDISH BANANA (Musa acuminata Colla) PEEL AND PRODUCTION OF ITS POWDER

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By

NUR ARNISAH BINTI ISHAK

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

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DEDICATION

This dissertation is dedicated especially to my beloved parents, Encik Ishak Bin Saidi and Puan Lega Murni Binti Mohammad Amin and other family members for their constant doa', encouragement and endless support during this journey.

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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

OPTIMIZATION OF TANNIN EXTRACTION FROM CAVENDISH BANANA (*Musa acuminata* Colla) PEEL AND PRODUCTION OF ITS POWDER

By

NUR ARNISAH BINTI ISHAK

May 2021

Chairman : Azhari Samsu Baharuddin, PhD
Faculty : Engineering

Musa acuminata Colla (Cavendish) is one of the most abundant bananas in Malaysia that is highly exported and considered vital commercial crops in the region. The rejected bananas comprise about 20% of unripe that are collected as agricultural residues during the sorting process. These agricultural residues cannot be imported due to the multiple quality requirements such as shape abnormality and prematureness of size, which do not meet the commercial standards. As a result, these agricultural residues may create detrimental environmental issues in the long term if there are no alternative solutions. Banana peel is the primary residue corresponding to 40% of the fruit weight with a broad natural antioxidant such as polyphenols. The recovery of these compounds will be valuable to the food industry. This study aimed to turn unripe Cavendish peel into beneficial nutraceutical powders containing antioxidant-rich tannin. The present study began with the characterization of the physicochemical analyses, solvent selection for high extracted tannin content from the unripe and ripe peels and evaluated the thin-layer drying characteristic for unripe material. Next, the response surface methodology (RSM) was designed to optimize ultrasound-assisted extraction (UAE) process parameters for extracted tannin content by water as a solvent. The spray drying was used to optimize the operating parameters at different levels to encapsulate powder containing bioactive compounds and performed good properties. The potential bioactive compounds from the optimum water extract and spray-dried powder were quantified by HPLC analysis.

The results showed that the total phenolic, tannin and flavonoid content from unripe Cavendish peel water extract was significantly higher ($p < 0.05$) than other solvents. Besides, a 40 ℃ drying condition was the best environment to dry the unripe peel as the extracted tannin content was significantly higher ($p < 0.05$) to be recovered than 50℃, 60℃ and 70℃. The UAE parameters were affected the yield recovery, total tannin and flavonoid content also antioxidant activities (DPPH and ABTS) significantly ($p < 0.05$). The optimum UAE extraction condition was at 60 ℃, an extraction time of 30.0 min, a

25.0 min for a pre-incubation time and a 5.03% solvent concentration as the recovery yield was 14.9% and 119.2 mg TAE/g sample of tannin content. It also contained a 29.0 mg RE/g sample of flavonoid, scavenging activities at 80.8% and 84.7% for DPPH and ABTS assays. Next, adding 7.09% maltodextrin concentration at 160 ℃ of inlet air temperature resulted in an optimum spray drying condition for unripe Cavendish peel powder. The response variables of powder recovery, moisture content, hygroscopicity, solubility, flowabilities (CI and HR), tannin and flavonoid content also antioxidant activities were fitted to the polynomial model significantly with a high coefficient of determination ($R^2 > 0.70$) and insignificant lack of fitness ($p > 0.05$), thus give the best characteristics in the encapsulated powder. The unripe Cavendish peel powder showed good characteristics and appearance as a powder-formed with 1.89% moisture content, 30.81 mg water/100 g dry solid hygroscopicity, 55.60% solubility, 0.53 gcm^{-3} bulk density, 49.81% CI, 1.97 of HR flowability, 26.66 mg TAE/g powder of tannin content, 0.20 mg RE/g powder of flavonoid content, 78.99% DPPH and 72.17% ABTS of antioxidant activities. The HPLC quantification revealed tannic acid was detected as a lead compound with the highest quantity in both optimum conditions with 1551.210 ± 4.90 µg/g sample and 409.542 ± 4.31µg/g sample, respectively. It could be seen that the amount of tannic acid was quite remarkable in the HPLC profile. Therefore, the optimum UAE extraction and spray-dried processes were successfully obtained for antioxidant-rich powder production from the unripe Cavendish peel. This product is a potential polyphenol source, especially the tannin content as a potent natural antioxidant with a stable formulation of spray-dried powder with strong reconstitution, lower water activity and is ideal for storage and used in the food industry for its antioxidants benefits.

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

PENGOPTIMUMAN PENGKEKSTRAKAN TANIN DARI KULIT PISANG CAVENDISH (*Musa acuminata* Colla) DAN PENGHASILAN SERBUKNYA

Oleh

NUR ARNISAH BINTI ISHAK

Mei 2021

Pengerusi : Azhari Samsu Baharuddin, PhD
Fakulti : Kejuruteraan

Musa acuminata Colla (Cavendish) adalah salah satu jenis pisang yang paling banyak dieksport di Malaysia dan dianggap sebagai salah satu tanaman komersil utama di negara ini. Terdapat kira-kira 20% jumlah buah pisang yang belum masak daripada keseluruhan buah yang dipetik dan telah dibuang sebagai sisa pertanian disebabkan ianya gagal memenuhi dan menepati keperluan kualiti piawai ketika proses pengasingan seperti saiz buah yang tidak sekata, terlalu kecil ataupun tidak sesuai untuk dikomersilkan sebelum aktiviti import. Seterusnya, kulit pisang meliputi 40% daripada jumlah berat buah pisang keseluruhan dan mengandungi pelbagai antioksidan semulajadi seperti polifenol. Pemulihan sebatian ini akan memberi manfaat bagi industri makanan. Pisang yang dibuang akan menjadi isu persekitaran jika tiada penyelesaian alternatif. Tujuan kajian ini adalah untuk mengubah kulit pisang Cavendish belum masak menjadi serbuk nutraseutikal berharga yang mengandungi antioksidan seperti tanin. Objektif pertama kajian ini adalah untuk mencirikan analisis fizikokimia, tingkah laku pengeringan dan memilih pelarut terbaik bagi pengekstrakan tanin secara perbandingan antara kulit pisang yang masak dan belum masak. Seterusnya, kaedah permukaan tindakbalas (RSM) direkabentuk untuk mengoptimumkan proses pengekstrakan berbantu ultrabunyi (UAE) untuk kandungan tanin dengan menggunakan air sebagai pelarut pada tahap parameter yang berlainan. Selanjutnya, teknik semburan pengeringan digunakan untuk mengoptimumkan parameter operasi bagi menghasilkan bahan serbuk bioaktif yang terkapsulasi dengan ciri yang baik melalui perubahan suhu salur udara masuk (℃) dan kepekatan maltodekstrin (%) pada tahap yang berbeza-beza. Kedua sebatian bioaktif pada keadaan optimum tersebut iaitu ekstrak kasar dan serbuk semburan kering dikuantifikasi melalui analisis HPLC.

Hasil kajian menunjukkan jumlah kandungan fenolik, tanin dan flavonoid dari kulit pisang yang belum masak diekstrak dengan menggunakan air adalah ketara lebih tinggi ($p < 0.05$) berbanding dengan pelarut lain. Selain daripada itu, suhu pengeringan pada 40 ℃ merupakan keadaan suhu yang terbaik bagi proses pendedahan dan pengeringan

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kulit pisang Cavendish yang belum masak disebabkan jumlah kandungan tanin yang dilindugi adalah ketara lebih tinggi ($p < 0.05$) berbading suhu pengeringan 50 ℃, 60 ℃ and 70 ℃. Faktor pengekstrakan UAE mempengaruhi pemulihan hasil ekstrak, jumlah kandungan tanin dan flavonoid serta aktiviti antioksidan. Keadaan optimum pengekstrakan diperoleh adalah pada suhu 60 ℃ selama 30.0 minit pengekstrakan, 25.0 minit masa pra-inkubasi dan 5.03% kepekatan pepejal ke pelarut yang memberikan 14.9% hasil pemulihan ekstrak dan 119.2 mg TAE/g sampel jumlah kandungan tanin. Ia juga mengandungi 29.0 mg RE/g sampel flavonoid dan aktiviti pemuliharaan radikal adalah 80.8% DPPH dan 84.7% ABTS. Penambahan 7.09% kepekatan maltodextrin pada suhu udara masuk 160 ℃ oleh penyembur kering memberikan ciri yang optimum kepada ekstrak kasar kulit pisang Cavendish belum masak. Pemboleh ubah gerak balas seperti hasil pemulihan serbuk, kandungan kelembapan, higroskopisiti, kelarutan, kebolehupayaan aliran (CI dan HR), kandungan jumlah tanin dan flavonoid serta aktiviti antioksidan yang signifikan berbeza disesuaikan ke dalam model polinomial dengan penentuan pekali keberkesanan yang tinggi ($R^2 > 0.70$) dan ujian kekurangan dengan nilai tidak ketara ($p > 0.05$), seterusnya memberikan ciri terbaik penghasilan serbuk terkapsulasi. Serbuk sembur kering daripada ekstrak menunjukkan ciri terbaik sebagai serbuk dengan 1.89% kelembapan, 30.81 mg air/100 g pepejal kering higroskopisiti, 55.60% kelarutan, 0.53 gcm^{-3} ketumpatan pukal, kadar aliran CI pada 49.81%, 1.97 nisbah Hausner, 26.66 mg TAE/g serbuk jumlah kandungan tanin, 0.20 mg RE/g serbuk jumlah kandungan flavonoid, aktiviti antioksidan 78.99% DPPH dan 72.17% aktiviti ABTS. Kuantifikasi HPLC menunjukkan asid tanin sebagai sebatian utama dengan kuantiti tertinggi diperolehi daripada keadaan optimum kedua-duanya dengan nilai masing – masing pada 1551.210 ± 4.90 dan 409.542 ± 4.31 µg TAE/g sampel. Asid tanin mudah dikenal pasti dalam profil analisi HPLC. Oleh itu, keadaan optimum bagi UAE dan pengeringan semburan telah berjaya menghasilkan produk serbuk yang kaya antioksidan daripada kulit pisang Cavendish yang belum masak. Ianya adalah sebagai sumber polifenol yang berpotensi, terutamanya kandungan tanin yang menjadi sumber antioksidan semulajadi beserta formulasi stabil berbentuk serbuk sembur kering dengan penggabungan yang kuat, rendah aktiviti air dan ideal bagi penyimpanan dan digunakan secara meluas dalam industri makanan dengan kebaikan antioksidan.

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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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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

FAOSTAT	Food and Organization of the United Nations
RSM	Response surface methodology
CCD	Central composite design
UAE	Ultrasound-assisted extraction
DE	Dextrose equivalent
BHT	Butylated hydroxytoluene
BHA	Butylated hydroxyanisole
ROS	Reactive oxygen species
RNS	Reactive nitrogen species
ABTS	2,2-azino-bis (3-ethylbenzothiazoline)-6-sulforic acid
DPPH	2,2-Diphenyl-1-picrylhydrazyl
PPO	Polyphenol oxidase
3D	Three-dimensional
2D	Two-dimensional
ANOVA	Analysis of variance
HPLC	High performance liquid chromatography
NA_2CO_3	Sodium carbonate
GAE	Gallic acid equivalent
RE	Rutin equivalent
TAE	Tannic acid equivalent
CI	Compressibility index
HR	Hausner ratio
HCI	Hydrochloric acid
DAD	Diode array detector

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Abs	Absorbance
Tg	Transition glass temperature

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LIST OF SYMBOLS

R^2	Determination coefficient
p	Probability
℃	Degree Celsius
µm	micrometer
C	chroma
h^o	hue angle
N	newton
%	percentage
mm	millimeter
mm/s	speed
nm	nanometer
W	watt
v/v	Volume per volume
kg	kilogram
g	gram

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Musa acuminata Colla (banana) is one of the most important crops globally in over 130 countries. In 2018, a total of 115 million tons of bananas were produced mainly in Asia (54%) and America (26%) (FAOSTAT, 2018). An estimated 128 million tons of bananas are grown annually in 150 countries (FAOSTAT, 2018). Banana is grown for domestic and export markets, listed as one of the 15 priority fruits for commercial cultivation in Malaysia (Ministry of Agriculture, 1998). Malaysia is one of the global producers with a total export of around 25 thousand tons USD's value as one of the leading commercial crops with leftover fruits production from banana plantations (FAOSTAT, 2018). This situation is similar to Brazilian plantation, with an overall 40% loss due to agricultural failure and most of the product types are intended for consumption (Izidoro et al., 2011).

Banana plants contribute to few agricultural residues such as peel, leaves, pseudostem, bracts and rejected fruits. The peel is a primary residue that accounts for about 38% of the total fruit weight and regards as a low-value waste in annual production (González-Montelongo et al., 2010). *Musa acuminata* Colla is one of the most abundant bananas in Malaysia and the Cavendish cultivar is a widespread international trade due to its high demand exported to various countries. The primary feature of the Cavendish cultivar is the peel, which remains green until the ripening stage and does not undergo any self-ripening process. Therefore, the external ethylene gas is required during the de-greening process of bananas to turn into yellow color before the post-ripening transport begins. This condition enhances its market value as the high-quality grade of Cavendish makes it appropriate for export purposes because it has a longer shelf life than other cultivars. During the fruit sorting process, banana fruit that fails to meet the quality standards for commercialization will be rejected up to 20% and about 10 to 13% of total banana production in proportion to be discarded (Guerrero et al., 2016). As the production of *M. acuminata* Colla (Cavendish) increases due to export and local consumption, the rate of fruit rejection also increases rapidly. The rejected banana fruit as an organic waste could cause severe environmental problems. Since banana fruit contains high nutritional and functional properties, it can be transformed into a valuable product. The issues related can be reduced by utilizing the unripe peel from the discarded fruit and converting these agricultural residues into rich-polyphenol products of materials.

Extraction is the first step that must be carried out to obtain the essential ingredients before being transformed and applied in the food industry. There is a great deal of research interest in isolating and targeting the bioactive compounds from the peel as a material to be applied in the food system since more than 40 phenolic compounds are responsible for high antioxidant activity (Vu et al., 2018). These natural components are strongly influenced by several factors such as genetic variables, geographical production region, growing conditions, fruit maturity, post-harvest handling and processing (Vu et

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al., 2018). Different phenolic compounds in the banana peel will interrupt oxidizable substrate chain reactions and decrease degenerative diseases. The previous study mentioned that the unripe Cavendish peel is an excellent source of tannin and high antioxidant activity with various potential functional properties (Ishak et al., 2020). These agricultural residues are an incredible source of natural antioxidants since the interest in incorporating nutraceuticals into the food is expanding. Thus, functional foods or nutraceutical products composed of these antioxidants can be manufactured and applied to the food system.

Water is considered an effective 'green' solvent in extracting phenolic compounds from the banana peel (Someya et al., 2002). However, water is insufficient to maximize the extraction process and lots of conventional and non-conventional extraction techniques have been applied in other studies. A non-conventional method such as ultrasound-assisted extraction (UAE) consumed less extraction time with high efficiency. It could be scaled up for industrial application than microwave-assisted extraction and other conventional methods (Vázquez et al., 2014). The optimized extract from UAE may have better benefits than the conventional way. However, the extract form can be oxidized and exposed to the oxidative environment, making it susceptible to contamination and spoilage by microorganisms. An additional process is required to encapsulate the antioxidant capacity and maintain the shelf life from the unripe Cavendish peel.

The encapsulation technique through spray drying is a reliable method to address these challenges since it enables and improves the retention of nutrients. It allows the release of bioactive materials, preserved the stability of compounds during processing and storage, prevented undesirable interactions with the food matrix, slowed down the degradation process, reduced the bad taste or smell, maintained the functionality and increased its bioavailability (Madene et al., 2006). The astringency of polyphenols such as tannin complex attributes to unpleasant compounds and would limit its food products applications. The concern to cover this unpleasant and astringent taste as well as restore the formation of the unstable water extract, the encapsulation system will produce a stable product with low astringency sensation. This technique also facilitates the handling process and allows adequate concentration or uniform dispersion to be added. The process starts with distributing extract droplets inside the chamber, which come in contact with the hot air and form the powder. A previous study was successfully encapsulated the anthocyanin content by spray drying with the binding agent of maltodextrin (Ersus & Yurdagel, 2007). It is vital to identify the optimum spray drying conditions as various compounds have different significant processing parameters.

Despite this, the response surface methodology (RSM) is a powerful tool to determine extraction and encapsulation conditions at an optimum level of plant materials. The effects of multiple variables and their interactions are helpful to be assessed (Baş & Boyacı, 2007). The RSM is more efficient than designing an orthogonal test or the single variable method because it requires fewer experimental studies to assess the impact of multiple interacting factors and optimize a process (Lee et al., 2000). The central composite design (CCD) is one of the design methods from RSM that has been employed in many studies to evaluate factors that affect the efficiency of the spray drying process. It also allows a deeper understanding of the interaction of each factor.

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Therefore, the main objective of this study was to utilize the agricultural residues, particularly the unripe Cavendish peel, into desired powder with good properties that are rich in antioxidant properties. This work will promote these residues as sustainable sources and boost Malaysia's economic value, especially in the food industry. The waste products potentially enhance the nutritional consumption among people by implementing natural antioxidants with an environmentally friendly process. The selection of appropriate solvent extraction, the thin-layer drying characteristic of peel and the optimization process of both extraction and encapsulation methods by the RSM were determined in the present work. The RSM of spray drying was optimized the processing parameters of the extracted tannin powder to produce as rich in antioxidants with good properties from unripe Cavendish peel. The optimum parameters for both technologies of UAE and spray drying were crucial to obtain the desired powder. In a further application, the recovery of tannin content and antioxidants from unripe Cavendish peel is worth it. However, to the best of our knowledge, the optimization process of polyphenol encapsulation, particularly tannin-water extract from the unripe Cavendish peel, is still very limited.

1.2 Problem Statement

Creating products that turn waste materials into valuable ingredients seems requisite and needs to be prioritized. As stated above, the export and local consumption of Cavendish banana is rising and becoming the largest fruit crop with high export value. However, the plantation area faces several challenges as the fruit rejection increases up to 20% due to failure in the sorting process. Cavendish bananas are harvested during the unripe stage for export purposes and incorporated into the discarded fruit due to agricultural residues or waste. The fruits that did not meet the standard quality for commercialization, such as abnormal shape, prematureness size and those with damaged or spoiled areas, will cause microbial contamination of the bunch and be rejected. This situation causes the underutilization of agricultural residues and eventually leads to severe environmental problems. When decomposed, these residues may produce noxious gases such as hydrogen sulfide and ammonia, posing a severe environmental hazard (Ilori et al., 2007). There are limitations in the plantation level, especially in establishing a proper collecting facility for the banana to be sorted according to their quality, stored and a handling system to prevent the loss of rejected banana fruits with damaged areas (Padam et al., 2014). Without a proper agricultural waste management practice, enormous amounts of valuable untapped commodities are lost and caused severe ecological damage. Another challenge is to overcome the problem related to the long-term storage of banana residues. Banana residues are highly biodegradable due to their richness in organic matter and high moisture content, leading to material instability and being degraded easily by exposure to microbes. It affects all the supply chain elements such as collection and storage, pre-processing, handling and transportation. The release of the pungent odor and fungi production also leads to the loss of dry matter and hygiene problems (Jaap & Sjaak, 2008). Besides, open burning activity for banana waste is still practiced in certain areas, contributing to serious environmental issues. The piling up of banana waste in plantations is also a disfigurement that ultimately obstructs farmers in their process of harvesting fruits (Padam et al., 2014). Therefore, drying the residue is an important step, but applying the optimal supply system should balance the banana residues' cost against removing the moisture and pre-processing the material.

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Some attempts have been to solve these problems by converting banana residues into valuable ingredients. For instance, the rejected banana would likely be used in starch production or as a low-cost banana flour ingredient made from the pulp (Zhang et al., 2005). Several uses of discarded bananas peel have been disclosed in animal feedstock production through microbial fermentation to minimize the production cost, but their high-water content required additional processing that significantly reduces the nutritional densities (Hong et al., 2004; Padam et al., 2014). A recent study trend is to convert the residues into energy by the combustion process, but it is not suitable for the direct combustion method because the peel had low density and high moisture content. Thus, energy production is deficient in its energy density and such an application is still at the research and development stages, so the commercial production has still not been completed (Padam et al., 2014).

The peel contains high nutritional ingredients and functional properties, such as polyphenol, which can be reuse into multiple valuable products especially in the food industry. It is an alternative source of natural antioxidants to replace the synthetic antioxidant that impacts health. People nowadays consider consuming natural preservatives or food supplements for their health benefits. However, despite their functional properties, the composition and activity of antioxidants are hampered due to the degradation triggered by extreme conditions and leading to a change in its natural morphology that limits its availability in the extract (Verma et al., 2014; Aguiar et al., 2016). It is not stable as a final product for long-term storage. The development of this phytochemical on the mainstream market is hindered and inherited from their susceptibility to high temperature, atmosphere and processing stress due to its instability behavior and restricted shelf life. Likewise, unsaturated polyphenol bonds of the extract caused deterioration when exposed to oxidants, light, heat, pH, volatility and contact with other compounds when applied in the food (Aguiar et al., 2016). Also, the unpleasant and astringent sensation of the tannin extract with the formation of unstable water content could increase the manufacturing cost in terms of product handling and packaging. It consumed more storage capacity and makes it prone to microorganism contamination and spoilage due to environmental sensitivity than the dried powder.

Shifting towards utilizing agricultural waste of banana residue is also perceived as an environmentally friendly approach to reduce the problems. There is a continuous need to create and invent new products with a value-added application from alternative bioresources and minimal recycling costs for developing a sustainable cavillation (Padam et al., 2014). A gradual improvement of the current technology to utilize the alternative resources in many industries cater to the needs of the growing world population. The enormous agricultural residues are an excellent source of precious materials for the industry by recycling the agricultural waste. Hence, research is needed to investigate the potential benefits of unripe banana peel as it is a rich source of tannin content and antioxidants.

Alternatively, it should be protected through the encapsulation process by spray drying before applying in the industry as the chemical damage can reduce its nutritional content. Thus, encapsulation based on a drying mechanism is required and more convenient for the storage, handling of powdery materials and preserve the antioxidant content. The

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study of optimizing the tannin extraction and encapsulation process by spray drying from the crude extract of the unripe Cavendish peel is scarce. The effective technique to maintain the recovery and stability of the bioactive compounds should be investigated. The powders have many advantages and economic potentials over their liquid counterparts, such as reduced volume, weight and packaging, more accessible transportation and longer shelf life. Its physical state is stable and generally used in many foods and pharmaceutical products like flavors and colors. The production of antioxidant powder was established from the Cavendish peel with green technology of water extract to expand the application and facilitate the handling and packaging of the powder. The present study was applicable because it could overcome these problems with optimum process conditions and low energy consumption cost from both extraction and encapsulation processes, as shown in Appendix D1.

1.3 Objectives of Research

The objectives of this study are:

1. To characterize the physicochemical properties, select the best solvent for extraction and evaluate the thin-layer drying characteristic from *Musa acuminata* Colla (Cavendish) banana peel.
2. To optimize the ultrasound-assisted extraction (UAE) parameters for extracted unripe *Musa acuminata* Colla (Cavendish) peel containing high tannin and antioxidant activities using response surface methodology (RSM).
3. To optimize and evaluate the efficiency of the spray-dried encapsulation process of unripe *Musa acuminata* Colla (Cavendish) peel powder using RSM.

1.4 Scope of Research

This study provides information on the physical, mechanical, chromatic, and chemical properties of two different ripening stages from Cavendish banana peels. The solvent extraction for both peels contributed to the effect of solvents with different polarities on the antioxidant extract, reflecting the best solvent that gives a high value of antioxidant content from the extraction process. The drying behavior of a thin-layer of banana peel was also characterized in this study with different temperature exposure by having different effects on the drying characteristic. Next, this study focuses on optimizing the process parameters for high tannin extract from unripe Cavendish peel as material from agricultural residues. Before the optimization process, a preliminary evaluation was studied, including comparing decoction and ultrasound extraction methods and the difference in pulse intensity used in ultrasound extraction. These data would help to design the optimization process of the experiment. The optimization process for ultrasound-assisted extraction (UAE) involved understanding variables toward the responses to produce an optimum condition. Different levels of each parameter, including temperature (15.00 - 75.00 ℃), extraction time (1.50 - 39.50 min), pre-incubation time (2.50 - 32.50 min) and solid to solvent concentration (2.05 - 12.65%)

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that had an impact contribution on the antioxidant extract. Then, the optimum extract was further analyzed for its encapsulation process.

The research continues with optimizing the spray drying process to achieve good properties of encapsulated powder with antioxidant properties. In this study, the powder was tested for its powder analysis and antioxidant assay involving the yield, moisture content, hygroscopicity, solubility, flowability, antioxidant content and activities. The encapsulated unripe Cavendish peel powder could be used as an innovation to enrich the functional characteristics and improve food preservation. The powder had several advantages over the liquid extract as it had strong reconstitution, lower water activity and ideal storage due to the usage of maltodextrin as drying aids which play a beneficial role as a carrier or encapsulating agent. Both optimum extract and powder were analyzed for quantification through HPLC. The comprehensive study revealed that the processing parameters of extraction and encapsulation from unripe Cavendish peel could emphasize the possibility of entire exploitation of the peel part as agricultural residues rich in antioxidant compounds and potentially used as functional food ingredients. It is vital to reduce the emission of solid waste and loss of valuable untapped residues and generate high-value-added foods or nutraceutical products for potential applications.

1.5 Thesis Structure

This thesis contains five chapters. In Chapter 1, the overall research is briefly introduced along with the research objectives and problem statements. In Chapter 2, there is a comprehensive literature review on current knowledge about unripe banana peel *Musa acuminata* Colla (Cavendish), tannin, antioxidants, extraction ultrasound (UAE), encapsulation and spray drying process. The overall experimental design framework is explained in Chapter 3. The goals of the research will be described in the results and discussions in Chapters 4. Firstly, the physicochemical analysis, solvent extraction and drying behavior of Cavendish peels will be characterized. The second objective is to optimize the UAE method for unripe Cavendish peel based on the high extracted tannin content with antioxidant activities. The third objective is to investigate the effects of the maltodextrin concentration and the inlet air temperature at different levels on the properties, antioxidant content of the powder and quantification analysis by the HPLC. Finally, the conclusions and some recommendations will be mentioned in Chapter 5. The appendix and references that are used throughout the study will be included in the background of the thesis.

To conclude this chapter, a general introduction of this research study was discussed briefly. This chapter gives an introduction background of overall research, problem statements based on the previous findings which come out with the idea of problems solving, the objective that needs to be achieved at the end of the study and each objective reflected the scope of research and finally the overview of the thesis structure. This chapter contributes to the general idea of the introduction. The theory of knowledge related to the problems and objectives of the study will be explained in detail in the next chapter.

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REFERENCES

Abadio, F. D., Domingues, A. M., Borges, S. V., & Oliveira, V. M. (2004). Physical properties of powdered pineapple (*Ananas comosus*) juice - effect of malt dextrin concentration and atomization speed. *Journal of Food Engineering, 64*(3), 285-287.

Aboul-Enein, A. M., Salama, Z. A., Gaafar, A. A., Aly, H. F., Faten, A., & Ahmed, H. (2016). Identification of phenolic compounds from banana peel (*Musa paradaisica* L.) as antioxidant and antimicrobial agents. *Journal of Chemical and Pharmaceutical Research, 8*(4), 46-55.

Adhikari, B., Howes, T., Bhandari, B. R., & Troung, V. (2004). Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying: Experiments and modelling. *Journal of Food Engineering, 62*(1), 53-68.

Adnan, S.N.A., Ibrahim, N., & Yaacob, W. A. (2017). Disruption of methicillin-resistant Staphylococcus aureus protein synthesis by tannins. *Germs, 7*(4), 186.

Aguiar, J., Estevinho, B. N., & Santos, L. (2016). Microencapsulation of natural antioxidants for food application–The specific case of coffee antioxidants: A review. *Trends in Food Science & Technology, 58*, 21-39.

Ahmadian-Kouchaksaraie, Z., Niazmand, R., & Najafi, M. N. (2016). Optimization of the subcritical water extraction of phenolic antioxidants from *Crocus sativus* petals of saffron industry residues: Box-Behnken design and principal component analysis. *Innovative Food Science & Emerging Technologies, 36*, 234-244.

Al-Farsi, M. A., & Lee, C. Y. (2008). Optimization of phenolics and dietary fibre extraction from date seeds. *Food Chemistry, 108*(3), 977-985.

Alisi, C. S., Nwanyanwu, C. E., Akujobi, C. O., & Ibegbulem, C. O. (2008). Inhibition of dehydrogenase activity in pathogenic bacteria isolates by aqueous extracts of *Musa paradisiaca* (var Sapientum). *African Journal of Biotechnology, 7*(12), 1821-1825.

Alkarkhi, A. F., Ramli, S. b., Yong, Y. S., & Easa, A. M. (2011). Comparing physicochemical properties of banana pulp and peel flours prepared from green and ripe fruits. *Food Chemistry, 129*(2), 312-318.

Alothman, M., Bhat, R., & Karim, A. A. (2009). Antioxidant capacity and phenolic content of selected tropical fruits from Malaysia, extracted with different solvents. *Food Chemistry, 115*(3), 785-788.

Anal, A. K., Jaisanti, S., & Noomhorm, A. (2014). Enhanced yield of phenolic extracts from banana peels (*Musa acuminata* Colla AAA) and cinnamon barks (*Cinnamomum varum*) and their antioxidative potentials in fish oil. *Journal of Food Science and Technology, 51*(10), 2632-2639.

© COPYRIGHT UPM

Anhwange, B. A., Ugye, T. J., & Nyiaatagher, T. D. (2009). Chemical composition of *Musa sapientum* (banana) peels. *Electronic Journal of Environmental, Agricultural and Food Chemistry, 8*(6), 437-442.

Antonkiewicz, J., & Łabętowicz, J. (2016). Chemical innovation in plant nutrition in a historical continuum from ancient Greece and Rome until modern times. *Chemistry-Didactics-Ecology-Metrology*, *21*(1-2), 29-43.

AOAC International. (2007). *Official Methods of Analysis of AOAC International (18th Ed.).* Gaithersburg, USA: Association of Analytical Communities.

Araji, S., Grammer, T. A., Gertzen, R., Anderson, S. D., Mikulic-Petkovsek, M., Veberic, R., Phu, M. L., Solar, A., Leslie, C. A., Dandekar, A. M. & Escobar, M. A. (2014). Novel roles for the polyphenol oxidase enzyme in secondary metabolism and the regulation of cell death in walnut. *Plant Physiology*, *164*(3), 1191-1203.

Araujo-Díaz, S. B., Leyva-Porras, C., Aguirre-Bañuelos, P., Álvarez-Salas, C., & Saavedra-Leos, Z. (2017). Evaluation of the physical properties and conservation of the antioxidants content, employing inulin and maltodextrin in the spray drying of blueberry juice. *Carbohydrate Polymers, 167*, 317-325.

Ayala-Zavala, J. F., & González-Aguilar, G. A. (2011). Use of additives to preserve the quality of fresh-cut fruits and vegetables. In Martin-Belloso, O. & Fortuny, R. S (Eds.), *Advances in Fresh-cut Fruits and Vegetables Processing* (pp.231-254). CRC Press.

Babbar, N., Oberoi, H. S., Uppal, D. S., & Patil, R. (2011). Total phenolic content and antioxidant capacity of extracts obtained from six important fruit residues. *Food Research International*, *44*(1), 391-396.

Bagavan, A., Rahuman, A. A., Kaushik, N. K., & Sahal, D. (2011). In vitro antimalarial activity of medicinal plant extracts against *Plasmodium falciparum*. *Parasitology Research*, *108*(1), 15-22.

Bagchi, D., Bagchi, M., Stohs, S. J., Das, D. K., Ray, S. D., Kuszynski, C. A., Joshi, S. S., & Pruess, H. G. (2000). Free radicals and grape seed proanthocyanidin extract: Importance in human health and disease prevention. *Toxicology*, *148*(2-3), 187-197.

Balasubramani, P., Viswanathan, R., & Vairamani, M. (2013). Response surface optimisation of process variables for microencapsulation of garlic (*Allium sativum* L.) oleoresin by spray drying. *Biosystems Engineering*, *114*(3), 205-213.

Ballard, T. S., Mallikarjunan, P., Zhou, K., & O'Keefe, S. F. (2009). Optimizing the extraction of phenolic antioxidants from peanut skins using response surface methodology. *Journal of Agricultural and Food Chemistry*, *57*(8), 3064-3072.

Baranauskienė, R., Venskutonis, P. R., Dewettinck, K., & Verhé, R. (2006). Properties of oregano (*Origanum vulgare* L.), citronella (*Cymbopogon nardus* G.) and marjoram (*Majorana hortensis* L.) flavors encapsulated into milk protein-based matrices. *Food Research International*, *39*(4), 413-425.

© COPYRIGHT UPM

Baş, D., & Boyacı, I. H. (2007). Modeling and optimization I: Usability of response surface methodology. *Journal of Food Engineering, 78*(3), 836-845.

Becker, E. M., Nissen, L. R., & Skibsted, L. H. (2004). Antioxidant evaluation protocols: Food quality or health effects. *European Food Research and Technology, 219*(6), 561-571.

Benchaachoua, A., Bessam , H. M., & Saidi, I. (2018). Effects of different extraction methods and solvents on the phenolic composition and antioxidant activity of *Silybum marianum* leaves extracts. *International Journal of Medical Science and Clinical Invention, 5*(3), 3641-3647.

Bhatta, R., Krishnamoorthy, U., & Mohammed, F. (2001). Effect of tamarind (*Tamarindus indica*) seed husk tannins on in vitro rumen fermentation. *Animal Feed Science and Technology, 90*(3-4), 143-152.

Boonchu, T., & Utama-ang, N. (2015). Optimization of extraction and microencapsulation of bioactive compounds from red grape (*Vitis vinifera* L.) pomace. *Journal of Food Science and Technology*, *52*(2), 783-792.

Boots, A. W., Haenen, G. R., & Bast, A. (2008). Health effects of quercetin: from antioxidant to nutraceutical. *European of Jurnal of Pharmacology, 585*(2-3), 325-337.

Bugaud, C., Alter, P., Daribo, M. O., & Brillouet, J. M. (2009). Comparison of the physico-chemical characteristics of a new triploid banana hybrid, FLHORBAN 920, and the Cavendish variety. *Journal of the Science of Food and Agriculture, 89*(3), 407-413.

Cacace, J. E., & Mazza, G. (2003). Mass transfer process during extraction of phenolic compounds from milled berries. *Journal of Food Engineering*, *59*(4), 379-389.

Cai, Y. Z., & Corke, H. (2000). Production and properties of spray-dried Amaranthus betacyanin pigments. *Journal of Food Science, 65*(7), 1248-1252.

Carvalho, A. G., Zanuncio, A. J., Mori, F. A., Mendes, R. F., da Silva, M. G., & Mendes, L. M. (2014). Tannin adhesive from *Stryphnodendron adstringens* (Mart.) Coville in plywood panels. *BioResources*, *9*(2), 2659-2670.

Castro, R. S. D., Caetano, L., Ferreira, G., Padilha, P. M., Saeki, M. J., Zara, L. F., Martines, M. A. U., & Castro, G. R. (2011). Banana peel applied to the solid phase extraction of copper and lead from river water: Preconcentration of metal ions with a fruit waste. *Industrial & Engineering Chemistry Research, 50*(6), 3446-3451.

Chan, K. W., & Ismail, M. (2009). Supercritical carbon dioxide fluid extraction of *Hibiscus cannabinus* L. seed oil: A potential solvent-free and high antioxidative edible oil. *Food Chemistry, 114*(3), 970-975.

Chanwitheesuk, A., Teerawutgulrag, A., & Rakariyatham, N. (2005). Screening of antioxidant activity and antioxidant compounds of some edible plants of Thailand. *Food Chemistry, 92*(3), 491-497.

© COPYRIGHT UPM

Chauhan, O. P., Raju, P. S., Dasgupta, D. K., & Bawa, A. S. (2006). Instrumental textural changes in banana (var. Pachbale) during ripening under active and passive modified atmosphere. *International Journal of Food Properties, 9*(2), 237-253.

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

Chemat, F., & Khan, M. K. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. *Ultrasonics sonochemistry, 18*(4), 813-835.

Cheok, C. Y., Chin, N. L., Yusof, Y. A., Talib, R. A., & Law, C. L. (2013). Optimization of total monomeric anthocyanin (TMA) and total phenolic content (TPC) extractions from mangosteen (*Garcinia mangostana* Linn.) hull using ultrasonic treatments. *Industrial Crops and Products, 50*, 1-7.

Chin , S. T., Nazimah, S. A., Quek, S. Y., Man, Y. B., Rahman, R. A., & Hashim, D. M. (2010). Effect of thermal processing and storage condition on the flavour stability of spray-dried durian powder. *LWT-Food Science and Technology, 43*(6), 856-861.

Conte, A., Sinigaglia, M., & Del Nobile, A. (2007). Use of lemon extract to inhibit the growth of malolactic bacteria. *Journal of Food Protection, 70*(1), 114-118.

Costa, G., Ferreira, J. P., Vitorino, C., Pina, M. E., Sousa, J. J., Figueiredo, I. V., & Batista, M. T. (2016). Polyphenols from *Cymbopogon citratus* leaves as topical anti-inflammatory agents. *Journal of Ethnopharmacology, 178*, 222-228.

Dabbs, D. M., Mulders, N., & Aksay, I. A. (2006). Solvothermal removal of the organic template from L 3 (“sponge”) templated silica monoliths. *Journal of Nanoparticle Research, 8*(5), 603-614.

de Jesus, O. N., e Silva, S. D., Amorim, E. P., Ferreira, C. F., de Campos, J. M., de Gaspari Silva, G., & Figueira, A. (2013). Genetic diversity and population structure of *Musa* accessions in ex situconservation. *BMC Plant Biology, 13*(1), 41.

Desai, K. G., & Jin Park, H. (2005). Recent developments in microencapsulation of food ingredients. *Drying Technology, 23*(7), 1361-1394.

Devatkal, S. K., Kumboj, R., & Paul, D. (2014). Comparative antioxidant effect of BHT and water extracts of banana and sapodilla peels in raw poultry meat. *Journal of Food Science and Technology, 51*(2), 387-391.

Dhanani, T., Shah, S., Gajbhiye, N. A., & Kumar, S. (2017). Effect of extraction methods on yield, phytochemical constituents and antioxidant activity of *Withania somnifera*. *Arabian Journal of Chemistry, 10*, 1193-1199.

Dolinsky, A., Maletskaya, K., & Snezhkin, Y. (2000). Fruit and vegetable powders production technology on the bases of spray and convective drying methods. *Drying technology, 18*(3), 747-758.

Dorman, H. D., & Deans, S. G. (2000). Antimicrobial agents from plants: Antibacterial activity of plant volatile oils. *Journal of Applied Microbiology, 88*(2), 308-316.

© COPYRIGHT UPM

dos Santos Oliveira, M., & Furlong, E. B. (2008). Screening of antifungal and antimycotoxigenic activity of plant phenolic extracts. *World Mycotoxin Journal, 1*(2), 139-146.

Doymaz, I. (2006). Thin-layer drying behaviour of mint leaves. *Journal of Food Engineering, 74*(3), 370-375.

Drusch, S., & Berg, S. (2008). Extractable oil in microcapsules prepared by spray-drying: Localisation, determination and impact on oxidative stability. *Food Chemistry, 109*(1), 17-24.

Dugas, J. A., Castañeda-Acosta, J., Bonin, G. C., Price, K. L., Fischer, N. H., & Winston, G. W. (2000). Evaluation of the total peroxyl radical-scavenging capacity of flavonoids: Structure− activity relationships. *Journal of Natural Products, 63*(3), 327-331.

Duvivier, P., Hsieh, P. C., Lai, P. Y., & Charle, A. L. (2010). Retention of phenolics, carotenoids, and antioxidant activity in the taiwanese sweet potato (*Ipomoea batatas* lam.) CV Tainong 66 subjected to different drying conditions. *African Journal of Food, Agriculture, Nutrition and Development*, *10*(11).

Eikani, M. H., Golmohammad, F., & Homami, S. S. (2012). Extraction of pomegranate (*Punica granatum* L.) seed oil using superheated hexane. *Food and Bioproduct Processing*, 90, 32-36.

Emaga, T. H., Andrianaivo, R. H., Wathelet, B., Tchango, J. T., & Paquot, M. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chemistry, 103*(2), 590-600.

Emaga, T. H., Ronkart, S. N., Robert, C., Wathelet , B., & Paquot, M. (2008). Characterisation of pectins extracted from banana peels (*Musa* AAA*)* under different conditions using an experimental design. *Food Chemistry, 108*(2), 463-471.

Ersus, S., & Yurdagel, U. (2007). Microencapsulation of anthocyanin pigments of black carrot (*Daucus carota* L.) by spray drier. *Journal of Food Engineering, 80*(3), 805-812.

Esquenazi, D., Wigg, M. D., Miranda, M. M., Rodrigues, H. M., Tostes, J. B., Rozental, S., da Silva, A. J. R., & Alviano, C. S. (2002). Antimicrobial and antiviral activities of polyphenolics from *Cocos nucifera* Linn.(Palmae) husk fiber extract. *Research in Microbiology, 153*(10), 657-652.

Fang, Z., & Bhandari, B. (2010). Encapsulation of polyphenols: A review. *Trends in Food Science & Technology, 21*(10), 510-523.

FAOSTAT. (2013). *FAO Statistical Database*. (Food and Agricultural Organization of the United Nations) Retrieved 15 July, 2019, from Agricultural data: http://www.fao.org/faostat/en/#data

FAOSTAT. (2018). *FAO Statistical Database*. (Food and Agricultural Organization of the United Nations) Retrieved 24 June, 2020, from Agricutural Data: http://www.fao.org/faostat/en/#data

© COPYRIGHT UPM

FAOSTAT. (2019). *FAO Statistical Database*. (Food and Agricultural Organization of United Nations) Retrieved 22 September, 2020, from Agricultural Data: http://www.fao.org/faostat/en/#data

Faried, A., Kurnia, D., Faried, L. S., Usman, N., Miyazaki, T., Kato, H., & Kuwano, H. (2007). Anticancer effects of gallic acid isolated from Indonesian herbal medicine, *Phaleria macrocarpa* (Scheff.) Boerl, on human cancer cell lines. *International Journal of Oncology, 30*(3), 605-613.

Fatemeh, S. R., Saifullah, R., Abbas, F. M., & Azhar, M. E. (2012). Total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours: Influence of variety and stage of ripeness. *International Food Research Journal, 19*(3), 1041.

Fattouch, S., Caboni, P., Coroneo, V., Tuberoso, C., Angioni, A., Dessi, S., Marzouki, N., & Cabras, P. (2008). Comparative analysis of polyphenolic profiles and antioxidant and antimicrobial activities of tunisian pome fruit pulp and peel aqueous acetone extracts. *Journal of Agricultural and Food Chemistry, 56*(3), 1084-1090.

Fernandes, E. R., Marangoni, C., Souza, O., & Sellin, N. (2013). Thermochemical characterization of banana leaves as a potential energy source. *Energy Conversion and Management, 75*, 603-608.

Ferrari, C. C., Germer, S. P., & de Aguirre, J. M. (2012). Effects of spray-drying conditions on the physicochemical properties of blackberry powder. *Drying Technology, 30*(2), 154-163.

Ferreira, O., & Pinho, S. P. (2012). Solubility of flavonoids in pure solvents. *Industrial & Engineering Chemistry Research, 51*(18), 6586-6590.

Filková, I., Huang, L. X., & Mujumdar, A. S. (2006). Industrial spray drying systems. In A. S. Mujumdar (Ed.), *Handbook of industrial drying* (pp. 240-281). CRC Press.

Franco, P. B., Almeida, L. A., Marques, R. F., Da Silva, M. A., & Campos, M. G. (2017). Chitosan associated with the extract of unripe banana peel for potential wound dressing application. *International Journal of Polymer Science*, *2017*.

Gaamoune, S., Harzallah, D., Kada, S., & Dahamna, S. (2014). The comparison of two tannin extraction methods from *Galium tunetanum* Poiret and their antioxidant capacities. *Der Pharmacia Lettre, 6*(1), 114-119.

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

Gallo, M., Ferracane, R., Graziani, G., Ritieni, A., & Fogliano, V. (2010). Microwave assisted extraction of phenolic compounds from four different spices. *Molecules, 15*(9), 6365-6374.

Gharsallaoui, A., Roudaut, G., Chambin, O., Voilley, A., & Saurel, R. (2007). Applications of spray-drying in microencapsulation of food ingredients: An overview. *Food Research International, 40*(9), 1107-1121.

© COPYRIGHT UPM

Ghosh, D. (2015). Tannins from foods to combat diseases. *International Journal of Pharma Research & Review, 4*(5), 40-44.

Gil, M. I., Tomás-Barberán, F. A., Hess-Pierce, B., & Kader, A. A. (2002). Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. *Journal of Agricultural and Food Chemistry, 50*(17), 4976-4982.

Goldsmith, C. D., Vuong, Q. V., Stathopoulos, C. E., Roach, P. D., & Scarlett, C. J. (2014). Optimization of the aqueous extraction of phenolic compounds from olive leaves. *Antioxidants, 3*(4), 700-712.

Gong, K. J., Shi, A. M., Liu, H. Z., Liu, L., Hu, H., Adhikari, B., & Wang, Q. (2016). Emulsifying properties and structure changes of spray and freeze-dried peanut protein isolate. *Journal of Food Engineering, 170*, 33-40.

González-Aguilar, G. A., Ruiz-Cruz, S., Soto-Valdez, H., Vázquez-Ortiz, F., Pacheco-Aguilar, R., & Wang, C. Y. (2005). Biochemical changes of fresh-cut pineapple slices treated with antibrowning agents. *International Journal of Food Science & Technology, 40*(4), 377-383.

González-Aguilar, G. A., Wang, C. Y., & Buta, J. G. (2000). Maintaining quality of fresh-cut mangoes using antibrowning agents and modified atmosphere packaging. *Journal of Agricultural and Food Chemistry, 48*(9), 4204-4208.

González-Aguilar, G., Robles-Sánchez, R. M., Martínez-Téllez, M. A., Olivas, G. I., Alvarez-Parrilla, E., & De La Rosa, L. A. (2008). Bioactive compounds in fruits: Health benefits and effect of storage conditions. *Stewart Postharvest Review, 4*(3), 1-10.

González-Montelongo, R., Lobo, M. G., & González, M. (2010). The effect of extraction temperature, time and number of steps on the antioxidant capacity of methanolic banana peel extracts. *Separation and Purification Technology, 71*(13), 347-355.

Gore, M. A., & Akolekar, D. (2003). Evaluation of banana leaf dressing for partial thickness burn wounds. *Burns, 29*(5), 487-492.

Gouin, S. (2004). Microencapsulation: Industrial appraisal of existing technologies and trends. *Trends in Food Science & Technology, 15*(7-8), 330-347.

Goula, A. M., & Adamopoulos, K. G. (2005). Spray drying of tomato pulp in dehumidified air: II. The effect on powder properties. *Journal of Food Engineering*, *66*(1), 35-42.

Goula, A. M., & Adamopoulos, K. G. (2008). Effect of maltodextrin addition during spray drying of tomato pulp in dehumidified air: II. Powder properties. *Drying Technology, 26*(6), 726-737.

Goula, A. M., & Adamopoulos, K. G. (2010). A new technique for spray drying orange juice concentrate. *Innovative Food Science & Emerging Technologies, 11*(2), 342-351.

Graefe, S., Dufour, D., Giraldo, A., Muñoz, L. A., Mora , P., Solís, H., Garcés, H., & Gonzalez, A. (2011). Energy and carbon footprints of ethanol production using

© COPYRIGHT UPM

banana and cooking banana discard: A case study from Costa Rica and Ecuador. *Biomass and Bioenergy, 35*(7), 2640-2649.

Guerrero, A. B., Aguado, P. L., Sánchez, J., & Curt, M. D. (2016). GIS-based assessment of banana residual biomass potential for ethanol production and power generation: a case study. *Waste and Biomass Valorization, 7*(2), 405-415.

Guo, C., Yang, J., Wei, J., Li, Y., Xu, J., & Jiang, Y. (2003). Antioxidant activities of peel, pulp and seed fractions of common fruits as determined by FRAP assay. *Nutrition Research, 23*(12), 1719-1726.

Hadjittofis, E., Das, S. C., Zhang, G. G., & Heng, J. Y. (2017). Interfacial phenomena. In Y. Qiu, Y. Chen, G. Zhang, L. Yu, & R. Mantri (Eds.), *Developing Solid Oral Dosage Forms* (pp. 225-252). Academic Press.

Haile, M., & Kang, W. (2019). Antioxidant activity, total polyphenol, flavonoid and tannin contents of fermented green coffee beans with selected yeasts. *Fermentation, 5*(1), 29.

Han, H. P., Liu, R. L., Cui, H. Y., & Zhang, Z. Q. (2013). Microwave-assisted extraction and LC/MS analysis of phenolic antioxidants in sweet apricot (*Prunus armeniaca* L.) kernel skins. *Journal of Liquid Chromatography & Related Technologies, 36*(15), 2182-2195.

Hässig, A., Linag, W. X., Schwabl, H., & Stampfli, K. (1999). Flavonoids and tannins: Plant based antioxidants with vitamin character. *Medical hypotheses*, *52*(5), 479-481.

He, B., Zhang, L. L., Yue, X. Y., Liang, J., Jiang, J., Gao, X. L., & Yue, P. X. (2016). Optimization of ultrasound-assisted extraction of phenolic compounds and anthocyanins from blueberry (*Vaccinium ashei*) wine pomace. *Food Chemistry, 204*, 70-76.

He, X. (2009). Integration of physical, chemical, mechanical, and biopharmaceutical properties in solid oral dosage form development. In Y. Qiu, Y. Chen, G. Zhang, L. Yu, & R. V. Mantri (Eds.), *Developing Solid Oral Dosage Forms* (pp. 407-441). Academic Press.

Heredia, J. B., & Martín, J. S. (2009). Removing heavy metals from polluted surface water with a tannin-based flocculant agent. *Journal of Hazardous Materials, 165*(1-3), 1215-1218.

Hertog, M. G., Hollman, P. C., & Venema, D. P. (1992). Optimization of a quantitative HPLC determination of potentially anticarcinogenic flavonoids in vegetables and fruits. *Journal of Agricultural and Food Chemistry, 40*(9), 1591-1598.

Hintz, T., Matthews, K. K., & Di, R. (2015). The use of plant antimicrobial compounds for food preservation. *BioMed research international*, *2015.*

Hoag, S. W. (2017). Capsules dosage form: Formulation and manufacturing considerations. In Y. Qiu, Y. Chen, G. Zhang, L. Yu, & R. V. Mantri (Eds.), *Developing Solid Oral Dosage Forms* (pp. 723-747). Academic Press.

© COPYRIGHT UPM

Hong, K. J., Lee, C. H., & Kim, S. W. (2004). Aspergillus oryzae GB-107 fermentation improves nutritional quality of food soybeans and feed soybean meals. *Journal of Medicinal Food*, *7*(4), 430-435.

Ilori, M. O., Adebusoye, S. A., Iawal, A. K., & Awotiwon, O. A. (2007). Production of biogas from banana and plantain peels. *Advances in Environmental Biology*, 33-39.

Ishak, N. A., Razak, N. A. A. , Dek, M. S. P., & Baharuddin, A. S. (2020). Production of high tannin content and antioxidant activity extract from an unripe peel of *Musa acuminata* (Cavendish) using ultrasound-assisted extraction (UAE). *Bioresources, 15*(1), 1877-1893.

Izadifar, Z. (2013). Ultrasound pretreatment of wheat dried distiller's grain (DDG) for extraction of phenolic compounds. *Ultrasonics Sonochemistry*, *20*(6), 1359-1369.

Izidoro, D. R., Sierakowski, M. R., Haminiuk, C. W., De Souza, C. F., & de Paula Scheer, A. (2011). Physical and chemical properties of ultrasonically, spray-dried green banana (*Musa cavendish*) starch. *Journal of Food Engineering, 104*(4), 639-648.

Jafari, S. M., Ghalenoei, M. G., & Dehnad, D. (2017). Influence of spray drying on water solubility index, apparent density, and anthocyanin content of pomegranate juice powder. *Powder Technology, 311*, 59-65.

Jagan, S., Ramakrishnan, G., Anandakumar, P., Kamaraj, S., & Devaki, T. (2008). Antiproliferative potential of gallic acid against diethylnitrosamine-induced rat hepatocellular carcinoma. *Molecular and Cellular Biochemistry, 319*(1-2), 51.

Jain, A., Ranade, R., Pritam, P., Joshi, N., Vavilala, S. L., & Jain, A. (2014). A comparative study of antioxidant activity, total phenolic and flavonoid contents in different parts of *Helicteres isora* L. *American Journal of Life Sciences*, *2*(5), 292-302.

Jamaluddin, S. H. (2000). Banana R & D Thrusts in Malaysia. In A. Molina, & V. Roa (Eds.), *Advancing Banana and Plantain R & D in Asia and the Pacific* (pp. 108-111). International Plant Genetic Resources Institute.

Ji, L., & Srzednicki, G. (2015). Extraction of aromatic compounds from banana peels. *Acta Horticulturae 1088*, 541-546.

Jorge, F. C., Neto, C. P., Irle, M. A., Gil, M. H., & De Jesus, J. P. (2002). Wood adhesives derived from alkaline extracts of maritime pine bark: Preparation, physical characteristics and bonding efficacy. *Holz als Roh-und Werkstoff*, *60*(4), 303-310.

Joshi, RV. Low calorie biscuits from banana peel pulp. *Journal of Solid Waste Technology Management*, *33*(3), 142–147.

Kaderides, K., Goula, A. M., & Adamopoulos, K. G. (2015). A process for turning pomegranate peels into a valuable food ingredient using ultrasound-assisted extraction and encapsulation. *Innovative Food Science & Emerging Technologies*, *31*, 204-215.

© COPYRIGHT UPM

Kalemelawa, F., Nishihara, E., Endo, T., Ahmad, Z., Yeasmin, R., Tenywa, M. M., & Yamamoto, S. (2012). An evaluation of aerobic and anaerobic composting of banana peels treated with different inoculums for soil nutrient replenishment. *Bioresource Technology, 126*, 375-382.

Kalt, W. (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *Journal of Food Science, 70*(1), 11-19.

Kamarudin, N. A., Markom, M., & Latip, J. (2016). Effects of solvents and extraction methods on herbal plants *Phyllanthus niruri*, *Orthosiphon stamineus* and *Labisia pumila*. *Indian Journal of Science and Technology, 9*(21), 1-5.

Kanatt, S. R., Chander, R., & Sharma, A. (2010). Antioxidant and antimicrobial activity of pomegranate peel extract improves the shelf life of chicken products. *International Journal of Food Science & Technology, 45*(2), 216-222.

Kaur, A., & Bhatt, D. (2011). Hybrid particle swarm optimization for regression testing. *International Journal on Computer Science and Engineering, 3*(5), 1815-1824.

Kha, T. C., Nguyen, M. H., & Roach, P. D. (2010). Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *Journal of Food Engineering, 98*(3), 385-392.

Khawas, P., Das, A. J., Sit, N., Badwaik, L. S., & Deka, S. C. (2014). Nutritional composition of culinary *Musa* ABB at different stages of development. *American Journal of Food Science and Technology, 2*(3), 80-87.

Khuenpet, K., Charoenjarasrerk, N., Jaijit, S., Arayapoonpong, S., & Jittanit, W. (2016). Investigation of suitable spray drying conditions for sugarcane juice powder production with an energy consumption study. *Agriculture and Natural Resources, 50*(2), 139-145.

Kim, E. H. J., Chen, X. D., & Pearce, D. (2009). Surface composition of industrial spray-dried milk powders. 2. Effects of spray drying conditions on the surface composition. *Journal of Food Engineering, 94*(2), 169-181.

Kitdamrongsont, K., Pothavorn, P., Swangpol, S., Wongniam, S., Atawongsa, K., Svasti, J., & Somana, J. (2008). Anthocyanin composition of wild bananas in Thailand. *Journal of Agricultural and Food Chemistry, 56*(22), 10853-10857.

Klimczak, l., Małecka, M., Szlachta, M., & Gliszczyńska-Świgło, A. (2007). Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices. *Journal of Food Composition and Analysis, 20*(33-4), 313-322.

Koc, B., Yilmazer, M. S., Balkır, P., & Ertekin, F. K. (2010). Spray drying of yogurt: Optimization of process conditions for improving viability and other quality attributes. *Drying Technology, 28*(4), 495-507.

Jaap, K., & Sjaak, V. L. (2008). *The handbook of biomass combustion and co-firing*. Routledge.

Krzyzowska, M., Tomaszewska, E., Ranoszek-Soliwoda, K., Bien, K., Orlowski, P., Celichowski, G., & Grobelny, J. (2017). Tannic acid modification of metal

© COPYRIGHT UPM

nanoparticles: Possibility for new antiviral applications. In E. Andronescu, & A. Grumezescu (Eds.), *Nanostructures for Oral Medicine* (pp. 335-363). Elsevier.

Kumar, S. K. (2015). Drying kinetics of banana peel. *Journal of Food Process Technology, 6*(11), 10-12.

Kumar, S. K., Bhowmik, D., Duraivel, S., & Umadevi, M. (2012). Traditional and medicinal uses of banana. *Journal of Pharmacognosy and Phytochemistry, 1*(3), 51-63.

Kurhade, A. H., & Waghmare, J. S. (2015). Effect of banana peel oleoresin on oxidative stability of sunflower and soybean oil. *Journal of Food Processing and Preservation, 39*(6), 1788-1797.

Kurtoglu, G., & Yildiz, S. (2011). Extraction of fructo-oligosaccaride components from banana peels. *Gazi University Journal of Science, 24*(4), 877-882.

Kwapińska, M., & Zbiciński, I. (2005). Prediction of final product properties after concurrent spray drying. *Drying Technology*, 23(8), 1653-1665.

Lee, J., Ye, L., Landen Jr, W. O., & Eitenmiller, R. R. (2000). Optimization of an extraction procedure for the quantification of vitamin E in tomato and broccoli using response surface methodology. *Journal of Food Composition and Analysis, 13*(1), 45-57.

Lee, W. C., Yusof, S. A., Hamid, N. S., & Baharin, B. S. (2006). Optimizing conditions for enzymatic clarification of banana juice using response surface methodology (RSM). *Journal of Food Engineering, 73*(1), 55-63.

León-Martínez, F. M., Mendez-Lagunas, L. L., & Rodriguez-Ramirez, J. (2010). Spray drying of nopal mucilage (*Opuntia ficus-indica*): Effects on powder properties and characterization. *Carbohydrate Polymers, 81*(4), 864-870.

Levi, S., Rac, V., Manojlovi, V., Raki, V., Bugarski, B., Flock, T., Krzyczmonik, K. E., & Nedovi, V. (2011). Limonene encapsulation in alginate/poly (vinyl alcohol). *Procedia Food Science, 1*, 1816-1820.

Liang, N., & Kitts, D. D. (2014). Antioxidant property of coffee components: Assessment of methods that define mechanisms of action. *Molecules, 19*(11), 19180-19208.

Lim, Y. Y., Lim , T. T., & Tee, J. J. (2007). Antioxidant properties of several tropical fruits: A comparative study. *Food chemistry, 103*(3), 1003-1008.

Lin, L., Lei, F., Sun, D. W., Dong, Y., Yang, B., & Zhao, M. (2012). Thermal inactivation kinetics of *Rabdosia serra* (Maxim.) Hara leaf peroxidase and polyphenol oxidase and comparative evaluation of drying methods on leaf phenolic profile and bioactivities. *Food chemistry, 134*(4), 2021-2029.

Liu, J., Sandahl, M., Sjöberg, P. J., & Turner, C. (2014). Pressurised hot water extraction in continuous flow mode for thermolabile compounds: Extraction of polyphenols in red onions. *Analytical and Bioanalytical Chemistry, 406*(2), 441-445.

© COPYRIGHT UPM

Liu, Y., Gong, G., Zhang, J., Jia, S., Li, F., Wang, Y., & Wu, S. (2014). Response surface optimization of ultrasound-assisted enzymatic extraction polysaccharides from *Lycium barbarum*. *Carbohydrate Polymers, 110*, 278-284.

Liyana-Pathirana, C., & Shahidi, F. (2005). Optimization of extraction of phenolic compounds from wheat using response surface methodology. *Food Chemistry, 93*(1), 47-56.

Londoño-Londoño, J., de Lima, V. R., Lara, O., Gil, A., Pasa, T. B., Arango, G. J., & Pineda, J. R. (2010). Clean recovery of antioxidant flavonoids from citrus peel: Optimizing an aqueous ultrasound-assisted extraction method. *Food Chemistry, 119*(1), 81-87.

Madene, A., Jacquot, M., Scher, J., & Desobry, S. (2006). Flavour encapsulation and controlled release - A review. *International Journal of Food Science & Technology, 41*(1), 1-21.

Mahendran, T. (2010). Physico-chemical properties and sensory characteristics of dehydrated guava concentrate: Effect of drying method and maltodextrin concentration. *Tropical Agricultural Research and Extension, 13*(2), 48-54.

Malaysia Food Regulation. (1985). *Malaysian Law on Food and Drugs.* Kuala Lumpur: Malaysian Law Publisher.

Mandalari, G., Bennett, R. N., Bisignano, G., Trombetta, D., Saija, A., Faulds, C. B., Gasson, M. J., & Narbad, A. (2007). Antimicrobial activity of flavonoids extracted from bergamot (*Citrus bergamia Risso*) peel, a byproduct of the essential oil industry. *Journal of Applied Microbiology, 103*(6), 2056-2064.

Maran, J. P., Sivakumar, V., Thirugnanasambandham, K., & Sridhar, R. (2015). Extraction of natural anthocyanin and colors from pulp of jamun fruit. *Journal of Food Science and Technology, 52*(6), 3617-3626.

Margen. (2002). *Nutritional values of banana.* Universitas Diponegoro, Semarang.

Markom, M., Hasan, M., Daud, W. R., Singh, H., & Jahim, J. M. (2007). Extraction of hydrolysable tannins from *Phyllanthus niruri* Linn.: Effects of solvents and extraction methods. *Separation and Purification Technology, 52*(3), 487-496.

Marques, G. R., Borges, S. V., de Mendonça, K. S., de Barros Fernandes, R. V., & Menezes, E. G. (2014). Application of maltodextrin in green corn extract powder production. *Powder Technology, 263*, 89-95.

Martinelli, L., Gabas, A. L., & Telis-Romero, J. (2007). Thermodynamic and quality properties of lemon juice powder as affected by maltodextrin and arabic gum. *Drying Technology, 25*(12), 2035-2045.

Meireles, M. A. (2008). *Extracting bioactive compounds for food products: Theory and applications.* New York: CRC press.

Mercer, P., & Armenta, R. E. (2011). Developments in oil extraction from microalgae. *European Journal of Lipid Science and Technology, 113*(5), 539-547.

Ministry of Agriculture. (1998). *Third National Agricultural Policy (1998-2010): Executive Summary.* Kuala Lumpur: Ministry of Agriculture.

© COPYRIGHT UPM

Missio, A. L., Mattos, B. D., Ferreira, D. D. F., Magalhães, W. L., Bertuol, D. A., Gatto, D. A., Petutschnigg, A., & Tondi, G. (2018). Nanocellulose-tannin films: From trees to sustainable active packaging. *Journal of Cleaner Production, 184*, 143-151.

Mohapatra, D., Mishra, S., & Sutar, N. (2010). Banana post harvest practices: Current status and future prospects: A review. *Agricultural Reviews, 31*(1), 56-62.

Mokbel, M. S., & Hashinaga, F. (2005). Antibacterial and antioxidant activities of banana (*Musa*, AAA cv. Cavendish) fruits peel. *American Journal of Biochemistry and Biotechnology, 1*(3), 125-131.

Molyneux, P. (2004). The use of the stable free radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity. *Songklanakarin Journal Science Technology, 26*(2), 211-219.

Mordi, R. C., Fadiaro, A. E., Owoeye, T. F., Olanrewaju, I. O., Uzoamaka, G. C., & Olorunshola, S. J. (2016). Identification by GC-MS of the components of oils of banana peels extract, phytochemical and antimicrobial analyses. *Research Journal of Phytochemistry, 10*(1), 39-44.

Moreira, G. E., Costa, M. G., de Souza, A. C., de Brito, E. S., de Medeiros, M. D., & de Azeredo, H. M. (2009). Physical properties of spray dried acerola pomace extract as affected by temperature and drying aids. *LWT-Food Science and Technology, 42*(2), 641-645.

Moure, A., Cruz, J. M., Franco, D., Domínguez, J. M., Sineiro, J., Domínguez, H., Núñez, M. J., & Parajó, J. C. (2001). Natural antioxidants from residual sources. *Food Chemistry, 72*(2), 145-171.

Nadeem, H. S., Torun, M., & Özdemir, F. (2011). Spray drying of the mountain tea (*Sideritis stricta*) water extract by using different hydrocolloid carriers. *LWT-Food Science and Technology, 44*(7), 1626-1635.

Nekkanti, V., Muniyappan, T., Karatgi, P., Hari, M. S., Marella, S., & Pillai, R. (2009). Spray-drying process optimization for manufacture of drug–cyclodextrin complex powder using design of experiments. *Drug Development and Industrial Pharmacy, 35*(10), 1219-1229.

Ngaha Njila, M. I., Mahdi, E., Massoma-Lembe, D., Zacharie, N. E., & Nyonseu, D. (2017). Review on extraction and isolation of plant secondary metabolites. *7th Int'l Conference on Agricultural, Chemical, Biological and Environmental Sciences.* Kuala Lumpur.

Nurliyana, R. D., Syed, Z. I., Mustapha, S. K., Aisyah, M. R., & Kamarul , R. K. (2010). Antioxidant study of pulps and peels of dragon fruits: A comparative study. *International Food Research Journal, 17*(2), 367-375.

Oberoi, H. S., Vadlani, P. V., Saida, L., Bansal, S., & Hughes, J. D. (2011). Ethanol production from banana peels using statistically optimized simultaneous saccharification and fermentation process. *Waste Management, 31*(7), 1576-1584.

© COPYRIGHT UPM

Oliveira, W. P., Bott, R. F., & Souza, C. R. (2006). Manufacture of standardized dried extracts from medicinal Brazilian plants. *Drying Technology, 24*(4), 523-533.

Ollanketo, M., Peltoketo, A., Hartonen, Hartonen, K., Hiltunen, R., & Riekkola, M. L. (2002). Extraction of sage (*Salvia officinalis* L.) by pressurized hot water and conventional methods: Antioxidant activity of the extracts. *European Food Research and Technology, 215*(2), 158-163.

Okuda, T., & Ito, H. (2011). Tannins of constant structure in medicinal and food plants-hydrolyzable tannins and polyphenols related to tannins. *Molecules*, *16*(3), 2191-2217.

Ou, S., & Kwok, K. C. (2004). Ferulic acid: Pharmaceutical functions, preparation and applications in foods. *Journal of the Science of Food and Agriculture, 84*(11), 1261-1269.

Ozcan, H. M., & Sagiroglu, A. (2010). A novel amperometric biosensor based on banana peel (*Musa cavendish*) tissue homogenate for determination of phenolic compounds. *Artificial Cells, Blood Substitutesand Biotechnology, 38*(4), 208-214.

Padam, B. S., Tin, H. S., Chye, F. Y., & Abdullah, M. I. (2014). Banana by-products: An under-utilized renewable food biomass with great potential. *Journal of Food Science and Technology, 51*(12), 3527-3545.

Palafox-Carlos, H., Ayala-Zavala, J. F., & González-Aguilar, G. A. (2011). The role of dietary fiber in the bioaccessibility and bioavailability of fruit and vegetable antioxidants. *Journal of Food Science*, *76*(1), 6-15.

Palafox-Carlos, H., Yahia, E. M., & González-Aguilar, G. A. (2012). Identification and quantification of major phenolic compounds from mango (*Mangifera indica*, cv. Ataulfo) fruit by HPLC–DAD–MS/MS-ESI and their individual contribution to the antioxidant activity during ripening. *Food Chemistry, 135*(1), 105-111.

Pan, G., Yu, G., Zhu, C., & Qiao, J. (2012). Optimization of ultrasound-assisted extraction (UAE) of flavonoids compounds (FC) from hawthorn seed (HS). *Ultrasonics Sonochemistry*, *19*(3), 486-490.

Papadakis, S. E., Gardeli, C., & Tzia, C. (2006). Spray drying of raisin juice concentrate. *Drying Technology, 24*(2), 173-180.

Patachia, S., & Croitoru, C. (2016). Biopolymers for wood preservation. In *Biopolymers and biotech admixtures for eco-efficient construction materials* (pp. 305-332). Woodhead Publishing.

Peleg, M. (2020). Humidity caking and its prevention. In G. V. Barbosa-Cï, A. J. Fontana Jr, S. J. Schmidt, & T. P. Labuza (Eds.), *Water Activity in Foods: Fundamentals and Applications*, (pp. 453-464). John Wiley & Sons.

Pereira, A., & Maraschin, M. (2015). Banana (*Musa* spp) from peel to pulp: Ethnopharmacology, source of bioactive compounds and its relevance for human health. *Journal of Ethnopharmacology, 160*, 149-163.

© COPYRIGHT UPM

Pisoschi, A. M., & Negulescu, G. P. (2011). Methods for total antioxidant activity determination: A review. *Biochemistry and Analytical Biochemistry, 1*(1), 106.

Pizzi, A. (2008). Tannins: Major sources, properties and applications. In M. N. Belgacem, & A. Gandini (Eds.), *Monomers, polymers and composites from renewable resources* (pp. 179-199). Elsevier.

Plaza, M., & Turner, C. (2015). Pressurized hot water extraction of bioactives. *TrAC Trends in Analytical Chemistry, 71*, 39-54.

Policegoudra, R. S., Abiraj, K., Gowda, D. C., & Aradhya, S. M. (2007). Isolation and characterization of antioxidant and antibacterial compound from mango ginger (*Curcuma amada* Roxb.) rhizome. *Journal of Chromatography B, 852*(1-2), 40-48.

Pradal, D., Vauchel, P., Decossin, S., Dhulster, P., & Dimitrov, K. (2016). Kinetics of ultrasound-assisted extraction of antioxidant polyphenols from food by-products: Extraction and energy consumption optimization. *Ultrasonics Sonochemistry, 32*, 137-146.

Pramote, B., Waranuch, N., & Kritsunankul, O. (2018). Simultaneous determination of gallic acid and catechins in banana peel extract by Reversed-Phase High Performance Liquid Chromatography. *Naresuan University Journal: Science and Technology (NUJST), 26*(3), 189-200.

Prasanna, V., Prabha, T. N., & Tharanathan, R. N. (2007). Fruit ripening phenomena–An overview. *Critical Reviews in Food Science and Nutrition, 47*(1), 1-19.

Prathapan, A., Lukhman, M., Arumughan, C., Sundaresan, A. B., & Raghu, K. G. (2009). Effect of heat treatment on curcuminoid, colour value and total polyphenols of fresh turmeric rhizome. *International Journal of Food Science & Technology, 44*(7), 1438-1444.

Preys, S., Mazerolles, G., Courcoux, P., Samson, A., Fischer, U., Hanafi, M., Bertrand, D., & Cheynier, V. (2006). Relationship between polyphenolic composition and some sensory properties in red wines using multiway analyses. *Analytica Chimica Acta, 563*(1-2), 126-136.

Qiu, L. P., Zhao, G. L., Wu, H., Jiang, L., Li, X. F., & Liu, J. J. (2010). Investigation of combined effects of independent variables on extraction of pectin from banana peel using response surface methodology. *Carbohydrate Polymers, 80*(2), 326-331.

Quek, S. Y., Chok, N. K., & Swedlund, P. (2007). The physicochemical properties of spray-dried watermelon powders. *Chemical Engineering and Processing: Process Intensification, 465*(5), 386-392.

Ramdani, D., Hernaman, I., Nurmeidiansyah, A. A., Heryadi, D., & Nurachma, S. (2019). Potential use of banana peels waste at different ripening stages for sheep feeding on chemical, tannin, and in vitro assessments. *IOP Conf. Series: Earth and Environmental Science, 334*.

Ramli, S., Alkarkhi, A. F., Yong, Y. S., Min-Tze, L., & Easa, A. M. (2009). Effect of banana pulp and peel flour on physicochemical properties and in vitro starch

© COPYRIGHT UPM

digestibility of yellow alkaline noodles. *International Journal of Food Sciences and Nutrition, 60*(sup4), 326-340.

Ravi, I., & Vaganan, M. M. (2016). Abiotic stress tolerance in banana. In N. S. Rao, & K. S. Shivashankara (Eds.), *Abiotic stress physiology of horticultural crops* (pp. 207-222). New Delhi: Springer.

Ray, S., Raychaudhuri, U., & Chakraborty, R. (2016). An overview of encapsulation of active compounds used in food products by drying technology. *Food Bioscience, 13*, 78-83.

Rebello, L. P., Ramos, A. M., Pertuzatti, P. B., Barcia, M. T., Castillo-Muñoz, N., & Hermosín-Gutiérrez, I. (2014). Flour of banana *(Musa* AAA) peel as a source of antioxidant phenolic compounds. *Food Research International, 55*, 397-403.

Redondo, L. M., Chacana, P. A., Dominguez, J. E., & Fernandez Miyakawa, M. E. D. (2014). Perspectives in the use of tannins as alternative to antimicrobial growth promoter factors in poultry. *Frontiers in Microbiology, 5*, 118.

Rehman, S., Nadeem, M., Ahmad, F., & Mushtaq, Z. (2013). Biotechnological production of xylitol from banana peel and its impact on physicochemical properties of rusks. *Journal of Agricultural Science and Technology, 15*, 747-756.

Riedl, K. M., Carando, S., Alessio, H. M., McCarthy, M., & Hagerman, A. E. (2002). Antioxidant activity of tannins and tannin-protein complexes: Assessment in vitro and in vivo. In M. J. Morello, & F. H.-T. Shahidi (Eds.). Washington, DC: American Chemical Society.

Robards, K. (2003). Strategies for the determination of bioactive phenols in plants, fruit and vegetables. *Journal of Chromatography A, 1000*(1-2), 657-691.

Robert, P., Gorena, T., Romero, N., Sepulveda, E., Chavez, J., & Saenz, C. (2010). Encapsulation of polyphenols and anthocyanins from pomegranate (*Punica granatum*) by spray drying. *International Journal of Food Science & Technology, 45*(7), 1386-1394.

Rodríguez-Hernández, G. R., González-García, R., Grajales-Lagunes, A., Ruiz-Cabrera, M. A., & Abud-Archila, M. (2005). Spray-drying of cactus pear juice (*Opuntia streptacantha*): Effect on the physicochemical properties of powder and reconstituted product. *Drying Technology, 23*(4), 955-973.

Rodríguez-Pérez, C., Quirantes-Piné, R., Fernández-Gutiérrez, A., & Segura-Carretero, A. (2015). Optimization of extraction method to obtain a phenolic compounds-rich extract from *Moringa oleifera* Lam leaves. *Industrial Crops and Products, 66*, 246-254.

Rojas-Graü, M. A., Oms-Oliu, G., Soliva-Fortuny, R., & Martín-Belloso, O. (2009). The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: A review. *International Journal of Food Science & Technology, 44*(5), 875-889.

Roos, Y. H. (2002). Importance of glass transition and water activity to spray drying and stability of dairy powders. *Le Lait, 82*(4), 475-484.

© COPYRIGHT UPM

Rudnicki, M., Silveira, M. M., Pereira, T. V., Oliveira, M. R., Reginatto, F. H., Dal-Pizzol, F., & Moreira, J. C. (2007). Protective effects of *Passiflora alata* extract pretreatment on carbon tetrachloride induced oxidative damage in rats. *Food and Chemical Toxicology, 45*(4), 656-661.

Saifullah, M., McCullum, R., McCluskey, A., & Vuong, Q. (2020). Comparison of conventional extraction technique with ultrasound assisted extraction on recovery of phenolic compounds from lemon scented tea tree (Leptospermum petersonii) leaves. *Heliyon, 6*(4), e03666.

Saénz, C., Tapia, S., Chávez, J., & Robert, P. (2009). Microencapsulation by spray drying of bioactive compounds from cactus pear (*Opuntia ficus-indica*). *Food Chemistry, 114*(2), 616-622.

Şahin, S., Aybastıer, Ö., & Işık, E. (2013). Optimisation of ultrasonic-assisted extraction of antioxidant compounds from *Artemisia absinthium* using response surface methodology. *Food Chemistry, 141*(2), 1361-1368.

Salvador, A., Sanz, T., & Fiszman, S. M. (2007). Changes in colour and texture and their relationship with eating quality during storage of two different dessert bananas. *Postharvest Biology and Technology*, *43*(3), 319-325.

Sagrin, M. S., & Chong, G. H. (2013). Effects of drying temperature on the chemical and physical properties of *Musa acuminata Colla* (AAA Group) leaves. *Industrial Crops and Products*, *45*, 430-434.

Saura-Calixto, F., & Goñi, I. (2006). Antioxidant capacity of the Spanish Mediterranean diet. *Food Chemistry, 94*(3), 442-447.

Savatin, D. V., Gramegna, G., Modesti, V., & Cervone, F. (2014). Wounding in the plant tissue: The defense of a dangerous passage. *Frontiers in Plant Science, 5*, 470-481.

Scalbert, A., Johnson, I. T., & Saltmarsh, M. (2005). Polyphenols: Antioxidants and beyond. *The American Journal of Clinical Nutrition*, *81*(1), 215-217.

Senadeera, W., Bhandari, B. R., Young, G., & Wijesinghe, B. (2003). Influence of shapes of selected vegetable materials on drying kinetics during fluidized bed drying. *Journal of Food Engineering*, *58*(3), 277-283.

Shavakhi, F., Boo, H. C., Osman, A., & Ghazali, H. M. (2011). Effects of enzymatic liquefaction, maltodextrin concentration, and spray-dryer inlet air temperature on pumpkin powder characteristics. *Food and Bioprocess Technology*, *5*(7), 2837-28847.

Shrestha, A. K., Ua-Arak, T., Adhikari, B. P., Howes, T., & Bhandari, B. R. (2007). Glass transition behavior of spray dried orange juice powder measured by differential scanning calorimetry (DSC) and thermal mechanical compression test (TMCT). *International Journal of Food Properties*, *10*(3), 661-673.

Shu, B., Yu, W., Zhao, Y., & Liu, X. (2006). Study on microencapsulation of lycopene by spray-drying. *Journal of Food Engineering*, *76*(4), 664-669.

© COPYRIGHT UPM

Silva, C. R., Gomes, T. F., Andrade, G. C., Monteiro, S. H., Dias, A. C., Zagatto, E. A., & Tornisielo, V. L. (2013). Banana peel as an adsorbent for removing atrazine and ametryne from waters. *Journal of Agricultural and Food Chemistry, 61*(10), 2358-2363.

Silva, P. I., Stringheta, P. C., Teófilo, R. F., & de Oliveira, I. R. (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.

Sirajudin, Z. N., Ahmed, Q. U., Chowdhury, A. J., Kamarudin, E. Z., Khan, A. V., & Uddin, A. B. (2014). Antimicrobial activity of banana (*Musa paradisiaca* L.) peels against food borne pathogenic microbes. *Journal Pure and Applied Microbiology, 8*, 3627-3639.

Smeriglio, A., Barreca, D., Bellocco, E., & Trombetta, D. (2017). Proanthocyanidins and hydrolysable tannins: occurrence, dietary intake and pharmacological effects. *British Journal of Pharmacology*, *174*(11), 1244-1262.

Someya, S., Yoshiki, Y., & Okubo, K. (2002). Antioxidant compounds from bananas (*Musa Cavendish*). *Food Chemistry, 79*(3), 351-354.

Soong, Y. Y., & Barlow, P. J. (2004). Antioxidant activity and phenolic content of selected fruit seeds. *Food Chemistry, 88*(3), 411-417.

Soto-Vaca, A., Gutierrez, A., Losso, J. N., Xu, Z., & Finley, J. W. (2012). Evolution of phenolic compounds from color and flavor problems to health benefits. *Journal of Agricultural and Food Chemistry, 60*(27), 6658-6677.

Stintzing, F. C., & Carle, R. (2004). Functional properties of anthocyanins and betalains in plants, food and in human nutrition. *Trends in Food Science & Technology, 15*(1), 19-38.

Sulaiman, S. F., Yusoff, N. A., Eldeen, I. M., Seow, E. M., Sajak, A. A., & Ooi, K. L. (2011). Correlation between total phenolic and mineral contents with antioxidant activity of eight Malaysian bananas (*Musa* sp.). *Journal of Food Composition and Analysis*, *24*(1), 1-10.

Sundaram, S., Anjum, S., Dwivedi, P., & Rai, G. K. (2011). Antioxidant activity and protective effect of banana peel against oxidative hemolysis of human erythrocyte at different stages of ripening. *Applied Biochemistry and Biotechnology*, *164*(7), 1192-1206.

Suvarnakuta, P., Chaweerungrat, C., & Devahastin, S. (2011). Effects of drying methods on assay and antioxidant activity of xanthones in mangosteen rind. *Food Chemistry*, *125*(1), 240-247.

Tee, Y. K., & Ding, P. (2011). Determination of optimum harvest maturity and postharvest quality of rastali banana (*Musa* AAB *Rastali*) during fruit ripening. *Transactions of the Malaysia Society of Plant Physiology, 9*, 39-42.

Tock, J. Y., Lai, C. L., Lee, K. T., Tan, K. T., & Bhatia, S. (2010). Banana biomass as potential renewable energy resource: A Malaysian case study. *Renewable and Sustainable Energy Reviews*, *14*(2), 798-805.

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Tomaino, A., Cimino, F., Zimbalatti, V., Venuti, V., Sulfaro, V., De Pasquale, A., & Saija, A. (2005). Influence of heating on antioxidant activity and the chemical composition of some spice essential oils. *Food Chemistry, 89*(4), 549-554.

Tonon, R. V., Brabet, C., & 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.

Tonon, R. V., Brabet, C., & Hubinger, M. D. (2010). Anthocyanin stability and antioxidant activity of spray-dried açai (*Euterpe oleracea* Mart.) juice produced with different carrier agents. *Food Research International, 43*(3), 907-914.

Tonon, R. V., Grosso, C. R., & Hubinger, M. D. (2011). Influence of emulsion composition and inlet air temperature on the microencapsulation of flaxseed oil by spray drying. *Food Research International*, *44*(1), 282-289.

Turchiuli, C., Fuchs, M., Bohin, M., Cuvelier, M. E., Ordonnaud, C., Peyrat-Maillard, M. N., & Dumoulin, E. (2005). Oil encapsulation by spray drying and fluidised bed agglomeration. *Innovative Food Science & Emerging Technologies, 6*(1), 29-35.

Turkmen, N., Sari, F., & Velioglu, Y. S. (2006). Effects of extraction solvents on concentration and antioxidant activity of black and black mate tea polyphenols determined by ferrous tartrate and Folin–Ciocalteu methods. *Food Chemistry, 99*(4), 835-841.

Tuyen, C. K., Nguyen, M. H., & Roach, P. D. (2010). Effects of spray drying conditions on the physicochemical and antioxidant properties of the Gac (*Momordica cochinchinensis*) fruit aril powder. *Journal of Food Engineering*, *98*(3), 3885-392.

Valmayor, R. V., Jamaluddin, S. H., Silayoi, B., Kusumo, S., Danh, L. D., Pascua, O. C., & Espino, R. R. (2000). Banana cultivar names and synonyms in Southeast Asia. In A. Molina, & V. Roa (Eds.). International Plant Genetic Resources Institute.

Vázquez, M. B., Comini, L. R., Martini, R. E., Montoya, S., Bottini, S., & Cabrera, J. L. (2014). Comparisons between conventional, ultrasound-assisted and microwave-assisted methods for extraction of anthraquinones from *Heterophyllaea pustulata* Hook f.(Rubiaceae). *Ultrasonics Sonochemistry, 21*(2), 478-484.

Verma, S., Kesh, K., Ganguly, N., Jana, S., & Swarnakar, S. (2014). Matrix metalloproteinases and gastrointestinal cancers: Impacts of dietary antioxidants. *World Journal of Biological Chemistry*, *5*(3), 355.

Vidović, S. S., Vladić, J. Z., Vaštag, Z. G., Zeković, Z. P., & Popović,, L. M. (2014). Maltodextrin as a carrier of health benefit compounds in *Satureja montana* dry powder extract obtained by spray drying technique. *Powder Technology, 258*, 209-215.

Vijayakumar, S., Presannakumar, G., & Vijayalakshmi, N. R. (2008). Antioxidant activity of banana flavonoids. *Fitoterapia, 79*(4), 279-282.

© COPYRIGHT UPM

Vilkhu, K., Mawson, R., Simons, L., & Bates, D. (2008). Applications and opportunities for ultrasound assisted extraction in the food industry: A review. *Innovative Food Science & Emerging Technologies, 9*(2), 161-169.

Villaverde, J. J., Oliveira, L., Vilela, C., Domingues, R. M., Freitas, N., Cordeiro, N., Freira, C. S. R., & Silvestre, A. J. (2013). High valuable compounds from the unripe peel of several *Musa* species cultivated in Madeira Island (Portugal). *Industrial crops and products, 42*, 507-512.

Virot, M., Tomao, V., Le Bourvellec, C., Renard, C. M., & Chemat, F. (2010). Towards the industrial production of antioxidants from food processing by-products with ultrasound-assisted extraction. *Ultrasonics Sonochemistry, 17*(6), 1066-1074.

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2016). Optimization of ultrasound-assisted extraction conditions for recovery of phenolic compounds and antioxidant capacity from banana (*Musa cavendish*) peel. *Journal of Food Processing and Preservation, 41*(5), 1-14.

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2018). Phenolic compounds within banana peel and their potential uses: A review. *Journal of Functional Foods, 40*, 238-248.

Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2019). Changes of phytochemicals and antioxidant capacity of banana peel during the ripening process; with and without ethylene treatment. *Scientia Horticulturae, 253*, 255-262.

Vural, N., Algan Cavuldak, Ö., & Anlı, R. E. (2018). Multi response optimisation of polyphenol extraction conditions from grape seeds by using ultrasound assisted extraction (UAE). *Separation Science and Technology*, *53*(10), 1540-1551.

Vuong, Q. V., Hirun, S., Roach, P. D., Bowyer, M. C., Phillips, P. A., & Scarlett, C. J. (2013). Effect of extraction conditions on total phenolic compounds and antioxidant activities of *Carica papaya* leaf aqueous extracts. *Journal of Herbal Medicine*, *3*(3), 104-111.

Wandrey, C., Bartkowiak, A., & Harding, S. E. (2010). Materials for Encapsulation. In N. &. Zuidam (Ed.), *Encapsulation Technologies for Active Food Ingredients and Food Processing* (pp. 31-100). New York, USA: Springer.

Wang, H., Helliwell, K., & You, X. (2000). Isocratic elution system for the determination of catechins, caffeine and gallic acid in green tea using HPLC. *Food Chemistry, 68*(1), 115-121.

Wang, L., & Weller, C. L. (2006). Recent advances in extraction of nutraceuticals from plants. *Trends in Food Science & Technology, 17*(6), 300-312.

Wina, E., Susana, I. W., & Tangendjaja, B. (2010). Biological activity of tannins from *Acacia mangium* bark extracted by different solvents. *Media Peternakan, 33*(2), 103-103.

Wong, J. Y., & Chye, F. Y. (2009). Antioxidant properties of selected tropical wild edible mushrooms. *Journal of Food Composition and Analysis, 22*(4), 269-277.

© COPYRIGHT UPM

Yang, J., Guo, J., & Yuan, J. (2008). In vitro antioxidant properties of rutin. *LWT-Food Science and Technology, 41*(6), 1060-1066.

Yolmeh, M., Najafi, M. B., & Farhoosh, R. (2014). Optimisation of ultrasound-assisted extraction of natural pigment from annatto seeds by response surface methodology (RSM). *Food Chemistry, 155*, 319-324.

Yoo, K. W., & Kim, J. H. (2018). Kinetics and Mechanism of Ultrasound-assisted Extraction of Paclitaxel from Taxus chinensis. *Biotechnology and Bioprocess Engineering*, *23*(5), 532-540.

Yuan, J., Huang, J., Wu, G., Tong, J., Xie, G., Duan, J., & Qin, M. (2015). Multiple responses optimization of ultrasonic-assisted extraction by response surface methodology (RSM) for rapid analysis of bioactive compounds in the flower head of *Chrysanthemum morifolium*. *Industrial Crops and Products, 74*, 192-199.

Yusri, N. M., Chan, K. W., Iqbal, S., & Ismail, M. (2012). Phenolic content and antioxidant activity of *Hibiscus cannabinus* L. seed extracts after sequential solvent extraction. *Molecules, 17*(11), 12612-12621.

Zarei, M., Azizi, M., & Bashir-Sadr, Z. (2011). Evaluation of physicochemical characteristics of pomegranate (*Punica granatum* L.) fruit during ripening. *Fruits, 66*(2), 121-129.

Zarena, A. S., & Sankar, K. U. (2009). A study of antioxidant properties from *Garcinia mangostana* L. pericarp extract. *Acta Scientiarum Polonorum Technologia Alimentaria, 8*(1), 23-34.

Zhang, P., & Whistler, R. B. J. & Hamaker, B. 2005. Banana starch: production, physicochemical properties, and digestibility, review. *Carbohydrate Polymers, 59*, 443-458.

Zhang, Z. S., Wang, L. J., Li, D., Jiao, S. S., Chen, X. D., & Mao, Z. H. (2008). Ultrasound-assisted extraction of oil from flaxseed. *Separation and Purification Technology, 62*(1), 192-198.

Živković, J., Šavikin, K., Janković, T., Ćujić, N., & Menković, N. (2018). Optimization of ultrasound-assisted extraction of polyphenolic compounds from pomegranate peel using response surface methodology. *Separation and Purification Technology, 194*, 40-47.

Zuo, Y., Chen, H., & Deng, Y. (2002). Simultaneous determination of catechins, caffeine and gallic acids in green, Oolong, black and pu-erh teas using HPLC with a photodiode array detector. *Talanta, 57*(2), 307-316.

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