Recovery of Phenolic Compounds from Banana (*Musa* Cavendish) Peel and Encapsulation of its Phenolic-rich Extract

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Doctor of Philosophy in Food Science

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Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

Hang Thi Vu Date: 15/07/2019

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*I hereby certify that this thesis is in the form of a series of *papers. I have included as part of the thesis a written statement from each co-author, endorsed in writing by the Faculty Assistant Dean (Research Training), attesting to my contribution to any jointly authored papers.*

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Hang Thi Vu Date: 15/07/2019

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List of publications included as part of the thesis

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Major research and review papers either published or under review

1. 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. doi: 10.1016/j.jff.2017.11.006

2. 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. doi: https://doi.org/10.1016/j.scienta.2019.04.043

3. Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2016). Effects of drying conditions on physicochemical and antioxidant properties of banana (*Musa* cavendish) Peels. *Drying Technology*, 1141-1151. doi: 10.1080/07373937.2016.1233884

4. 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). doi: 10.1111/jfpp.13148

5. Vu, H. T., Scarlett, C. J., & Vuong, Q. V. (2019). Maximising recovery of phenolic compounds and antioxidant properties from banana peel using microwave assisted extraction and water. *Journal of Food Science and Technology*. doi: 10.1007/s13197-019-03610-2

6. Vu, H.T., C.J. Scarlett, and Q.V. Vuong, Phytochemical, Antioxidant and Antimicrobial Properties of Bananana (*Musa* Cavendish) Peel Crude Extracts and Their Fractions. *Journal of Food Science and Technology*, submitted July 10th 2019

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Statement of contribution of others

15th July 2019

To Whom It May Concern

This is to confirm that Hang Thi Vu has contributed to the series of major research papers, which are submitted as a part of her PhD thesis as shown in each paper below.

…… Date: 15/07/2019 …… Date: 15/7/2019

Prof Christopher J. Scarlett Dr Quan V. Vuong

Endorsed by

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Contributor	**Statement of contribution**
Hang Thi Vu	Reviewed the literature (100%) Wrote the paper (85%)
Christopher J. Scarlett	Critically reviewed the manuscript (40%)
Quan V. Vuong	Wrote the paper (15%) Critically review the manuscript (60%)

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Conference oral presentations

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Abstract

Banana is one of the most popular fruits with annual production of 112 million tonnes, mainly from the *Musa* Cavendish variety. Banana peel accounts for about 38% of the fruit weight and is generally known as waste. Although the peel has been traditionally used for the treatment of various ailments and has been found to exhibit potent antioxidant and antimicrobial activities, the majority of the peel usually ends up in landfill. Our review (Chapter 2) revealed that banana peel is a rich source of phenolic compounds, with dopamine and levodopa among the major individual phenolic compounds present. The peel can be potentially used as functional ingredients in food, cosmetic or pharmaceutical industries; however limited studies have been conducted in depth to answer the following questions, which includes (1) whether or not phenolic compounds are affected by different ripening stages with and without ethylene treatment; (2) how the drying methods and conditions affect retention of phenolic compounds in banana peel during the dehydration process; (3) what are optimal extraction conditions for maximum recovery of phenolic compounds from dried banana peel; (4) how to prepare the powdered extracts and their fractions enriched with phenolic compounds and assess their biological properties; and (5) what are the best conditions for encapsulation of the banana peel enriched extracts to improve their stability. To answer these research questions, this thesis aimed to maximise recovery of bioactive compounds from banana (*Musa* Cavendish) peel by selecting the most suitable ripening stage and applying optimal drying, extraction, isolation and encapsulation conditions for further utilisation in food products as functional ingredients.

The results are presented in the six research articles (Chapters 4 to 8). This study found that the banana peel without ethylene treatment had a relatively higher phenolic content and antioxidant power than those of the peel treated by ethylene. Fully ripened peel had higher phenolics and

antioxidant capacity than less or overripe peels (Chapter 4). This study also found that drying significantly affected retention of phenolics and antioxidant capacity. Microwave drying at the power level of 960 W for 6 min was the best technique to dehydrate banana peel for further extraction and isolation as it was faster and retained higher phenolics and antioxidant capacity than other drying methods, such as freeze-drying, vacuum oven, hot air oven, dehumidified air, and sun drying (Chapter 5). The optimal extraction conditions of the two common advanced extraction techniques, including ultrasound assisted extraction (UAE) and microwave assisted extraction (MAE) were then investigated for maximizing extraction yield of phenolics from dried banana peel. The results (Chapter 6) showed that the optimal UAE conditions were 30°C, 5 min, 150W, sample to solvent ratio of 8:100 mg/mL, and acetone concentration of 60%. Whereas, the optimal MAE conditions were found at solvent pH of 1, ratio of 2:100 mg/mL, 6 min of continuous irradiation, and microwave power of 960W. The optimal UAE obtained 23.49 mg of phenolics, while the optimal MAE achieved 50.55 mg phenolics from 1g of banana peel. MAE also gave higher extractable solids than that of UAE (Chapter 6).

The extracts were used for further preparation of powdered extracts and fractions. The results (Chapter 7) indicated that more powder can be obtained from MAE extract but concentration of phenolics was lower in MAE extract as compared to UAE extract. Both extracts exhibited potent antioxidant and antimicrobial activities. Fractions were prepared from UAE and MAE extracts using a liquid-liquid partition technique with n-hexane, dichloromethane, and n-butanol as the solvents. The n-butanol and aqueous fractions derived from the UAE extract had higher TPC, dopamine content and antioxidant capacity than the corresponding fractions derived from the MAE extract. Of those, the n-butanol fraction from UAE extract had the highest level of TPC, dopamine and thus this fraction is recommended for further isolation of phenolic compounds and dopamine.

The results also revealed that all fractions prepared from UAE and MAE possessed inhibitory activity against *E. aero*, *E. coli* and *E. faecalis*. Fractions prepared from MAE demonstrated higher inhibitory activities, indicating that these fractions are potential sources of antimicrobial agents and possess many potential useful industrial properties. Considering the more environmental friendly method of extraction, recovery yield of extractable solid content and biological properties of the extract, the MAE extract was selected for preparation of a powdered extract for further applications.

Different spray drying conditions and wall materials were tested to identify the optimal encapsulation process. The results (Chapter 8) found that the optimal encapsulating conditions for preparation of powdered extract enriched with phenolic compounds from banana peel were at inlet air temperature of 150°C, feed rate of 9 mL/min, and ratio of dry-mater in fresh extract – to – wall material of 1:1 (w/w) with the wall material being a combination of gum acacia and maltodextrin M100. The powdered extract prepared under optimal conditions had a spherical shape with a rough surface, good solubility and high dopamine content as well as phenolic compounds. Encapsulation protected the phenolic compounds from degradation under storage conditions of 40 °C for 4 weeks.

In conclusion, the overall aim of this study was achieved. This study illustrated the impact of different ripening stages with and without ethylene treatment, different drying methods and conditions, and two advanced extraction methods (MAE and UAE) on phenolics and antioxidant properties of the peel, and revealed the best conditions to recover phenolic compounds from fresh banana peel. Composition and properties of the enriched extracts and their fractions were also identified. Finally, a suitable encapsulation conditions were also developed to prepare the powdered extract, ready for further applications. Future studies are recommended to prepare and

test properties of powdered extracts from the fractions of the peel, and to apply these powdered extracts as functional ingredients in food, cosmetic or pharmaceutical products.

List of figures

List of Abbreviations

ABTS	22′-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid
ANOVA	Analysis of variance
CE	Catechin equivalents
CIP	Ciprofloxacin
CUPRAC	Cupric ion reducing antioxidant capacity
DM	Dried matter
DM-to-WM	Dried matter in fresh extract to wall material
DMSO	Dimethyl sulfoxide
DPPH	11-diphenyl-2-picrylhydrazyl
FRAP	Ferric reducing antioxidant power
GAE	Gallic acid equivalents
HPLC	High performance/pressure liquid chromatography
MAE	Microwave assisted extraction
MHA	Mueller Hinton agar
MIC	Minimum inhibitory concentration
NB	Nutrient broth
Pro.A	Proanthocyanidin
RE	Rutin equivalents
RSM	Response surface methodology
TE	Trolox equivalents
TPC	Total phenolic content
TPTZ	Tripyridyltriazine

TFC	Total flavonoid content
UAE	Ultrasound assisted extraction