

**Progressive Freeze Concentration With
Partial Ice Melting and Non-Thermal
Pasteurization for Liquid Foods**

by

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Ph.D.

2019

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Thesis submitted to the University of Sri Jayewardenepura for the
award of the Degree of Doctor of Philosophy on 2019

Declaration of the candidate

The work described in the thesis was carried out by me under the supervision of Dr.(Mrs.).M.P.G. Vanniarachchy and Prof.M.A.J. Wansapala and this dissertation has not been submitted in whole or in part to any university or any other institution for another Degree/Diploma.

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ABBREVIATIONS

AOAC	Association of Official Analytical Chemists
Bx	Brix
CI	Confidence Interval
CIP	Cleaning In Place
CW	Coconut Water
FAO	Food and Agricultural Organization
FC	Freeze Concentration
GC-MS	Gas Chromatography-Mass Spectrometry
HPP	High-Pressure Processing
MCW	Mature Coconut Water
PEF	Pulsed Electric Field
PFC	Progressive Freeze Concentration
RE	Rotary Evaporation
SD	Standard Deviation
SFC	Suspension Freeze Concentration
SLS	Sri Lanka Standards
SPME	Solid Phase Microextraction
TCW	Tender Coconut Water
TPC	Total Plate Count

US

Ultrasonication

USDA

United States Department of Agriculture

UV-C

Ultraviolet-C

ACKNOWLEDGEMENT

First of all, I am extremely grateful to my research supervisors Dr. Mihiri Vanniarachchy, and Prof. Jagath Wansapala, Department of Food Science & Technology, Faculty of Applied Sciences; University of Sri Jayewardenepura for their valuable guidance, patience, scholarly inputs and consistent encouragement I received throughout the research work. It is with immense gratitude that I acknowledge the support and help of my primary supervisor Dr. Mihiri Vanniarachchy for her unconditional support and She has always made herself available to clarify my doubts despite her busy schedules and I consider it as a great opportunity to do my doctoral program under her guidance and to learn from her research expertise. Thank you very much, madam.

I express my greatest gratitude to my supervisor Prof. Jagath Wansapala, recommending me to get this great opportunity to conduct my Ph.D. study with Dr. Mihiri Vanniarachchy and also for his support, guidance, advice, and motivation gave throughout my journey.

I offer my sincere gratitude to Dr. R.A.U.J. Marapana (Head of the Department of Food Science & Technology), Senior Prof. K.K.D.S Ranaweera, Prof. S.B Navarathna, Prof. Indira Wickramasinghe, Dr. Jagath Jayasinghe, Dr. Rupika Perera, Dr. Suraji Senanayaka, Dr. Isuru Wijesekara, Dr. Dulani Somendrika, Dr.Madhura Jayasinghe and Dr. Piyumi Abesundara for their valuable guidance, advice, encouragement and for the support provided in completion of this study programme. I wish to acknowledge all the non-academic staff members of Department of Food Science & Technology, Faculty of

Applied Sciences, University of Sri Jayewardenepura for their valuable support, and providing laboratory facilities throughout my research work.

I greatly acknowledge the financial assistance provided by the university grants; (ASP/01/RE/SCI/2015/33 and ASP/01/RE/SCI/2017/51) of University of Sri Jayewardenepura.

I owe my special gratitude to the Faculty of Graduate studies to giving me the opportunity to do a doctoral degree and all the academic and non-academic staff (specially Ms. Sachintha) for their support throughout my research work.

I would like to appreciate Advanced Engineers (Pvt) Ltd. for their immense support on machine fabrication and facilities to provide me to do trial experiments at their premises.

I am very much grateful to Dr. Dakshika Vanniarachchi, Senior Lecturer, Instrument center, Faculty of Applied sciences, University of Sri Jayewardenepura for the valuable support and the guidance provided to analyze my samples using GC/MS. And I wish to acknowledge Ms. Randi (Demonstrator, Instrument center) and Ms. Tharaga Sharmilan (Research assistant, Department of Physics) giving me support to do flavor profile analysis.

I highly acknowledge Mr. Aruna Fonseka, and St. Joseph DC Mills, Watinapaha and Silvermills beverages (Pvt) Ltd for their support provided in obtaining coconut water.

Also, I wish to thank Ms. Lakruwani Jayarathna and Mr. Dineshkumar, as the junior fellows work with me for their valuable support during my research work.

I am deeply indebted to my parents, my sister, brother-in-law and their kids for unconditional love, support, guidance, and precious encouragement give throughout the

study and also at every stage of my personal and academic life, and desired to see this achievement come true. I am very much indebted to, my husband Mr. Janaka Weerasuriya, for provide me through moral and emotional support and caring in my life and supported me in every possible way to see the completion of this work. Also, I am much grateful to my husband's mother and sister for their valuable support and kind concern throughout the study and all along the way. These all kept me going and this work has not been possible without them.

My appreciation also extends to all my colleagues of the Department of Food Science & Technology, Faculty of Applied Sciences, University of Sri Jayewardenepura and Ms. Dilmini Prasadi and Ms. Lakmini Bagya for being with me all the time and their countless support in every possible way, through their personal and scholarly interactions, and with their valuable encouragements, motivations on my ups and downs at various points of my academic journey.

J.A.E.C Jayawardena

May 2019

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ABSTRACT

Concentration is a major unit operation in the beverage industry to reduce packaging, transportation and storage cost and to improve the stability of products. Evaporation, membrane concentration and freeze concentration (FC) are major concentration methods. Freeze concentration (FC) is the most suitable method for liquid concentration over other methods since FC operates below 0 °C. Suspension freeze-concentration (SFC) and progressive freeze-concentration (PFC) are the available FC methods and SFC is a complex and expensive method compared to PFC. PFC is a novel FC technique relatively simple and a feasible. The limitation of PFC is lower product yield and to overcome the problem, the partial ice-melting technique can be used. Emerging non-thermal pasteurization techniques are applied as substitutions to thermal processes in order to maintain the microbial safety and quality of the liquids. The main objective of this study is to develop PFC and partial ice melting as a novel high-quality liquid food concentration method and exploring a non-thermal pasteurization method to preserve liquid food products made using PFC. A lab-scale PFC set up was constructed and it mainly consisted of a cooling bath, cylindrical sample vessel equipped with a stirrer. The set up was optimized to agitator speed of 290 rpm and dipping speed of 1.3 cm h⁻¹ to collect the maximum achievable concentration of liquids. Coconut (*Cocos nucifera*) water, pineapple (*Ananas comosus*) juice, tomato (*Solanum lycopersicum*) juice, star fruit (*Averrhoa carambola*)_juice, jew plum/ambarella (*Spondias dulcis*) juice, and nasranan (*Citrus madurensis*) juice were selected by exploring their applicability to PFC

and all the liquids were concentrated by PFC up to 8.5 °, 14.5°, 6.1°, 13.5°, 8.8°, and 8.5° Brix from the initial concentration of 3.5°, 12.1°, 3.4°, 6.4°, 7.2°, and 5.7° Brix respectively. Coconut water achieved the highest yield (73.56 %), concentration ratio (2.42) and the lowest ice phase concentration (0.7°). The partial melting method was applied to recover the initial ice fractions with high solute concentrations to improve the yield. The concentration properties of PFC liquids were compared with rotary evaporated (RE) liquids. RE products achieved the highest yield, highest concentration, and the lowest Vitamin-C content compared with PFC products. The flavor profiles of original liquid and reconstituted PFC and RE concentrates were analyzed and PFC achieved the highest flavor quality with minimal damage to the flavor profile. Coconut water was selected as the best liquid to develop a PFC ready to drink product. To find out the best preservation method; the properties of a treated product by UV-C radiation (33 kJ L⁻¹) and ultrasonication (20kHz, 30 min) were compared with thermal pasteurization (85 °C for 10 min and sterilized at 121 °C, 30min). Analyzing the results of TSS, pH, conductivity, and microbial reduction level and deterioration factor of Vitamin-C content, UV-C light was selected as the best pasteurization method for PFC coconut water. The UV treated PFC coconut water product was microbiologically safe within 9 weeks of storage period at 4 °C ±1 °C temperature. The developed product contains 91% moisture, 2.5 % total sugar, 0.002 % of fat, 0.19 % of protein, 1.4 mg/100 g of vitamin-C with 269.53 mg/100 mL of total minerals content.

Keywords: Progressive freeze concentration (PFC), Partial ice melting, Liquid food concentration, UV-C radiation, Rotary evaporation