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OSMOTIC DEHYDRATION OF PINEAPPLE (Ananas comosus L. Merr.) USING SUCROSE-SORBITOL MIXTURES AND MICROBIAL STABILITY DURING STORAGE

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By

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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

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Osmotic dehydration (OD) is an effective preservation technique to remove water from fruits and produce high quality products with minimal nutrients loss. Sorbitol is a low-glycemic carbohydrate with complementary sugar's functionality with lower glycemic index compared to sucrose. The osmotic dehydration kinetic and microbial stability of the osmodehydrated pineapple of sorbitol-sucrose mixtures during storage were determined in this study. OD were conducted using 65 °Brix sucrose-sorbitol mixture ranging from 0 to 100 % concentration at 40 °C for 240 minutes and subjected to hot air drying at 50 °C to approximately 30 % moisture content. Samples were vacuum-packed and stored at 4 °C for storage study. Textural, moisture content, a_w, pH, colour, flavonoids, vitamin C and bromelain were determined using texture analyzer, moisture analyzer, water activity meter, pH meter, Hunter LAB calorimeter, spectrophotometer, standard Vitamin C AOAC 967.21 and casein digestion unit (CDU) method, respectively. The results showed that in general all formulations studied gave decreasing trend for weight reduction (WR) and water loss (WL) and increasing trend for solutes gain (SG). Sorbitol substitution at 75 % and 100 % were recommended for osmodehydrated pineapple because both formulations gave the lowest WR, highest WL and SG values, which fulfilled the requirement as a high quality osmodehydrated fruits. In addition, both formulations had the lowest water activity, low pH values, medium firmness and no obvious browning. Results on microbial stability showed that osmodehydrated pineapple with sorbitol can be stored at 4ºC for more than 2 months at bacteria count < 10^6 CFU/g and yeast and mould ≤ 10^4 CFU/g. However, there were no significant effects of different osmotic solutions used on the retention of vitamin C content and total flavonoid content because all showed degradation throughout storage and firmness of osmodehydrated pineapple decreased with storage. However, for bromelain activity, sorbitol treated pineapple is significant in retaining the bromelain activity.

In conclusion, sorbitol treated osmodehydrated pineapple have a better extended shelf life and better retention of bromelain activity which showed that sorbitol can be used as an alternative osmotic solution in osmotic dehydration of pineapple.

Keywords: Osmotic dehydration kinetic, pineapple, sucrose-sorbitol, bromelain, flavonoids, vitamin C, shelf life

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DIHIDRASI OSMOSIS BAGI BUAH NENAS (*Ananas comosus* L. Merr.) DENGAN MENGGUNAKAN CAMPURAN SUKROSA-SORBITOL DAN KESTABILAN MIKROBIOLOGI SEMASA PENYIMPANAN

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Dehidrasi osmosis (OD) adalah teknik pengawetan yang berkesan untuk menyingkirkan air daripada buah-buahan dan menghasilkan produk yang berkualiti tinggi dengan kehilangan nutrien yang minimum. Sorbitol adalah karbohidrat berglisemik rendah berbanding sukrosa yang mempunyai fungsi yang sama dengan gula. Kinetik dihidrasi osmosis dan kestabilan mikrob buah nenas osmodehidrasi semasa tempoh penyimpanan telah dikaji dalam kajian ini. OD telah dijalankan menggunakan campuran 65 °Brix sukrosa - sorbitol dari kepekatan 0 sehingga 100 % pada suhu 40 °C selama 240 minit dan pengeringan pada 50 °C sehingga kandungan kelembapan mencecah 30 %. Sampel telah dibungkus dalam keadaan vakum dan disimpan pada 4 °C untuk kajian penyimpanan. Tekstur, kandungan kelembapan, a_w, pH, warna, flavonoid, vitamin C dan bromelain telah ditentukan dengan menggunakan analyzer tekstur , kelembapan analyzer , meter aktiviti air , meter pH , Hunter LAB kalorimeter , spektrofotometer , vitamin C standard AOAC 967,21 dan casein digestion unit (CDU), masing-masing . Hasil analisis menunjukkan bahawa secara umumnya semua formulasi yang dikaji memberi tren berkurang untuk pengurangan berat (WR) dan kehilangan air (WL), manakala tren peningkatan untuk peningkatan bahan larut (SG). Penggantian sorbitol pada 75 % dan 100 % telah disyorkan untuk nenas osmodehidrasi kerana kedua-duanya memberikan nilai WR paling rendah, WL dan SG tinggi, yang memenuhi syarat sebagai buah-buahan osmodehidrasi yang berkualiti tinggi. Di samping itu, kedua formulasi tersebut mempunyai aktiviti air yang paling rendah, nilai pH yang rendah, keteguhan sederhana dan tiada perubahan warna yang jelas. Analisis mikrob menunjukkan nenas osmodehidrasi dengan sorbitol boleh disimpan pada suhu 4 ºC untuk tempoh melebihi dua bulan dengan kiraan bakteria < 10^6 CFU/g dan kiraan kulat ≤ 10^4 CFU/g. Walau bagaimanapun, penggunaan larutan osmosis yang berlainan tidak memberikan perbezaan pada pengekalan kandungan vitamin C dan jumlah

kandungan flavonoid serta tekstur keteguhan nenas osmodihidrasi menurun semasa tempoh penyimpanan. Bagaimanapun, nenas dihidrasi dengan sorbitol boleh mengekalkan activiti bromelain lebih signifikasi kalau berbanding dengan nenas dihidrasi dengan sukrosa sahaja. Pada kesimpulan, nenas osmodihidrasi dengan sorbitol mempunyai jangka hayat yang lebih baik dan boleh mengekalkan aktiviti bromelain. Ini menunjukkan bahawa sorbitol boleh digunakan sebagai alternatif dalam dehidrasi osmosis buah nenas.

Kata Kunci : kinetik osmotik dehidrasi , nenas , sukrosa - sorbitol , bromelain , flavonoid , vitamin C , jangka hayat

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I certify that a Thesis Examination Committee has met on 18 April 2017 to conduct the final examination of Lim Chee Hui on his thesis entitled "Osmotic Dehydration of Pineapple (*Ananas comosus* L. Merr) using Sucrose-Sorbitol Mixtures and Microbial Stability During Storage" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

OD	Osmotic Dehydration
CDU	Casein Digestion Unit
WR	Weight Reduction
WL	Water Loss
SG	Solute Gains
CFU	Colony Forming Unit
DCPIP	2,6-dichoroindophenol
QE	Quecertin

CHAPTER 1

INTRODUCTION

1.1 Background

Osmotic dehydration (OD) is known as a process of removing water from water-containing solid by using osmotic pressure in the osmotic solution (Rastogi & Raghavarao, 2004a). Osmotic pressure is the driving force for OD and this driving force will cause the natural osmosis of water from the fruits into the osmotic solution through cell membrane (Rastogi, Raghavarao, & Niranjan, 2005). OD is becoming more popular in recent years as an effective method in preserving fruits due to the ability to preserve the natural characteristics of the fruits (Chavan & Amarowicz, 2012). OD process is conducted by immersing the fruits in a hypertonic solution to induce removal of water from the fruits cell through the cell membrane without changing of phase and at low or ambient temperature (García-Martínez et al., 2002; Igual, Contreras, & Martínez-Navarrete, 2010). There are several advantages of OD such as minimum effect on the natural characteristics of the fruits after processed because the temperature used in process is at low or ambient temperature (Chavan & Amarowicz, 2012). OD also used less energy due to the low temperature treatment (Igual et al., 2010). OD combined with other drying method can produce higher fruit quality products for local and international market (Rastogi et al., 2005). Many types of osmodehydrated fruits using sucrose have been produced such as pineapple, apple, guava, strawberry, grapefruits and kiwi (Panadés-Ambrosio et al., 1996; Silveira, Rahman, & Buckle, 1996; Saputra, 2001; García-Martínez et al., 2002; Lombard et al., 2008; Nuñez-Mancilla et al., 2013).

Pineapple (*Ananas comosus*) fruits are widely grown in Johor located in the southern area of peninsular Malaysia and Malaysia is known as one of the largest producers in the world (MPIB, 2012d). Statistic data shows that there is a total export of 13653 tonnes worth RM 37.2 million (MPIB, 2012a). Pineapple is rich in vitamin C, vitamin B (B1 and B3), potassium content, sodium and contain enzyme Bromelain which used in medical applications. There is a wide opportunity to expand pineapple based products with better health benefits and nutraceutical properties in order to introduce Malaysia pineapple cultivar to international markets and increase the annual total export of pineapple products in Malaysia.

The conventional preservations of pineapple are done using high thermal processing which will affect the natural characteristics of fruits that the natural colour of the fruits, flavour and specific nutrients such as vitamin C will degrade (García-Martínez *et al.*, 2002). Also, the common pineapple based products are usually produced in high glycemic and calorie indexes such as pineapple jam and candied pineapple which will affect the human health particularly in diabetes (Basu, *et al.*, 2011). The problem statement for this research is the preservation of pineapple using osmotic dehydration with minimal temperature to prevent losses of natural characteristics and

using low calorie sugar substitute to minimize the calorie and glycemic index in the osmodehydrated pineapple.

In the previous researches, there is lacking of information on substitution of sucrose with sorbitol in the osmotic dehydration process and physical and microbial stability of osmodehydrated pineapple during storage. The focus of this research is on preparing the osmodehydrated pineapple for further process application in pineapple base products.

1.2 Objectives

Overall, the research is undertaken with the aim to produce healthier osmodehydrated pineapple and extend the shelf life. The specific objectives of this research were:

i) To determine the osmotic dehydration kinetic, textural and physicochemical properties of pineapple at different concentration of sucrose and sorbitol mixtures

ii) To determine physicochemical properties, microbial stability and kinetic of quality changes of osmodehydrated pineapple during storage

REFERENCES

Abdullah, A., & Cheng, T. C. (2001). Optimization of reduced calorie tropical mixed fruits jam. *Food Quality and Preference, 12*, 63-68.

Abraão, A. S., Lemos, A. M., Vilela, A., Sousa, J. M., & Nunes, F. M. (2013). Influence of osmotic dehydration process parameters on the quality of candied pumpkins. *Food and Bioproducts Processing, 91(4)*, 481-494.

Adams, M., & Moss, M. (2000). *Food Microbiology*. Cambridge: Royal Society of Chemistry.

Alonso, S., & Setser, C. (1994). Functional replacements for sugars in foods. *Trends in Food Science & Technology, 5*, 139-146.

AOAC. (1990). Official methods of analysis(13th ed) *Official method 967.21. Vitamin C (Ascorbic Acid) in vitamin preparations and juices.* Washington DC: AOAC International.

AOAC. (2000). Association of Official Analytical Chemist Official Methods of Analysis, 17th edition. USA: ML.

Baltacio, C. E. M., Velio, S., & Karacabey, E. (2011). Changes in total phenolic and flavonoid contents of rowanberry fruit during postharvet storage. *Journal of Food Quality, 34*(4), 278-283.

Barbosa-Cánovas, G. V., Fernández-Molina, J. J., Alzamora, S. M., Tapia, M. S., López-Malo, A., & Chanes, J. W. (2003). *Handling and Preservation of Fruits and Vegetables by Combined Methods for Rural Areas*. Rome: Food and Agriculture Organization of the United Nations.

Basantia, N. C., Arora, S., Seth, R., & Singh, A. (2000). Milk proteins in the preparation of edible coatings. *Indian Food Industry, 19*, 36–47.

Basu, S., Shivhare, U. S., Singh, T. V., & Beniwal, V. S. (2011). Rheological, textural and spectral characteristics of sorbitol substituted mango jam. *Journal of Food Engineering, 105*, 503-512.

Bierhals, V. S., Chiumarelli, M., & Hubinger, M. D. (2011). Effect of cassava starch coating on quality and shelf life of fresh-cut pineapple (*Ananas comosus* L. Merril cv "Perola"). (1750-3841 (Electronic)).

Calorie Control Council. (2012). Facts about polyols. Retrieved 30th July, 2012, from http://www.polyol.org/facts_about_polyols.html

Cárnara, M., Díez, C., & Torija, E. (1995). Chemical characterization of pineapple juices and nectars. Principal components analysis. *Food Chemistry, 54*(1), 93-100.

Castelló, M. L., Igual, M., Fito, P. J., & Chiralt, A. (2009). Influence of osmotic dehydration on texture, respiration and microbial stability of apple slices (Var. Granny Smith). *Journal of Food Engineering, 91*, 1-9.

Chakraborty, S., Rao, P. S. and Mishra, H. N. 2016. Changes in quality attributes during storage of high-pressure and thermally processed pineapple puree. *Food and Bioprocess Technology, 9*, 768-791.

Chaurasiya, R. S., & Umesh Hebbar, H. (2013). Extraction of bromelain from pineapple core and purification by RME and precipitation methods. *Separation and Purification Technology, 111*(0), 90-97.

Chavan, U. D., & Amarowicz, R. (2012). Osmotic dehydration process for preservation of fruits and vegetables. *Journal of Food Research, 1(2),* 202-209.

Chia, S. L., Rosnah, S., Noranizan, M. A., & Wan Ramli, W. D. (2012). The effect of storage on the quality attributes of ultraviolet-irradiated and thermally pasteurised pineapple juices. *International Food Research Journal, 19*(3), 1001-1010.

Chiralt, A., Fito, P., Andres, A., Gonzalez-Martinez, C., Escriche, I., & Camacho, M. M. (2001). Use of vacuum impregnation in food salting process. *Journal of Food Engineering, 49*(2-3), 141-151.

Chottanom, P., & Srisa-Ard, M. (2011). Osmotic dehydration as a factor in freezing of tomato. *American Journal of Food Technology, 6*(6), 483-491.

Corzo, C. A., Waliszewski, K. N., & Welti-Chanes, J. (2012). Pineapple fruit bromelain affinity to different protein substrates. *Food Chemistry, 133*(3), 631-635.

da Silva, D. I. S., Nogueira, G. D. R., Duzzioni, A. G., & Barrozo, M. A. S. (2013). Changes of antioxidant constituents in pineapple (*Ananas comosus*) residue during drying process. *Industrial Crops and Products, 50*(0), 557-562.

Dapeou, G. (1976). *Methods in Enzymology* (Vol. Vol. XLV). New York: Academic Press.

Department of Islamic Development Malaysia (JAKIM) (2010). Handbook of Halal Food Additives, 3rd Edition. Department of Islamic Development Malaysia.

Diaz, M. N., Frei, B., Vita, J. A., & Keaney, J. F., Jr. (1997). Antioxidants and atherosclerotic heart disease. *The New England Journal of Medicine, 337(6),* 408-416.

El-Aouar, A. A., Azoubel, P. M., Barbosa Jr., J. L., & Murr, F. E. X. (2006). Influence of the osmotic agent on the osmotic dehydration of papaya (*Carica papaya* L.). *Journal of Food Engineering, 75,* 267-274.

Falada, K. O., Igbeka, J. C., & Ayanwuyi, F. A. (2007). Kinetics of mass transfer, and colour changes during osmotic dehydration of watermelon. *Journal of Food Engineering, 80,* 979-985.

Faramade, O. O. (2007). Kinetics of ascorbic acid degradation in commercial orange juice produced locally in Nigeria. *African Crop Science Society, 8,* 1813-1816.

Fitch, C., & Keim, K. S. (2012). Position of the academy of nutrition and dietetics: Use of nutritive and nonnutritive sweeteners. *Journal of the Academy of Nutrition and Dietetics, 112,* 739-758.

Food and Drug Administration. (2001). Evaluation & Definition of Potentially Hazardous Foods. Retrieved 6th March 2013, from http://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094141.htm

Food Standard Australia New Zealand. (2001). Guidelines for the microbiological examination of ready - to - eat foods. Retrieved 25 September, 2014, from http://www.foodstandards.gov.au/publications/documents/Guidelines%20for%20Micro%20exam.pdf

García-Martínez, E., Ruiz-Diaz, G., Martínez-Monzó, J., Camacho, M. M., Martínez-Navarrete, N., & Chiralt, A. (2002). Jam manufacture with osmodehydrated fruit. *Food Research International, 35,* 301-306.

García-Segovia, P., Mognetti, C., Andrés-Bello, A., & Martínez-Monzó, J. (2010). Osmotic dehydration of *Aloe vera* (*Aloe barbadensis* Miller). *Journal of Food Engineering, 97*(2), 154-160.

Giannotti, A., Sacchetti, G., Guerzoni, M. E. & Dalla Rosa, M. (2001). Microbial aspects on short-time osmotic treatment of kiwifruit. *Journal of Food Engineering, 49,* 265-270.

Hajare, S. N., Dhokane, V. S., Shashidhar, R., Saroj, S., Sharma, A., & Bandekar, J. R. (2006). Radiation processing of minimally processed pineapple (*Ananas comosus* Merr.): Effect on nutritional and sensory quality. *Journal of Food Science, 71*(6), S501-S505.

Hossain, M. A., & Rahman, S. M. M. (2011). Total phenolics, flavonoids and antioxidant activity of tropical fruit pineapple. *Food Research International, 44*(3), 672-676.

Hung, P. V. & Duy, T. L. (2012). Effects of drying methods on bioactive compounds of vegetables and correlation between bioactive compounds and their antioxidants. *International Food Research Journal, 19(1),* 327-322.

ICMSF. (2002). *Microbial ecology of food commodities. In: Microorganisms in foods* (Vol. 6). New York: Kluwer Academic/Plenum Publishers.

Igual, M., Contreras, C., & Martínez-Navarrete, N. (2010). Non-conventional techniques to obtain grapefruit jam. *Innovative Food Science & Emerging Technologies, 11,* 335-341.

Igual, M., Garcia-Martinez, E., Camacho, M. M., & Martinez-Navarrete, N. (2013). Jam processing and storage effects on beta-carotene and flavonoids content in grapefruit. *Journal of Functional Foods, 5(2),* 736-744.

Islek, M., Nilufer-Erdil, D., & Knuthsen, P. (2014). Changes in flavonoids of sliced and fried yellow onions (*Allium cepa L. var. zittauer*) during storage at different atmospheric, temperature and light conditions. *Journal of Food Processing and Preservation, 39(4),* 357-368..

Jena, S. & Das, H. (2005). Modelling for moisture variation during osmo-concentration in apple and pineapple. *Journal of Food Engineering, 66,* 425-432.

Kaymak_Ertekin, F. & Sultanoglu, M. (2000). Modelling of mass transfer durign osmotic dehydration of apples. *Journal of Food Engineering, 46,* 243-250.

Kesarkar, S., Bhandage, A., Deshmukh, S., Shevkar, K., & Abhyankar, M. (2009). Flavonoids: An overview. *Journal of Pharmacy Research, 2,* 1148-1154.

Khin, M. M., Weibiao, Z., & Perera, C. (2005). Development in the combined treatment of coating and osmotic dehydration of food: a review. *International Journal of Food Engineering,* 1-19.

Khoyi, M. R., & Hesari, J. (2007). Osmotic dehydration kinetics of apricot using sucrose solution. *Journal of Food Engineering, 78*(4), 1355-1360.

Kim, D.-O., Jeong, S. W., & Lee, C. Y. (2003). Antioxidant capacity of phenolic phytochemicals from various cultivars of plums. *Food Chemistry, 81*(3), 321-326.

Kroger, M., Meister, K., & Kava, R. (2006). Low-calorie sweeteners and other sugar substitutes: A review of the safety issues. *Comprehensive Reviews in Food Science and Food Safety, 5,* 35-47.

Kumar, S., Hemavathi, A. B., & Hebbar, H. U. (2011). Affinity based reverse micellar extraction and purification of bromelain from pineapple (*Ananas comosus L. Merryl*) waste. *Process Biochemistry, 46*(5), 1216-1220.

Laorko, A., Li, Z., Tongchitpakdee, S., Chantachum, S., & Youravong, W. (2010). Effect of membrane property and operating conditions on phytochemical properties and permeate flux during clarification of pineapple juice. *Journal of Food Engineering, 100*(3), 514-521.

Lazarides, H. N. (2001). Reasons and possibilities to control solid uptake during osmotic treatment of fruit and vegetables. In P. Fito, A. Chiralt, M. J. Barat, E. W. Spiess & D. Behsnillian (Eds.), *Osmotic dehydration and vacuum impregnation*. USA: Technomic Publishing Company.

Leistner, L. (1992). Food preservation by combined methods. *Food Research International, 25*(2), 151-158.

Lenart, A. (1996). OSMO-convective drying of fruits and vegetables: technology and application. *Drying Technology, 14*(2), 391-413.

Lespinard, A. R., Bambicha, R. R., & Mascheroni, R. H. (2012). Quality parameters assessment in kiwi jam during pasteurization. Modelling and optimization of the thermal process. *Food and Bioproducts Processing, 90*, 799-808.

Lombard, G. E., Oliveira, J. C., Fito, P., & Andrés, A. (2008). Osmotic dehydration of pineapple as a pre-treatment for further drying. *Journal of Food Engineering, 85*, 277-284.

Maftoonazad, N. & Ramaswamy, H. S. (2008). Effect of pectin-based coating on the kinetics of quality change associated with stored avocados. *Journal of Food Processing and Preservation, 32, 621-643.*

Maltini, E., Torreggiani, D., Venir, E., & Bertolo, G. (2003). Water activity and the preservation of plant foods. *Food Chemistry, 82*(1), 79-86.

Mantilla, N., Castell-Perez, M. E., Gomes, C., & Moreira, R. G. (2013). Multilayered antimicrobial edible coating and its effect on quality and shelf-life of fresh-cut pineapple (Ananas comosus). *LWT - Food Science and Technology, 51*(1), 37-43.

Markis, D. P. and Rossiter, J. T. 2000. Heat-induced, metal-catalyzed oxidative degradation of quercetin and rutin (quercetin 3-o-rhamnosylglucoside) in aqueous model systems. *Journal of Agricultural and Food Chemistry, 48(9),* 3830–3838.

Mercali, G. D., Marczak, L. D. F., Tessaro, I. C., & Norena, C. P. Z. (2011). Evaluation of water, sucrose and NaCl effective diffusivities during osmotic dehydration of banana (*Musa sapientum, shum.*), *LWT – Food Science and Technology, 44*, 82-91.

Ministry of Health, M. (2012). *The future of Diabetes in Malaysia*. Paper presented at the Malaysia Diabetes Educators Society Seminar 2012, 20 April 2012, Malaysia.

Montes, C., Vicario, I. M., Raymundo, M., Fett, R., & Heredia, F. J. (2005). Application of tristimulus colorimetry to optimize the extraction of anthocyanins from Jaboticaba (*Myricia jaboticaba* Berg.). *Food Research International, 38*(8–9), 983-988.

Moraga, M. J., Moraga, G., & Martínez-Navarrete, N. (2011). Effect of the re-use of the osmotic solution on the stability of osmodehydro-refrigerated grapefruit. *LWT - Food Science and Technology, 44*, 35-41.

Moura, C. P., Masson, M. L., & Yamamoto, C. I. (2005). Effect of osmotic dehydration in the apple (*Pyrus malus*) varieties Gala, Gold and Fugi. *Thermal Engineering, 4*(1), 46-49.

MPIB. (2012a). Export of Malaysian Canned Pineapple and Pineapple Juice. Retrieved 21th June, 2012, from http://www.mpib.gov.my/c/document_library/get_file?uuid=77274d73-43af-4bdc-a2e5-c13a41c93e32&groupId=22005

MPIB. (2012b). Pineapple Resource: Nutrition of Pineapple. Retrieved 20th June, 2012, from http://www.mpib.gov.my/web/guest/khasiat_nanas

MPIB. (2012c). Pineapple Resource: Product. Retrieved 20th June, 2012, from http://www.mpib.gov.my/web/guest/produk

MPIB. (2012d). Pineapple Resources: Origin of Pineapple. Retrieved 20th June, 2012, from http://www.mpib.gov.my/web/guest/asal_usul_nanas

Mrmosanin, J. M., Pavlovic, A. N., Veljkovic, J. N., Mitiec, S. S., Tosic, S. B. & Mitic, M. N. (2015). The effect of storage temperature and thermal processing on cathecins, procyanidins and total flavonoid stability in commercially available cocoa powders. *Physics, Chemistry and Technology, 13(1)*, 39-49.

Myung, K., Hamilton-Kemp Tr Fau - Archbold, D. D., & Archbold, D. D. (2006). Biosynthesis of trans-2-hexenal in response to wounding in strawberry fruit. *Journal of Agricultural Food Chemistry, 54(4)*, 1442-1448.

Nabors, L., & Hedrick, T. (2012). Sugar reduction with polyols. *Food Technology Magazine September 2012, 66*.

Naidu, K. A. (2003). Vitamin C in human health and disease is still a mystery ? An overview. *Nutrition Journal*, *2*(7).

Naknean, P., Maneyam, R., & Kam-Onsri, A. (2013). Effect of different osmotic agents on the physical, chemical and sensory properties of osmo-dried cantaloupe. *Chiang Mai Journal of Science*, *40*(3), 427-439.

NCBI. (2014). Ascorbic Acid. Retrieved 20th September, 2014, from http://pubchem.ncbi.nlm.nih.gov/summary/summary.cgi?cid=54670067

Nowakunda, K., Andres, A., & Fito, P. (2004). Osmotic dehydration of banana slices as a pretreatment for drying process. *Proceedings of the 14th International Drying Symposium*, 2077-2083.

Nuñez-Mancilla, Y., Pérez-Won, M., Uribe, E., Vega-Gálvez, A., & Di Scala, K. (2013). Osmotic dehydration under high hydrostatic pressure: Effects on antioxidant activity, total phenolics compounds, vitamin C and colour of strawberry (*Fragaria vesca*). *LWT - Food Science and Technology*, *52*, 151-156.

Oey, I., Van der Plancken, I., Van Loey, A. & Hendrickx, M. (2008). Does high pressure processing influence nutritional aspects of plant based food system? *Trend in Food Science and Technology, 19(6)*, 300-308.

Osorio, C., Franco, M. S., Castaño, M. P., González-Miret, M. L., Heredia, F. J., & Morales, A. L. (2007). Colour and flavour changes during osmotic dehydration of fruits. *Innovative Food Science & Emerging Technologies, 8*(3), 353-359.

Panadés-Ambrosio, G., Treto-Cárdenas, O., Fernández-Torres, C., Castro, D., & M, N. d. V. (1996). Deshidratación osmótica de guayaba a vacío pulsante / pulse vacuum osmotic dehydration of guava. *Food Science and Technology International*, *2*, 301-306.

Pandhair, V., & Sekhon, B. S. (2006). Reactive Oxygen Species and Antioxidants in Plants: An Overview. *Journal of Plant Biochemistry and Biotechnology, 15*(2), 71-78.

Pattanapa, K., Therdthai, N., Chantrapornchai, W., & Zhou, W. (2010). Effect of sucrose and glycerol mixtures in the osmotic solution on characteristics of osmotically dehydrated mandarin cv. (Sai-Namphaung). *International Journal of Food Science and Technology, 45*(9), 1918-1924.

Peinado, I., Rosa, E., Heredia, A., & Andrés, A. (2011). *Influence of dry and wet osmotic dehydration on colour and texture of spread kiwi product.* Paper presented at the 11th Internationa Congress on Engineering and Food, Athens, Greece. May 22-26, 2011, 1995-1996.

Peinado, I., Rosa, E., Heredia, A., & Andrés, A. (2012). Rheological characteristics of healthy sugar substituted spreadable strawberry product. *Journal of Food Engineering, 113*, 365-373.

Pereira, M. A., Kartashov, A. I., Ebbeling, C. B., Van Horn, L., Slattery, M. L., Jacobs Jr, D. R., & Ludwig, D. S. (2005). Fast-food habits, weight gain, and insulin resistance (the CARDIA study): 15-year prospective analysis. *The Lancet, 365*, 36-42.

Phisut, N. (2012). Mini Review: Factors affecting mass transfer during osmotic dehydration of fruits. *International Food Research Journal, 19*, 7-18.

Poh, S. S., & Abdul Majid, F. A. (2011). Thermal stability of free bromelain and bromelain-polyphenol complex in pineapple juice. *International Food Research Journal, 18*(3), 1051-1060.

Prosapio, V. & Norton, I. (2017). Influence of osmotic dehydration pre-treatment on oven drying and freeze drying performance. *LWT-Food Science and Technology, 80*, 401-408.

Pua, M. Y., Shamsudin, R., Hamzah, A., & Endan, J. (2011). Kinetic studies on cooking of pineapple bakery jam. *American Journal of Food Technology, 6*, 594-603.

Ramallo, L. A., & Mascheroni, R. H. (2012). Quality evaluation of pineapple fruit during drying process. *Food and Bioproducts Processing, 90*(2), 275-283.

Rastogi, N. K., Raghavarao, K., & Niranjan, K. (2005). 9 - Developments in Osmotic Dehydration. In S. Da-Wen (Ed.), *Emerging Technologies for Food Processing* London: Academic Press. 221-249.

Rastogi, N. K., & Raghavarao, K. S. M. S. (2004a). Mass transfer during osmotic dehydration of pineapple: considering Fickian diffusion in cubical configuration. *LWT - Food Science and Technology, 37*, 43-47.

Rastogi, N. K., & Raghavarao, K. S. M. S. (2004b). Mass transfer during osmotic dehydration: Determination of moisture and solute diffusion coefficients from concentration profiles. *Food and Bioproducts Processing, 82*, 44-48.

Rattanathanalerk, M., Chiewchan, N., & Srichumpoung, W. (2005). Effect of thermal processing on the quality loss of pineapple juice. *Journal of Food Engineering, 66*(2), 259-265.

Rodrigues, A. S., Pérez-Gregorio, M. R., García-Falcón, M. S., Simal-Gándara, J., & Almeida, D. P. F. (2010). Effect of post-harvest practices on flavonoid content of red and white onion cultivars. *Food Control, 21*(6), 878-884.

Ronda, F., Gómez, M., Blanco, C. A., & Caballero, P. A. (2005). Effects of polyols and nondigestible oligosaccharides on the quality of sugar-free sponge cakes. *Food Chemistry, 90*(4), 549-555.

Rosnah, R., Coskan, I., Wan Ramli, W. D., Mohd Sobri, T., & Osman, H. (2011). *Effect of Temperature on the Rheological Behaviour of 'Josapine' Pineapple (Ananas comosusL.) Pulp. Acta Horticulture, 902,* 449-452.

Sandrou, D. K., & Arvanitoyannis, I. S. (2000). Low-Fat/Calorie Foods: Current State and Perspectives. *Critical Reviews in Food Science and Nutrition, 40*, 427-447.

Santos, P. H. S., & Silva, M. A. (2009). Kinetics of L-Ascorbic acid degradation in pineapple drying under ethanolic atmosphere. *Drying Technology, 27*(9), 947-954.

Sapei, L. & Hwa, L. (2014). Study on the kinetics of Vitamin C degradation in fresh strawberry juice. *Procedia Chemistry, 9,* 62-68.

Saputra, D. (2001). Osmotic dehydration of pineapple. *Drying Technology, 19,* 415-425.

Saurel, R., Raoult-Wack, A. L., Rios, G., & Guilbert, S. (1994). Mass transfer phenomena during osmotic dehydration of apple I. Fresh plant tissue. *International Journal of Food Science and Technology, 29*(5), 531-542.

Saxena, S., Mishra, B. B., Chander, R., & Sharma, A. (2009). Shelf stable intermediate moisture pineapple (*Ananas comosus*) slices using hurdle technology. *LWT - Food Science and Technology, 42*(10), 1681-1687.

Sedas, V. T. P., Kubiak, K. N. W., & Alvarado, M. A. G. (1994). Ascorbic acid loss and sensory changes in intermediate moisture pineapple during storage at 30–40°C. *International Journal of Food Science & Technology, 29*(5), 551-557.

Shamsudin, R., Wan Daud, W. R., Takrif, M. S., & Hassan, O. (2009). Physico-Mechanical properties of the josapine pineapple fruits. *Pertanika Journal Science & Technology, 17*(1), 117-123.

Shamsudin, R., Wan Daud, W. R., Takrif, M. S., Hassan, O., Mustapha Kamal, S. M., & A.G.L., A. (2007). Influence of temperature and soluble solid contents on rheological properties of the josapine variety of pineapple fruit (*Ananas Comosus L.*). *International Journal of Engineering and Technology, 4*(2), 213-220.

Shi, J., & Xue, S. J. (2009). Application and development of osmotic dehydration technology in food processing. In C. Ratti (Ed.), *Advance in Food Dehydration* (pp. 187–208). USA: CRC Press.

Silva, M. A. D. C., Silva, Z. E. D., Mariani, V. C., & Darche, S. (2012). Mass transfer during the osmotic dehydration of West Indian cherry. *LWT - Food Science and Technology, 45*(2), 246-252.

Silveira, E. T. F., Rahman, M. S., & Buckle, K. A. (1996). Osmotic dehydration of pineapple: kinetics and product quality. *Food Research International, 29*, 227-233.

Sipahi, R. E., Castell-Perez, M. E., Moreira, R. G., Gomes, C., & Castillo, A. (2013). Improved multilayered antimicrobial alginate-based edible coating extends the shelf life of fresh-cut watermelon (*Citrullus lanatus*). *LWT - Food Science and Technology, 51*(1), 9-15.

Sulaiman, S. F., Sajak, A. A. B., Ooi, K. L., Supriatno, & Seow, E. M. (2011). Effect of solvents in extracting polyphenols and antioxidants of selected raw vegetables. *Journal of Food Composition and Analysis, 24*(4–5), 506-515.

Terao, J., Piskula, M., & Yao, Q. (1994). Protective effect of epicatechin, epicatechin gallate, and quercetin on lipid peroxidation in phospholipid bilayers. *Archives of Biochemistry and Biophysics, 308*(1), 278-284.

Thakur, B. R., & Singh, R. K. (1995). Combination processes in food irradiation. *Trends in Food Science & Technology, 6*(1), 7-11.

Todorova, S., Veleva, N., Arnaudov, I., Taneva, T., & Andreev, D. (1982). Effect of dietetic fruit products prepared with sorbitol and pectin on the blood sugar and insulin levels in diabetic patients. *Vutreshni Bolesti, 21*, 88-96.

Tomás-Barberán, F. A., & Espín, J. C. (2001). Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. *Journal of the Science of Food and Agriculture, 81*(9), 853-876.

Torreggiani, D. (1993). Osmotic dehydration in fruit and vegetable processing. *Food Research International, 26*, 59-68.

Truc, T. T., Thanh, L. K., & Muoi, N. V. (2010). Effect of pH and temperature on activity of bromelaine in pineapple fruit. *The Kasetsart Journal (Natural Science), 44*, 943-948.

U.S. Food and Drug Adminstration (2001). Evaluation & definition of potentially hazardous foods. Retrieved 11th June, 2015, from http://www.fda.gov/Food/FoodScienceResearch/SafePracticesforFoodProcesses/ucm094141.htm

U.S. Department of Agriculture, A. R. S. (2012a). Nutrient data for 09201, Oranges, raw, California, valencias. *USDA National Nutrient Database for Standard Reference, Release 25.* Retrieved 20th November, 2012, from http://ndb.nal.usda.gov/ndb/foods/show/2301?fg=&man=&lfacet=&format=&count=&max=25&offset=&sort=&qlookup=orange

U.S. Department of Agriculture, A. R. S. (2012b). Nutrient data for 09266, Pineapple, raw, all varieties. *USDA National Nutrient Database for Standard Reference, Release 25.* Retrieved 20th November, 2012, from http://ndb.nal.usda.gov/ndb/foods/show/2356?fg=&man=&lfacet=&format=&count=&max=25&offset=&sort=&qlookup=pineapple

Umesh Hebbar, H., Sumana, B., & Raghavarao, K. S. (2008). Use of reverse micellar systems for the extraction and purification of bromelain from pineapple wastes. *Bioresource Technology, 99(11),* 4896-4902.

Venderbosch, R. H., & Heeres, H. J. (2011). Pyrolysis Oil Stabilisation by Catalytic Hydrotreatment. In M. A. d. S. Bernardes (Ed.), *Biofuel's Engineering Process Technology*.

Vibhakara, H. S., & Bawa, A. S. (2006). Manufacturing Jams and Jellies. In Y. H. Hui (Ed.), *Handbook of Fruits and Fruit Processing*: Blackwell Publishing, 189-203.

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

Wardy, W., Saalia., F. K., Steiner-Asiedu, M., Budu, A. S., & Sefa-Dedeh, S. (2009). A comparison of some physical, chemical and sensory attributes of three pineapple (Ananas comosus) varieties grown in Ghana. *African Journal of Food Science, 3*(1), 22-25.

WebMD. (2014a). The Benefits of Vitamin C. Retrieved 20th September, 2014, from http://www.webmd.com/diet/features/the-benefits-of-vitamin-c

WebMD. (2014b). Bromelain. Retrieved 20th September, 2014, from http://www.webmd.com/vitamins-supplements/ingredientmono-895-bromelain.aspx?activeingredientid=895&activeingredientname=bromelain

Weddig, L. M. (2007). *Canned Food: Principal of Thermal Process Control, Acidification and Container Closure Evaluation* (7th Edition ed.). Washington, D.C., United State of America: GMA Science adn Education Foundation Washington, D.C.

Woolworths Quality Assurance. (2012). Appendix 2 – Microbiological and Chemical Requirements. Retrieved 30th Spetember, 2014, from http://www.wowlink.com.au/cmgt/wcm/connect/8cd89a004568281f8330ff91

99e896f3/220812+WQA+Manufactured+Food+Standard+Version+7+Appendix+2+07+Aug+2012.pdf?MOD=AJPERES.

WorldHealth. (2005). Bromelain (Pineapple enzyme). Retrieved 20th September, 2014, from http://www.worldhealth.net/news/bromelain_pineapple_enzyme/

Xue, Y., Wu, C.-Y., Branford-White, C. J., Ning, X., Nie, H.-L., & Zhu, L.-M. (2010). Chemical modification of stem bromelain with anhydride groups to enhance its stability and catalytic activity. *Journal of Molecular Catalysis B: Enzymatic*, *63*(3–4), 188-193.