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OPTIMIZATION AND MATHEMATICAL MODELING OF GREEN SOLVENT-MEDIATED EXTRACTION OF ESSENTIAL OIL FROM Citrus hystrix DC. LEAVES

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By

NOOR AMIRAH BINTI ABDUL HALIM

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

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This thesis is fondly dedicated to my beloved late father, Abdul Halim, who has always been my source of strength despite his absence, my dearest mother Noor Sidah for her never-ending loves and prayers, and my darling husband Wan Shuhairi for his unconditional support throughout this journey.

'The only true wisdom is in knowing you know nothing'
-Socrates-

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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July 2022

Chair : Prof. Zurina Zainal Abidin, PhD
Faculty : Engineering

Citrus hystrix DC. leaves or Kaffir lime leaves is known for its prominent organoleptic properties and therapeutical functionalities but are still underutilized as a source for the high-demand citrus-based essential oil (EO), due to the limitation of conventional hydrodistillation (HD) method that results in low yield. Green solvents such as natural deep eutectic mixture and subcritical-phase water described in previous studies not only improved the bioproduct extraction but also friendlier to the environment. However, the use of a natural deep eutectic solvent (NADES) requires correct formulation to be effective, while adopting water at subcritical conditions can affect the quality of EO. Hence, in this work, the application and the effectiveness of natural deep eutectic solvent-assisted hydrodistillation (NADES-HD) and subcritical water extraction (SWE) methods were comparatively studied.

Based on screening and optimization studies, NADES-HD and SWE techniques successfully improved the EO yield by twice (1.32% w/w), and almost fourfold (2.14% w/w) respectively, in comparison to conventional HD (0.57% w/w) at their corresponding optimum extraction conditions. Both methods were well-fitted to the one-site kinetic desorption model at an extraction rate (k) of 0.0107 to 0.0136 min^{-1} and 0.0224 to 0.0463 min^{-1} for NADES-HD and SWE, respectively. Assessment of the mass transfer behavior estimates that the effective diffusivity, (D) values for NADES-HD and SWE corresponded to 3.68 x 10^{-6} to 5.59 x 10^{-6} cm^2/s and 8.91 x 10^{-8} to 1.47 x 10^{-7} cm^2/s, respectively, and obeys the Fick's second law of diffusion. Meanwhile, for thermodynamics behavior, both methods were identified as exergonic and spontaneous processes with the free Gibbs energy (ΔG) values ranging from 6.83 to 8.73 kJ/mol for NADES-HD and 2.23 to 4.74 kJ/mol for SWE.

The chemical profile analysis revealed that the SWE produced more EO compounds, where isopulegol (52.21%) was the predominant constituent, meanwhile NADES-HD

has yielded EO that is rich in citronellal (75.99%), similar to conventional HD (75.04%). Besides, SWE-extracted EO exhibited a superior antioxidant activity while the EO extracted by NADES-HD demonstrated a better antimicrobial activity. The physical characterization of the post-extraction leaves samples indicated that the lignocellulosic structures of SWE-extracted leaves were severely disrupted compared to the damages observed on NADES-HD and conventional HD samples, hence implying the reason for the higher EO yield obtained by the SWE process. In brief, NADES-HD and SWE are the potential alternatives to conventional HD, where the quantity and quality of EO could be enhanced within a shorter extraction time and at the same time could minimize the energy requirement.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN DAN PEMODELAN MATEMATIK BAGI PENGEKSTRAKAN-PERANTARAAN PELARUT HIJAU MINYAK PATI DARI DAUN *Citrus hystrix* DC.

Oleh

NOOR AMIRAH BINTI ABDUL HALIM

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Daun *Citrus hystrix* DC. atau daun limau purut terkenal dengan ciri-ciri organoleptik dan fungsi-fungsi terapeutik yang ketara, namun masih kurang digunakan sebagai sumber minyak pati (EO) berasaskan sitrus yang mempunyai permintaan tinggi, disebabkan oleh pengehadan kaedah penyulingan hidro (HD) konvensional yang menghasilkan hasil yang rendah. Pelarut hijau seperti campuran eutektik dalam semulajadi dan air pada fasa di bawah suhu kritikal yang diterangkan dalam kajian-kajian terdahulu bukan sahaja dapat meningkatkan pengekstrakan bioproduk tetapi juga lebih mesra alam. Walau bagaimanapun, penggunaan pelarut eutektik dalam semulajadi (NADES) memerlukan formulasi yang betul untuk menjadikannya berkesan, manakala penggunaan air pada keadaan di bawah suhu kritikal boleh menjejaskan kualiti EO. Oleh itu, dalam kajian ini, aplikasi dan keberkesanan penyulingan hidro berbantukan pelarut eutektik dalam semulajadi (NADES-HD) dan kaedah pengekstrakan oleh air di bawah suhu kritikal (SWE) telah dikaji secara perbandingan.

Berdasarkan kajian saringan dan pengoptimuman, teknik NADES-HD dan SWE masing-masing berjaya meningkatkan hasil EO sebanyak dua kali ganda (1.32% b/b), dan hampir empat kali ganda (2.14% b/b), berbanding HD konvensional (0.57% b/b) pada keadaan pengekstrakan optimum yang sepadan. Kedua-dua kaedah adalah sesuai dengan model nyah serapan kinetik satu kawasan, pada kadar pengekstrakan (k) masing-masing, iaitu 0.0107 hingga 0.0136 min^{-1} dan 0.0224 hingga 0.0463 min^{-1} bagi NADES-HD dan SWE. Penilaian berkenaan tingkah laku pemindahan jisim, menganggarkan bahawa nilai-nilai resapan berkesan, (D) untuk NADES-HD dan SWE masing-masing sepadan dengan 3.68 x 10^{-6} hingga 5.59 x 10^{-6} cm^2/s dan 8.91 x 10^{-8} hingga 1.47 x 10^{-7} cm^2/s, dan mematuhi hukum resapan kedua Fick. Sementara itu, bagi tingkah laku termodinamik, kedua-dua kaedah telah dikenal pasti sebagai proses eksergonik dan spontan, dengan nilai tenaga Gibbs bebas (ΔG) antara 6.83 hingga 8.73 kJ/mol untuk NADES-HD dan 2.23 hingga 4.74 kJ/mol untuk SWE.

Analisa profil kimia mendedahkan bahawa SWE menghasilkan lebih banyak sebatian EO, di mana isopulegol (52.21%) adalah juzuk utama, manakala NADES-HD telah menghasilkan EO yang kaya dengan sitronelal (75.99%) menyamai dengan HD konvensional (75.04%). Selain itu, EO yang diekstrak oleh SWE mempamerkan aktiviti antioksidan yang unggul manakala EO yang diekstrak oleh NADES-HD menunjukkan aktiviti antimikrob yang lebih baik. Pencirian fizikal sampel daun selepas pengekstrakan menunjukkan bahawa struktur lignoselulosa daun yang diekstrak oleh SWE telah terjejas teruk berbanding dengan kemusnahan yang diperhatikan ke atas sampel-sampel NADES-HD dan HD konvensional, justeru menjelaskan sebab bagi hasil EO yang lebih tinggi diperolehi oleh SWE. Secara ringkasnya, NADES-HD dan SWE merupakan alternatif-alternatif yang berpotensi kepada HD konvensional, di mana kuantiti dan kualiti EO boleh dipertingkatkan dalam masa pengekstrakan yang lebih singkat dan pada masa yang sama dapat meminimumkan keperluan tenaga.

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Declaration by Members of Supervisory Committee

This is to certify that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BET	Brunauer-Emmett-Teller
BJH	Barrett-Joyner-Halenda
CCD	Central composite design
DES	Deep eutectic solvent
DES-HD	Deep eutectic solvent assisted hydrodistillation
DPPH	2,2-diphenyl-1-picrylhydrazyl
EO	Essential oil
FTIR	Fourier transform infra-red
GC-MS	Gas chromatography-mass spectroscopy
HD	Hydrodistillation
HBA	Hydrogen bond acceptor
HBD	Hydrogen bond donor
NADES	Natural deep eutectic solvent
NLSF	Nonlinear squared fitting
RSM	Response surface methodology
SD	Steam distillation
SEM	Scanning electron microscopy
SSR	Sum of squared residual
SWE	Subcritical water extraction

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Plant essential oils (EOs) are known for various benefits, particularly their organoleptic and bioactive properties. Complex chemical compositions, which are predominantly composed of terpenic compounds give synergy of biological effects to the EOs, offering a broad spectrum of bioactivities. The demand for EOs especially for citrus-based oil by the food industry has increased in line with the diversity of the functionality of EOs, particularly in food flavoring and preservation (Giacometti et al., 2018; Tongnuanchan and Benjakul, 2014). Among the EOs, citrus-based EOs dominate the global market demand due to their strong organoleptic properties, notable bioactive functionalities, a vast array of applications, and sturdy demand dynamics (Gonçalves et al., 2018; Mustafa, 2015).

Citrus hystrix (*C. hystrix*) or generally known as Kaffir lime is an aromatic perennial plant that native to South-East Asia. The leaves and the fruits are commonly used as culinary herbs to improve the organoleptic properties of food, as well as a traditional remedy for various illnesses (e.g., digestive aid, blood cleansing, cold, congestion, and cough). The leaves of *C. hystrix* are unique among citrus varieties and, for some particular applications, are more pronounced than the fruits due to its significant organoleptic characteristic (Wongpornchai, 2012). The EO extract of *C. hystrix* leaves has been revealed to have notable bioactivities such as antioxidant, antibacterial, antimicrobial, antileukemic, and antitussive properties (Dilla Dertyasasa and Anindito Sri Tunjung, 2017; Md Othman et al., 2016; Norkaew et al., 2013). These features make *C. hystrix* leaves promising sources that can satisfy the increasing demands on citrus-based EO in numerous applications, particularly in food flavoring and fragrance formulation, cosmetic, pharmaceutical, and household products.

EOs are generally extracted by hydrodistillation (HD) and steam distillation (SD) methods due to their practicability and being economically viable. However, HD is a time-consuming process that always leads to multiple unfavorable consequences, including low production yield. The amount of EO in plants only contains about 0.01% to 10% of the total mass, depending on the plant parts (Giacometti et al., 2018). Due to this small proportion, the extraction process is a crucial aspect influencing the quantity and quality of the EOs. Thus, alternatives in EO extraction are continually upgraded to improve extraction efficiency. In HD, the distillation mechanism enabled the use of water as the extraction medium for nonpolar EO compounds. This has become a better alternative to organic solvent extraction and thus, fulfills the criterion of the green extraction approach. Besides, the use of water is undeniably favorable for EO extraction in order to ensure the safety aspect of the product that is vital in food, nutraceutical, and pharmaceutical manufacturing.

However, the solubility of water is limited by its high polarity characteristic, which restricts the solubilization of nonpolar EO compounds. Due to this factor, innovations in the extraction protocol involving water as the extraction medium are worth to be explored. Hence, the applicability of emerging green solvents such as deep eutectic mixtures and the use of water at the subcritical phase for EO extraction has been the subject of interest in this study. The efficiency of EO extraction could be enhanced by the assistance of the natural deep eutectic solvent (NADES), a harmless supramolecule solvent made of hydrogen bond-donor (HBD) and hydrogen bond-acceptor (HBA) (Vilková et al., 2020). Meanwhile, the limitation of highly polar water during non-polar EO extraction can be overcome by pressurizing water enough to maintain its liquid state while ensuring a high temperature above its atmospheric boiling point (>100 °C) and below its critical point (<374 °C) (Plaza and Turner, 2015).

1.2 Problem Statement

Increasing awareness among consumers of the therapeutic properties of EOs triggers a growth trend in the current EO market with citrus-based EO being the leading segment. Most of the citrus-based EOs that dominate the global market are mainly obtained from the peels of citrus fruits (González-Mas et al., 2019; Mustafa, 2015) which predominantly consist of limonene, a hydrocarbon monoterpene fraction. The high content of this fraction is usually undesirable, requiring a subsequent 'deterpenation' process to concentrate the oxygenated fractions to improve the oil quality and its storage stability (Luque De Castro et al., 1999; Mustafa, 2015). On the contrary, *C. hystrix* leaves EO has primarily consisted of citronellal, an oxygenated monoterpene, which is a desirable fraction of EO (Phanthong et al., 2013; Wongpornchai, 2012). Oxygenated monoterpenes are always preferable due to their superior flavor, and highly odoriferous characteristics (Ferhat et al., 2007; Liu et al., 2018) compared to hydrocarbon monoterpenes, which are prone to deterioration and the possibility of producing undesirable compounds that can affect the flavor and aroma of the oils (Gonçalves et al., 2018; Luque De Castro et al., 1999). Therefore, a higher proportion of oxygenated monoterpene in the *C. hystrix* leaves EO would be advantageous against the conventional citrus oils.

The isolation of EO is implemented conventionally by HD and SD. However, this method suffers from several drawbacks, such as being time-consuming, which leads to high energy consumption, uneven heat distribution, and low production yield (Solanki et al., 2018). A lengthy operation would demand a high energy consumption for the heating and cooling of water at elevated temperatures. It has been found that the industrial extraction process by distillation uses about 50% of the energy of the whole industrial process, which could have a significant environmental impact (Chemat et al., 2012). Besides, prolonged contact between analytes and heated water can cause degradation and alteration of the compounds, affecting the quantity and quality of the EOs (Asbahani et al., 2015; Cook and Lanaras, 2015). Worse still, the yield of EO produced is frequently low and always requires a massive amount of plant materials to produce a reasonable volume of EO (Chemat et al., 2012; Liu et al., 2018). According to the literature, the average yield of C. *hystrix* leaves EO extracted using HD were lesser than 1% (Kasuan et al., 2009; Yahya et al., 2018). Despite the limitations, the use of water as a green extraction medium in the conventional HD method is regarded as highly advantageous

for the extraction of EO compounds. Therefore, the innovations in the extraction procedure employing inherently safer extraction mediums such as water, with potency to improve the EO extraction yield are indeed desirable.

NADES with its unique physicochemical properties could potentially use as the co-solvent to water in HD, to aid the release of EO compounds, by enhancing the disruption of the plant's cellular matrixes. According to Flamini et al.(2015) and Solanki et al. (2019), the ionic-based solvent can dissolve the lignocellulosic barrier in plant cellular matrices, hence enhancing the release of more EO compounds. On another note, water under a subcritical phase has tunable physicochemical properties that can enhance its solubilization capacity on less polar compounds (Plaza and Marina, 2019; Teo et al., 2010). The efficacy of subcritical water extraction (SWE) in EO extraction has been proven in several studies (Khajenoori et al., 2015, 2013; Samadi et al., 2020, 2019). Plaza and Marina (2019) have also claimed that subcritical condition allows modification of the water's dielectric constant and polarity, facilitating a better extraction of compounds by improving the mass transfer rate. Thereby, NADES-assisted HD and SWE could offer an alternative method to conventional HD, which can still exploit the advantages of green solvent but with an improved extraction efficiency.

The application of NADES-assisted HD and SWE approaches in the extraction of *C. hystrix* leaves or another citrus-based EO has not been reported in the literature to date. Thus, the effectiveness and capacity of these procedures as an alternative in enhancing the yield of *C. hystrix* leaves EO was uncertain since the knowledge of the influence of extraction factors, the optimal operational conditions, as well as the kinetic behavior, were still indeterminate. The application of NADES in HD procedures has never been reported elsewhere, thereby the industrial application of this innovation would never be achieved without the preliminary experimental data. However, in terms of an economic perspective, the production cost of NADES has been predicted to be only 20% of the ionic liquid (Xu et al., 2016). Hence, this could be the added value to the NADES-HD as it can be considered an economical approach to EO extraction. Besides, according to Reyes-Jurado et al.(2014), the chemical profile of EO extract is significantly affected by the extraction method, hence the investigation of the chemical profiles of *C.hystrix* leaves EOs yielded from NADES-HD and SWE is crucial as it possibly exhibits different bioactivities that might influence the quality of the EO. In fact, the implications of both extraction procedures in terms of quantity and quality, relative to the conventional practice were also unknown. Thereby, this study was initiated to fill these voids as both of the innovations are perceived as among the potential alternatives to improve the extraction efficiency of *C. hystrix* leaves EO in order to meet the growing demand for end-use product manufacturing.

1.3 Objectives of Study

This study is conducted to investigate the effectiveness, efficacy, and efficiency of an innovative green-solvent-mediated extraction approach through NADES-HD and SWE procedures in order to enhance the quantity and quality of the EO from *C. hystrix* leaves. Thus, the specific aims of the study are;

(i) To investigate the factors influencing the EO yield from *C. hystrix* leaves extracted through NADES-HD and SWE procedures.

(ii) To obtain the optimal extraction conditions and establish the empirical regression models for the extraction of EOs from *C. hystrix* leaves for both NADES-HD and SWE procedures.

(iii) To assess the kinetics, mass transfers and thermodynamics behaviors of *C. hystrix* leaves EO extraction through NADES-HD and SWE procedures.

(iv) To elucidate and compare the physicochemical effects of NADES-HD and SWE procedures on the characteristics of the isolated EOs, and the leaves structures relative to the conventional HD.

1.4 Scope and Limitation of Study

This study involved the application of deep eutectic mixture solution and subcritical water as green solvent alternatives employing NADES-HD and SWE procedures, for the extraction of EO from *C. hystrix* leaves. The effectiveness of the extraction methods was investigated through the screening of the extraction parameters, hence the effects of the parameters on EO yield were evaluated. Both methods were then subjected to optimization in order to analyze the efficacy of the procedure to produce the desired outcome. Thus, their kinetic and thermodynamic behaviors were investigated accordingly. Finally, the efficiency of both methods was assessed based on the product (EO) attributes as well as the physicochemical effects of the procedures on the raw material (*C. hystrix* leaves). The efficiency of the NADES-HD and SWE were also evaluated and compared quantitative and qualitatively relative to the conventional HD. Hence, the evaluation of HD procedures only covers the characterization part for comparison purposes.

1.5 Significance of Study

C. hystrix leaves could be one of the potential sources that ensure a continuous supply to satisfy the market demand. Not just to sustain the supply, the use of *C. hystrix* leaves also could provide variability in citrus EO products that offer different organoleptic properties and bioactivities than the current-commercialized citrus oil. This study essentially proposed another alternative method for EO extraction using *C. hystrix* leaves as the source. The proposed methods suggest another approach in extraction protocol to improve the EO yield by green solvent-mediated extraction. Hence, the effectiveness of the extraction processes is evaluated. The effects of operational conditions, optimization, kinetic modeling, and characterization process were performed and thoroughly studied. In short, this research might lead to an advancement of knowledge in future studies to improve the low EO yield issue.

REFERENCES

AOAC. (1990). *Official methods of analysis of AOAC international.* (15th ed.). Arlington VA; Association of Official Analytical Chemists.

AOAC. (1995). *Official methods of analysis of AOAC international.* (16th ed.). Washington DC; Association of Official Analytical Chemists.

Abbasi, N.M., Farooq, M.Q., Anderson, J.L., 2021a. Modulating solvation interactions of deep eutectic solvents formed by ammonium salts and carboxylic acids through varying the molar ratio of hydrogen bond donor and acceptor. J. Chromatogr. A 1643, 462011. https://doi.org/10.1016/j.chroma.2021.462011.

Abbasi, N.M., Farooq, M.Q., Anderson, J.L., 2021b. Modulating solvation interactions of deep eutectic solvents formed by ammonium salts and carboxylic acids through varying the molar ratio of hydrogen bond donor and acceptor. J. Chromatogr. A 1643, 462011. https://doi.org/10.1016/j.chroma.2021.462011.

Abbott, A.P., Harris, R.C., Ryder, K.S., D'Agostino, C., Gladden, L.F., Mantle, M.D., 2011. Glycerol eutectics as sustainable solvent systems. Green Chem. https://doi.org/10.1039/c0gc00395f.

Abdelmoez, W., Abdelfatah, R., 2017. Therapeutic Compounds From Plants Using Subcritical Water Technology, in: Water Extraction of Bioactive Compounds: From Plants to Drug Development. https://doi.org/10.1016/B978-0-12-809380-1.00002-4.

Abdullah, G.H., Kadhom, M.A., 2016. Studying of two choline chloride's deep eutectic solvents in their aqueous mixtures. Int. J. Eng. Res. Dev.

Abed, K.M., M. Kurji, B., A. Rashid, S., A. Abdulmajeed, B., 2019. Kinetics and Thermodynamics of Peppermint Oil Extraction from Peppermint Leaves. Iraqi J. Chem. Pet. Eng. 20, 1–6. https://doi.org/10.31699/ijcpe.2019.4.1.

Abirami, A., Nagarani, G., Siddhuraju, P., 2014. The medicinal and nutritional role of underutilized citrus fruit-*Citrus hystrix* (Kaffir lime): A review. Drug Invent. Today.

Agcam, E., Akyıldız, A., Balasubramaniam, V.M., 2017. Optimization of anthocyanins extraction from black carrot pomace with thermosonication. Food Chem. https://doi.org/10.1016/j.foodchem.2017.05.098.

Agouillal, F., M. Taher, Z., Moghrani, H., Nasrallah, N., El Enshasy, H., 2017. A Review of Genetic Taxonomy, Biomolecules Chemistry and Bioactivities of Citrus hystrix DC. Biosci. Biotechnol. Res. Asia 14, 285–305. https://doi.org/10.13005/bbra/2446.

Ait Amer Meziane, I., Maizi, N., Abatzoglou, N., Benyoussef, E.H., 2020. Modelling and optimization of energy consumption in essential oil extraction processes. Food Bioprod. Process. 119, 373–389. https://doi.org/10.1016/j.fbp.2019.11.018.

Alonso, D.A., Baeza, A., Chinchilla, R., Guillena, G., Pastor, I.M., Ramón, D.J., 2016. Deep Eutectic Solvents: The Organic Reaction Medium of the Century. European J. Org. Chem. 2016, 612–632. https://doi.org/10.1002/ejoc.201501197.

Anderson, M., Whitcomb, P.J., 2016. RSM Simplified, RSM Simplified. CRC Press. https://doi.org/10.4324/9781482293777.

Anderson, M.J., Whitcomb, P.J., 2017. RSM Simplified: Optimizing Processes Using Response Surface Methods for Design of Experiments, CRC Press.

Asbahani, A. El, Miladi, K., Badri, W., Sala, M., Addi, E.H.A., Casabianca, H., Mousadik, A. El, Hartmann, D., Jilale, A., Renaud, F.N.R., Elaissari, A., 2015. Essential oils: From extraction to encapsulation. Int. J. Pharm. 483, 220–243. https://doi.org/10.1016/j.ijpharm.2014.12.069.

Asghar, A., Raman, A.A.A., Daud, W.M.A.W., 2014. A Comparison of Central Composite Design and Taguchi Method for Optimizing Fenton Process. Sci. World J. 2014. https://doi.org/10.1155/2014/869120.

Ashton, H., 2004. The Royal Horticultural Society New Encyclopedia of Herbs & Their Uses (revised edition)2004152Deni Brown. The Royal Horticultural Society New Encyclopedia of Herbs & Their Uses (revised edition) . London: Dorling Kindersley 2002. 448 pp., ISBN: 1 45053 . Ref. Rev. https://doi.org/10.1108/09504120410528289.

Asl, A.H., Khajenoori, M., 2021. Green Extraction in Separation Technology, Green Extraction in Separation Technology. https://doi.org/10.1201/9781003195771.

Aumeeruddy-Elalfi, Z., Gurib-Fakim, A., Mahomoodally, M.F., 2016. Kinetic studies of tyrosinase inhibitory activity of 19 essential oils extracted from endemic and exotic medicinal plants. South African J. Bot. 103, 89–94. https://doi.org/10.1016/j.sajb.2015.09.010.

Babu, A.K., Kumaresan, G., Raj, V.A.A., Velraj, R., 2018. Review of leaf drying: Mechanism and influencing parameters, drying methods, nutrient preservation, and mathematical models. Renew. Sustain. Energy Rev. 90, 536–556. https://doi.org/10.1016/j.rser.2018.04.002.

Bachir, R.G., Benali, M., 2012. Antibacterial activity of the essential oils from the leaves of *Eucalyptus globulus* against *Escherichia coli* and *Staphylococcus aureus*. Asian Pac. J. Trop. Biomed. https://doi.org/10.1016/S2221-1691(12)60220-2.

Bakkali, F., Averbeck, S., Averbeck, D., Idaomar, M., 2008. Biological effects of essential oils - A review. Food Chem. Toxicol. 46, 446–475. https://doi.org/10.1016/j.fct.2007.09.106.

Baser, K.H.C., Buchbauer, G., 2015. Handbook of Essential Oils: Science, Technology, and Applications, Second Edition. https://doi.org/10.1201/b19393.

Bezerra, M.A., Santelli, R.E., Oliveira, E.P., Villar, L.S., Escaleira, L.A., 2008. Response surface methodology (RSM) as a tool for optimization in analytical chemistry.

Talanta 76, 965–977. https://doi.org/10.1016/j.talanta.2008.05.019.

Bi, W., Tian, M., Row, K.H., 2013. Evaluation of alcohol-based deep eutectic solvent in extraction and determination of flavonoids with response surface methodology optimization. J. Chromatogr. A. https://doi.org/10.1016/j.chroma.2013.02.041.

Biglari, M., Shirini, F., Mahmoodi, N.O., Zabihzadeh, M., Mashhadinezhad, M., 2020. A choline chloride-based deep eutectic solvent promoted three-component synthesis of tetrahydrobenzo[b]pyran and pyrano[2,3-d] pyrimidinone (thione) derivatives. J. Mol. Struct. 1205, 127652. https://doi.org/10.1016/j.molstruc.2019.127652.

Blois, M.S., 1958. Antioxidant determinations by the use of a stable free radical [10]. Nature. https://doi.org/10.1038/1811199a0.

Boutekedjiret, C., Bentahar, F., Belabbes, R., Bessiere, J.M., 2003. Extraction of rosemary essential oil by steam distillation and hydrodistillation. Flavour Fragr. J. https://doi.org/10.1002/ffj.1226.

Brunner, G., 2009. Near critical and supercritical water. Part I. Hydrolytic and hydrothermal processes. J. Supercrit. Fluids. https://doi.org/10.1016/j.supflu.2008.09.002

Buckle, J., 2015. Basic Plant Taxonomy, Basic Essential Oil Chemistry, Extraction, Biosynthesis, and Analysis. Clin. Aromather. 37–72. https://doi.org/10.1016/b978-0-7020-5440-2.00003-6.

Budiarto, R., Poerwanto, R., Santosa, E., Efendi, D., Agusta, A., 2019. Production , Post-Harvest and Marketing of Kaffir Lime (*Citrus hystrix* DC) In Tulungagung , Indonesia. J. Trop. Crop Sci. 6.

Carr, A.G., Mammucari, R., Foster, N.R., 2011. A review of subcritical water as a solvent and its utilisation for the processing of hydrophobic organic compounds. Chem. Eng. J. 172, 1–17. https://doi.org/10.1016/j.cej.2011.06.007.

Cassel, E., Vargas, R.M.F., Martinez, N., Lorenzo, D., Dellacassa, E., 2009. Steam distillation modeling for essential oil extraction process. Ind. Crops Prod. 29, 171–176. https://doi.org/10.1016/j.indcrop.2008.04.017.

Chamoli, S., 2015. ANN and RSM approach for modeling and optimization of designing parameters for a v down perforated baffle roughened rectangular channel. Alexandria Eng. J. 54, 429–446. https://doi.org/10.1016/j.aej.2015.03.018.

Chan, C., Yusoff, R., Ngoh, G., 2014. Modeling and kinetics study of conventional and assisted batch solvent extraction. Chem. Eng. Res. Des. 92, 1169–1186.

Chanioti, S., Tzia, C., 2019. Evaluation of ultrasound assisted and conventional methods for production of olive pomace oil enriched in sterols and squalene. Lwt 99, 209–216. https://doi.org/10.1016/j.lwt.2018.09.068.

Chao, J., Dai, Y., Cheng, H.Y., Lam, W., Cheng, Y.C., Li, K., Peng, W.H., Pao, L.H., Hsieh, M.T., Qin, X.M., Lee, M.S., 2017. Improving the Concentrations of the

Active Components in the Herbal Tea Ingredient, Uraria crinita: The Effect of Post-harvest Oven-drying Processing. Sci. Rep. https://doi.org/10.1038/srep38763.

Charles S. Sell, 2003. A Fragrant Introduction to Terpenoid Chemistry by Charles S. Sell, Royal Society of Chemistry.

Chelladurai, S.J.S., K., M., Ray, A.P., Upadhyaya, M., Narasimharaj, V., S., G., 2020. Optimization of process parameters using response surface methodology: A review. Mater. Today Proc. https://doi.org/10.1016/j.matpr.2020.06.466.

Chemat, F., Vian, M.A., Cravotto, G., 2012. Green extraction of natural products: Concept and principles. Int. J. Mol. Sci. 13, 8615–8627. https://doi.org/10.3390/ijms13078615.

Chen, Z., Bai, X., Lusi, A., Wan, C., 2018. High-Solid Lignocellulose Processing Enabled by Natural Deep Eutectic Solvent for Lignin Extraction and Industrially Relevant Production of Renewable Chemicals. ACS Sustain. Chem. Eng. https://doi.org/10.1021/acssuschemeng.8b02541.

Chenni, M., Abed, D. El, Rakotomanomana, N., Fernandez, X., Chemat, F., 2016. Comparative study of essential oils extracted from egyptian basil leaves (*Ocimum basilicum* L.) Using hydro-Distillation and solvent-Free microwave extraction. Molecules 21. https://doi.org/10.3390/molecules21010113.

Chilev, C., Koleva, V., Simeonov, E., 2014. A new empirical model for calculation the effective diffusion coefficient for solid-liquid extraction from plants. Ind. Eng. Chem. Res. 53, 6288–6296. https://doi.org/10.1021/ie402473r.

Chimnoi, N., Reuk-ngam, N., Chuysinuan, P., Khlaychan, P., Khunnawutmanotham, N., Chokchaichamnankit, D., Thamniyom, W., Klayraung, S., Mahidol, C., Techasakul, S., 2018. Characterization of essential oil from *Ocimum gratissimum* leaves: Antibacterial and mode of action against selected gastroenteritis pathogens. Microb. Pathog. 118, 290–300. https://doi.org/10.1016/j.micpath.2018.03.041.

Ching, L.S., Mohamed, S., 2001. Alpha-tocopherol content in 62 edible tropical plants. J. Agric. Food Chem. https://doi.org/10.1021/jf000891u.

Choi, Y.H., Verpoorte, R., 2019. Green solvents for the extraction of bioactive compounds from natural products using ionic liquids and deep eutectic solvents. Curr. Opin. Food Sci. 26, 87–93. https://doi.org/10.1016/j.cofs.2019.04.003.

Chong, C.H., Figiel, A., Szummy, A., Wojdyło, A., Chua, B.L., Khek, C.H., Yuan, M.C., 2021. Chapter 5 - Herbs drying, in: Aromatic Herbs in Food. https://doi.org/https://doi.org/10.1016/B978-0-12-822716-9.00005-6.

Chowdhury, N., Ghosh, A., Bhattacharjee, I., Laskar, S., Chandra, G., 2010. Determination of the n-alkane profile of epicuticular wax extracted from mature leaves of Cestrum nocturnum (Solanaceae: Solanales). Nat. Prod. Res. 24, 1313–1317. https://doi.org/10.1080/14786410903246868.

Clevenger, J.F., 1928. Apparatus for the Determination of Volatile Oil*. J. Am. Pharm. Assoc. 17, 345–349. https://doi.org/10.1002/jps.3080170407.

Cook, C.M., Lanaras, T., 2015. Essential Oils: Isolation, Production and Uses, 1st ed, Encyclopedia of Food and Health. Elsevier Ltd. https://doi.org/10.1016/B978-0-12-384947-2.00261-0.

Copolovici, L., Niinemets, Ü., 2015. Temperature dependencies of Henry's law constants for different plant sesquiterpenes. Chemosphere 138, 751–757. https://doi.org/10.1016/j.chemosphere.2015.07.075.

Cottis, R.A., 2010. 1.01 Chemical Thermodynamics 1–12.

Cox-Georgian, D., Ramadoss, N., Dona, C., Basu, C., 2019. Therapeutic and medicinal uses of terpenes. Med. Plants From Farm to Pharm. 333–359. https://doi.org/10.1007/978-3-030-31269-5_15.

Crank, J., 1975. The mathematics of diffusion. 2nd Edn. https://doi.org/10.1088/0031-9112/26/11/044.

Craveiro, R., Aroso, I., Flammia, V., Carvalho, T., Viciosa, M.T., Dionísio, M., Barreiros, S., Reis, R.L., Duarte, A.R.C., Paiva, A., 2016. Properties and thermal behavior of natural deep eutectic solvents. J. Mol. Liq. 215, 534–540. https://doi.org/10.1016/j.molliq.2016.01.038.

Cvetanović, A., Švarc-Gajić, J., Gašić, U., Tešić, Ž., Zengin, G., Zeković, Z., Đurović, S., 2017. Isolation of apigenin from subcritical water extracts: Optimization of the process. J. Supercrit. Fluids. https://doi.org/10.1016/j.supflu.2016.10.012.

Cvjetko Bubalo, M., Vidović, S., Radojčić Redovniković, I., Jokić, S., 2018. New perspective in extraction of plant biologically active compounds by green solvents. Food Bioprod. Process. 109, 52–73. https://doi.org/10.1016/j.fbp.2018.03.001.

Czitrom, V., 1999. One-factor-at-a-time versus designed experiments. Am. Stat. 53, 126–131. https://doi.org/10.1080/00031305.1999.10474445.

Dai, Y., Witkamp, G.J., Verpoorte, R., Choi, Y.H., 2015. Tailoring properties of natural deep eutectic solvents with water to facilitate their applications. Food Chem. 187, 14–19. https://doi.org/10.1016/j.foodchem.2015.03.123.

Delgado-Mellado, N., Larriba, M., Navarro, P., Rigual, V., Ayuso, M., García, J., Rodríguez, F., 2018. Thermal stability of choline chloride deep eutectic solvents by TGA/FTIR-ATR analysis. J. Mol. Liq. 260, 37–43. https://doi.org/10.1016/j.molliq.2018.03.076.

Delort, E., Bowen, D., 2014. Exploring Citrus Diversity to Create the Next Generation of Citrus Flavors a. Perfum. Flavorist 39.

Deng, C., Yao, N., Wang, A., Zhang, X., 2005. Determination of essential oil in a traditional Chinese medicine, Fructus amomi by pressurized hot water extraction followed by liquid-phase microextraction and gas chromatography-mass

spectrometry. Anal. Chim. Acta. https://doi.org/10.1016/j.aca.2004.12.044.

Desai, M.A., Parikh, J., De, A.K., 2014. Modelling and optimization studies on extraction of lemongrass oil from *Cymbopogon flexuosus* (Steud.) Wats. Chem. Eng. Res. Des. 92, 793–803. https://doi.org/10.1016/j.cherd.2013.08.011.

Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., Mnif, W., 2016. Essential Oils' Chemical Characterization and Investigation of Some Biological Activities: A Critical Review. Medicines 3, 25. https://doi.org/10.3390/medicines3040025.

Díaz Reinoso, B., González Muñoz, M.J., Domínguez González, H., 2017. Introduction, Water Extraction of Bioactive Compounds: From Plants to Drug Development. https://doi.org/10.1016/B978-0-12-809380-1.00001-2.

Dilla Dertyasasa, E., Anindito Sri Tunjung, W., 2017. Volatile Organic Compounds of Kaffir Lime (*Citrus hystrix* DC.) Leaves Fractions and their Potency as Traditional Medicine. Biosci. Biotechnol. Res. Asia 14, 1235–1250. https://doi.org/10.13005/bbra/2566.

Dima, C., Dima, S., 2015. Essential oils in foods: Extraction, stabilization, and toxicity. Curr. Opin. Food Sci. 5, 29–35. https://doi.org/10.1016/j.cofs.2015.07.003.

Do, D.N., Pham, N.T., Lam, T.D., Bach, L.G., Nguyen, D.C., Tran, Q.T., Nhan, L.T.H., 2019. Kinetic Modeling of Hydrodistillation of Essential Oil Production from Orange (*Citrus sinensis*) Peels on Pilot Scale. Asian J. Chem. 31, 2298–2302. https://doi.org/10.14233/ajchem.2019.22145.

do Nascimento Silveira Dorneles, L., Luís Duarte Goneli, A., Andrea Lima Cardoso, C., Bezerra da Silva, C., Rosemari Hauth, M., Cardoso Oba, G., Schoeninger, V., 2019. Effect of air temperature and velocity on drying kinetics and essential oil composition of *Piper umbellatum* L. leaves. Ind. Crops Prod. 142, 111846. https://doi.org/10.1016/j.indcrop.2019.111846.

Dorman, H.J.D., Figueiredo, A.C., Barroso, J.G., Deans, S.G., 2000. In vitro evaluation of antioxidant activity of essential oils and their components. Flavour Fragr. J. https://doi.org/10.1002/(SICI)1099-1026(200001/02)15:1<12::AID-FFJ858>3.0.CO;2-V.

Duba, K.S., Casazza, A.A., Mohamed, H. Ben, Perego, P., Fiori, L., 2015. Extraction of polyphenols from grape skins and defatted grape seeds using subcritical water: Experiments and modeling. Food Bioprod. Process. 94, 29–38. https://doi.org/10.1016/j.fbp.2015.01.001.

Eikani, M.H., Golmohammad, F., Rowshanzamir, S., 2007. Subcritical water extraction of essential oils from coriander seeds (Coriandrum sativum L.). J. Food Eng. https://doi.org/10.1016/j.jfoodeng.2006.05.015.

El Achkar, T., Fourmentin, S., Greige-Gerges, H., 2019. Deep eutectic solvents: An overview on their interactions with water and biochemical compounds. J. Mol. Liq. 288, 111028. https://doi.org/10.1016/j.molliq.2019.111028.

Elyemni, M., Louaste, B., Nechad, I., Elkamli, T., Bouia, A., Taleb, M., Chaouch, M., Eloutassi, N., 2019. Extraction of Essential Oils of *Rosmarinus officinalis* L. by Two Different Methods: Hydrodistillation and Microwave Assisted Hydrodistillation. Sci. World J. 2019. https://doi.org/10.1155/2019/3659432.

Essien, S.O., Young, B., Baroutian, S., 2020. Recent advances in subcritical water and supercritical carbon dioxide extraction of bioactive compounds from plant materials. Trends Food Sci. Technol. 97, 156–169. https://doi.org/10.1016/j.tifs.2020.01.014

Europe, C. of, Commission, E.P., Healthcare, E.D. for the Q. of M.&, 2010. European Pharmacopoeia, European Pharmacopoeia. Council Of Europe.

Fagbemi, K.O., Aina, D.A., Olajuyigbe, O.O., 2021. Soxhlet Extraction versus Hydrodistillation Using the Clevenger Apparatus: A Comparative Study on the Extraction of a Volatile Compound from Tamarindus indica Seeds. Sci. World J. 2021. https://doi.org/10.1155/2021/5961586.

Fan, R., Xiang, J., Li, N., Jiang, X., Gao, Y., 2016. Impact of extraction parameters on chemical composition and antioxidant activity of bioactive compounds from Chinese licorice (*Glycyrrhiza uralensis Fisch*.) by subcritical water. Sep. Sci. Technol. https://doi.org/10.1080/01496395.2015.1117103.

Fang, C., Thomsen, M.H., Frankær, C.G., Brudecki, G.P., Schmidt, J.E., Alnashef, I.M., 2017. Reviving Pretreatment Effectiveness of Deep Eutectic Solvents on Lignocellulosic Date Palm Residues by Prior Recalcitrance Reduction. Ind. Eng. Chem. Res. https://doi.org/10.1021/acs.iecr.6b04733.

Ferhat, M.A., Meklati, B.Y., Chemat, F., 2007. Comparison of different isolation methods of essential oil from Citrus fruits: Cold pressing, hydrodistillation and microwave "dry" distillation. Flavour Fragr. J. https://doi.org/10.1002/ffj.1829.

Ferreira, R.M., Ribeiro, A.R., Patinha, C., Silva, A.M.S., Cardoso, S.M., Costa, R., 2019. Water Extraction Kinetics of Bioactive Compounds of *Fucus vesiculosus*. Molecules 24, 1–15. https://doi.org/10.3390/molecules24183408.

Filly, A., Fabiano-Tixier, A.S., Louis, C., Fernandez, X., Chemat, F., 2016. Water as a green solvent combined with different techniques for extraction of essential oil from lavender flowers. Comptes Rendus Chim. 19, 707–717. https://doi.org/10.1016/j.crci.2016.01.018.

Flamini, G., Melai, B., Pistelli, L., Chiappe, C., 2015. How to make a green product greener: Use of ionic liquids as additives during essential oil hydrodistillation. RSC Adv. 5, 69894–69898. https://doi.org/10.1039/c5ra12649e.

Florindo, C., Oliveira, F.S., Rebelo, L.P.N., Fernandes, A.M., Marrucho, I.M., 2014. Insights into the synthesis and properties of deep eutectic solvents based on cholinium chloride and carboxylic acids. ACS Sustain. Chem. Eng. https://doi.org/10.1021/sc500439w.

Frey, D.D., Engelhardt, F., Greitzer, E.M., 2003. A role for "one-factor-at-a-time"

experimentation in parameter design. Res. Eng. Des. 14, 65–74. https://doi.org/10.1007/s00163-002-0026-9.

Gajardo-Parra, N.F., Lubben, M.J., Winnert, J.M., Leiva, Á., Brennecke, J.F., Canales, R.I., 2019. Physicochemical properties of choline chloride-based deep eutectic solvents and excess properties of their pseudo-binary mixtures with 1-butanol. J. Chem. Thermodyn. 133, 272–284. https://doi.org/10.1016/j.jct.2019.02.010.

Gallego, R., Bueno, M., Herrero, M., 2019. Sub- and supercritical fluid extraction of bioactive compounds from plants, food-by-products, seaweeds and microalgae – An update. TrAC - Trends Anal. Chem. https://doi.org/10.1016/j.trac.2019.04.030.

Gámiz-Gracia, L., Luque de Castro, M.D., 2000. Continuous subcritical water extraction of medicinal plant essential oil: Comparison with conventional techniques. Talanta 51, 1179–1185. https://doi.org/10.1016/S0039-9140(00)00294-0.

Gao, W., Chen, K., Xiang, Z., Yang, F., Zeng, J., Li, J., Yang, R., Rao, G., Tao, H., 2013. Kinetic study on pyrolysis of tobacco residues from the cigarette industry. Ind. Crops Prod. 44, 152–157. https://doi.org/10.1016/j.indcrop.2012.10.032.

Ghasemzadeh, A., Jaafar, H.Z.E., Karimi, E., Rahmat, A., 2014. Optimization of ultrasound-assisted extraction of flavonoid compounds and their pharmaceutical activity from curry leaf (*Murraya koenigii* L.) using response surface methodology. BMC Complement. Altern. Med. https://doi.org/10.1186/1472-6882-14-318.

Giacometti, J., Bursać Kovačević, D., Putnik, P., Gabrić, D., Bilušić, T., Krešić, G., Stulić, V., Barba, F.J., Chemat, F., Barbosa-Cánovas, G., Režek Jambrak, A., 2018. Extraction of bioactive compounds and essential oils from mediterranean herbs by conventional and green innovative techniques: A review. Food Res. Int. 113, 245–262. https://doi.org/10.1016/j.foodres.2018.06.036.

Golmakani, M.T., Rezaei, K., 2008. Comparison of microwave-assisted hydrodistillation withthe traditional hydrodistillation method in the extractionof essential oils from Thymus vulgaris L. Food Chem. https://doi.org/10.1016/j.foodchem.2007.12.084.

Gonçalves, D., Costa, P., Rodrigues, C.E.C., Rodrigues, A.E., 2018. Effect of citrus sinensis essential oil deterpenation on the aroma profile of the phases obtained by solvent extraction. J. Chem. Thermodyn. 116, 166–175. https://doi.org/10.1016/j.jct.2017.09.011.

González-Mas, M.C., Rambla, J.L., López-Gresa, M.P., Amparo Blázquez, M., Granell, A., 2019. Volatile compounds in citrus essential oils: A comprehensive review. Front. Plant Sci. 10, 1–18. https://doi.org/10.3389/fpls.2019.00012.

Haghighi, A., Khajenoori, M., 2013. Subcritical Water Extraction. Mass Transf. - Adv. Sustain. Energy Environ. Oriented Numer. Model. https://doi.org/10.5772/54993.

Haqqyana, H., Tania, V.F.W., Suyadi, A.M., Kusuma, H.S., Altway, A., Mahfud, M., 2020. Kinetic study in the extraction of essential oil from clove (Syzgium aromaticum) stem using microwave hydrodistillation. Moroccan J. Chem. 8.

Hasheminya, S.M., Dehghannya, J., 2020. Composition, phenolic content, antioxidant and antimicrobial activity of Pistacia atlantica subsp. kurdica hulls' essential oil. Food Biosci. 34, 100510. https://doi.org/10.1016/j.fbio.2019.100510.

Hasmita, I., Adisalamun, Alam, P.N., Satriana, Mahlinda, Dani Supardan, M., 2015. Effect of drying and hydrodistillation time on the amount of ginger essential oil. Int. J. Adv. Sci. Eng. Inf. Technol. 5, 300–303. https://doi.org/10.18517/ijaseit.5.5.567.

Hayyan, M., Mbous, Y.P., Looi, C.Y., Wong, W.F., Hayyan, A., Salleh, Z., Mohd-Ali, O., 2016. Natural deep eutectic solvents: cytotoxic profile. Springerplus. https://doi.org/10.1186/s40064-016-2575-9.

Ho, Y., Harouna-oumarou, H.A., Fauduet, H., Porte, C., 2005. Kinetics and model building of leaching of water-soluble compounds of Tilia sapwood 45, 169–173. https://doi.org/10.1016/j.seppur.2005.03.007.

Islam, M.N., Jo, Y.T., Jung, S.K., Park, J.H., 2013. Thermodynamic and kinetic study for subcritical water extraction of PAHs. J. Ind. Eng. Chem. 19, 129–136. https://doi.org/10.1016/j.jiec.2012.07.014.

Jablonský, M., Škulcová, A., Šima, J., 2019. Use of deep eutectic solvents in polymer chemistry–a review. Molecules 24, 1–33. https://doi.org/10.3390/molecules24213978

Jantan, I., Ahmad, A.S., Ahmad, A.R., Ali, N.A.M., Ayop, N., 1996. Chemical composition of some citrus oils from Malaysia. J. Essent. Oil Res. https://doi.org/10.1080/10412905.1996.9701030.

Jeyaratnam, N., Nour, Abdurahman Hamid, Kanthasamy, R., Nour, Azhari Hamid, Yuvaraj, A.R., Akindoyo, J.O., 2016. Essential oil from Cinnamomum cassia bark through hydrodistillation and advanced microwave assisted hydrodistillation. Ind. Crops Prod. https://doi.org/10.1016/j.indcrop.2016.07.049.

Jiménez-Carmona, M.M., Ubera, J.L., Luque De Castro, M.D., 1999. Comparison of continuous subcritical water extraction and hydrodistillation of marjoram essential oil. J. Chromatogr. A 855, 625–632. https://doi.org/10.1016/S0021-9673(99)00703-7.

Kalhor, P., Ghandi, K., 2019. Deep eutectic solvents for pretreatment, extraction, and catalysis of biomass and food waste. Molecules 24. https://doi.org/10.3390/molecules24224012.

Kalinichev, A.G., Bass, J.D., 1997. Hydrogen bonding in supercritical water. 2. Computer simulations. J. Phys. Chem. A. https://doi.org/10.1021/jp971218j.

Karacabey, E., Bayindirli, L., Artik, N., Mazza, G., 2013. Modeling solid-liquid extraction kinetics of trans-resveratrol and trans-ε-viniferin from grape cane. J. Food Process Eng. https://doi.org/10.1111/j.1745-4530.2011.00660.x.

Kasuan, N., Yunus, M., Rahiman, M.H.F., Aris, S.R.A., Taib, M.N., 2009. Essential oil

composition of Kaffir lime: Comparative analysis between controlled steam distillation and hydrodistillation extraction process. SCOReD2009 - Proc. 2009 IEEE Student Conf. Res. Dev. 479–482. https://doi.org/10.1109/SCORED.2009.5442958.

Khajenoori, M., Asl, A.H., Bidgoli, H.N., 2013. Subcritical water extraction of essential oils from *Matricaria Chamomilla* L. Int. J. Eng. Trans. B Appl. 26, 489–494. https://doi.org/10.5829/idosi.ije.2013.26.05b.04.

Khajenoori, M., Asl, A.H., Eikani, M.H., 2015. Subcritical Water Extraction of Essential Oils from *Trachyspermum ammi* Seeds. J. Essent. Oil-Bearing Plants 18, 1165–1173. https://doi.org/10.1080/0972060X.2013.831565.

Khajenoori, M, Asl, A.H., Hormozi, F., 2009. Proposed Models for Subcritical Water Extraction of Essential Oils. Chinese J. Chem. Eng. 17, 359–365. https://doi.org/10.1016/S1004-9541(08)60217-7.

Khajenoori, M., Asl, A.H., Hormozi, F., Eikani, M.H., Bidgoli, H.N., 2009. Subcritical water extraction of essential oils from *Zataria multiflora Boiss*. J. Food Process Eng. 32, 804–816. https://doi.org/10.1111/j.1745-4530.2008.00245.x.

Khuwijitjaru, P., Adachi, S., Matsuno, R., 2002. Solubility of saturated fatty acids in water at elevated temperatures. Biosci. Biotechnol. Biochem. https://doi.org/10.1271/bbb.66.1723.

Khuwijitjaru, P., Sayputikasikorn, N., Samuhasaneetoo, S., Penroj, P., Siriwongwilaichat, P., Adachi, S., 2012. Subcritical water extraction of flavoring and phenolic compounds from cinnamon bark (*Cinnamomum zeylanicum*). J. Oleo Sci. https://doi.org/10.5650/jos.61.349.

Kim, D., Lim, S., 2020. Separation and Puri fi cation Technology Kinetic study of subcritical water extraction of fl avonoids from citrus unshiu peel. Sep. Purif. Technol. 250, 117259. https://doi.org/10.1016/j.seppur.2020.117259.

Kim, S.H., Park, S., Yu, H., Hyun, J., Joo, H., Yang, Y., Hwan, Y., Jin, K., Kan, E., Hyun, S., 2016. Effect of deep eutectic solvent mixtures on lipase activity and stability. "Journal Mol. Catal. B, Enzym. 128, 65–72. https://doi.org/10.1016/j.molcatb.2016.03.012.

Kim, W.J., Kim, J., Veriansyah, B., Kim, J.D., Lee, Y.W., Oh, S.G., Tjandrawinata, R.R., 2009. Extraction of bioactive components from *Centella asiatica* using subcritical water. J. Supercrit. Fluids. https://doi.org/10.1016/j.supflu.2008.11.007.

Ko, M.J., Nam, H.H., Chung, M.S., 2019. Conversion of 6-gingerol to 6-shogaol in ginger (*Zingiber officinale*) pulp and peel during subcritical water extraction. Food Chem. https://doi.org/10.1016/j.foodchem.2018.07.078.

Kohli, K., Katuwal, S., Biswas, A., Sharma, B.K., 2020. Effective delignification of lignocellulosic biomass by microwave assisted deep eutectic solvents. Bioresour. Technol. https://doi.org/10.1016/j.biortech.2020.122897.

Koroch, A.R., Rodolfo Juliani, H., Zygadlo, J.A., 2007. Bioactivity of essential oils and their components, in: Flavours and Fragrances: Chemistry, Bioprocessing and Sustainability. https://doi.org/10.1007/978-3-540-49339-6_5.

Kotz, S., Read, C.B., Balakrishnan, N., Vidakovic, B., Johnson, N.L., 2004. Encyclopedia of Statistical Sciences, Encyclopedia of Statistical Sciences. https://doi.org/10.1002/0471667196.

Kretzschmar, H.J., Wagner, W., 2019. International steam tables: Properties of water and steam based on the industrial formulation IAPWS-IF97, International Steam Tables: Properties of Water and Steam based on the Industrial Formulation IAPWS-IF97. https://doi.org/10.1007/978-3-662-53219-5.

Kusuma, H.S., Mahfud, M., 2018. Kinetic studies on extraction of essential oil from sandalwood (*Santalum album*) by microwave air-hydrodistillation method. Alexandria Eng. J. https://doi.org/10.1016/j.aej.2017.02.007.

Li, C., Huang, C., Zhao, Y., Zheng, C., Su, H., Zhang, L., Luo, W., Zhao, H., Wang, S., Huang, L.J., 2021. Effect of choline-based deep eutectic solvent pretreatment on the structure of cellulose and lignin in Bagasse. Processes 9, 1–14. https://doi.org/10.3390/pr9020384.

Liang, X., Fu, Y., Chang, J., 2019. Effective separation, recovery and recycling of deep eutectic solvent after biomass fractionation with membrane-based methodology. Sep. Purif. Technol. https://doi.org/10.1016/j.seppur.2018.08.021.

Liu, Z., Deng, B., Li, S., Zou, Z., 2018. Optimization of solvent-free microwave assisted extraction of essential oil from *Cinnamomum camphora* leaves. Ind. Crops Prod. https://doi.org/10.1016/j.indcrop.2018.08.016.

Loh, F.S., Awang, R.M., Omar, D., Rahmani, M., 2011. Insecticidal properties of *Citrus hystrix* DC leaves essential oil against *Spodoptera litura fabricius.* J. Med. Plants Res.

López-Rosales, A.R., Ancona-Canché, K., Chavarria-Hernandez, J.C., Barahona-Pérez, F., Toledano-Thompson, T., Garduño-Solórzano, G., López-Adrian, S., Canto-Canché, B., Polanco-Lugo, E., Valdez-Ojeda, R., 2019. Fatty acids, hydrocarbons and terpenes of nannochloropsis and nannochloris isolates with potential for biofuel production. Energies. https://doi.org/10.3390/en12010130.

Ludwiczuk, A., Skalicka-Woźniak, K., Georgiev, M.I., 2017. Terpenoids, Pharmacognosy: Fundamentals, Applications and Strategy. https://doi.org/10.1016/B978-0-12-802104-0.00011-1.

Luque De Castro, M.D., Jiménez-Carmona, M.M., Fernández-Pérez, V., 1999. Towards more rational techniques for the isolation of valuable essential oils from plants. TrAC - Trends Anal. Chem. 18, 708–716. https://doi.org/10.1016/S0165-9936(99)00177-6.

Ma, C.H., Yang, L., Zu, Y.G., Liu, T.T., 2012. Optimization of conditions of solvent-free microwave extraction and study on antioxidant capacity of essential oil from

Schisandra chinensis (Turcz.) Baill. Food Chem. 134, 2532–2539. https://doi.org/10.1016/j.foodchem.2012.04.080.

Madhumita, M., Guha, P., Nag, A., 2019. Extraction of betel leaves (*Piper betle* L.) essential oil and its bio-actives identification: Process optimization, GC-MS analysis and anti-microbial activity. Ind. Crops Prod. 138, 111578. https://doi.org/10.1016/j.indcrop.2019.111578.

Maimulyanti, A., Prihadi, A.R., 2016. Chemical composition of essential oil and hexane extract and antioxidant activity of various extracts of *Acmella uliginosa* (Sw.) Cass flowers from Indonesia. Agric. Nat. Resour. https://doi.org/10.1016/j.anres.2015.11.002.

Mandal, S.C., Mandal, V., Das, A.K., 2015. Essentials of Botanical Extraction: Principles and Applications, Essentials of Botanical Extraction: Principles and Applications. https://doi.org/10.1016/C2014-0-02889-4.

Manurung, R., Simanjuntak, G.C., Perez, R.N., Syahputra, A., Alhamdi, M.A., Siregar, H., Syahputri Zuhri, R.R., 2019. Production of Choline Chloride-Based Deep Eutectic Solvent with Hydrogen Bond Donor D-Glucose and Ethylene Glycol. IOP Conf. Ser. Mater. Sci. Eng. 505. https://doi.org/10.1088/1757-899X/505/1/012134.

Mbous, Y.P., Hayyan, M., Hayyan, A., Wong, W.F., Hashim, M.A., Looi, C.Y., 2017. Applications of deep eutectic solvents in biotechnology and bioengineering—Promises and challenges. Biotechnol. Adv. 35, 105–134. https://doi.org/10.1016/j.biotechadv.2016.11.006.

Md Othman, S., Hassan, M., Nahar, L., Basar, N., Jamil, S., Sarker, S., 2016. Essential Oils from the Malaysian Citrus (Rutaceae) Medicinal Plants. Medicines 3, 13. https://doi.org/10.3390/medicines3020013.

Mgoma, S.T., Basitere, M., Mshayisa, V.V., 2021. Kinetics and thermodynamics of oil extraction from South African hass avocados using hexane as a solvent. South African J. Chem. Eng. 37, 244–251. https://doi.org/10.1016/j.sajce.2021.06.007.

Milojevi, S.Ž., Radosavljevi, D.B., Pavi, V.P., Veljkovi, V.B., 2013. Modeling the kinetics of essential oil hydrodistillation from plant materials. Hem. Ind. 67, 843–859. https://doi.org/10.2298/HEMIND121026009M.

Moghaddam, M., Mehdizadeh, L., 2017. Chemistry of Essential Oils and Factors Influencing Their Constituents, in: Soft Chemistry and Food Fermentation. Elsevier, pp. 379–419. https://doi.org/10.1016/B978-0-12-811412-4.00013-8.

Morsy, N.F.S., 2017. Chemical Structure, Quality Indices and Bioactivity of Essential Oil Constituents. Act. Ingredients from Aromat. Med. Plants. https://doi.org/10.5772/66231.

Muhammad Hazwan, H., Hasfalina, C.M., Hishamuddin, J., Zurina, Z.A., 2012. Optimization and Kinetics of Essential Oil Extraction from Citronella Grass by Ohmic Heated Hydro Distillation. Int. J. Chem. Eng. Appl. 3.

Munir, M.T., Kheirkhah, H., Baroutian, S., Quek, S.Y., Young, B.R., 2018. Subcritical water extraction of bioactive compounds from waste onion skin. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2018.02.166.

Mustafa, N., 2015. Citrus Essential Oils: Current and Prospective Uses in the Food Industry. Recent Pat. Food. Nutr. Agric. 7, 115–127. https://doi.org/10.2174/2212798407666150831144239.

National Committee for Clinical Laboratory Standards, N., 2015. M02-A12: Performance Standards for Antimicrobial Disk Susceptibility Tests; Approved Standard—Twelfth Edition. Clin. Lab. Stand. Inst.

Natolino, A., Da Porto, C., 2020. Kinetic models for conventional and ultrasound assistant extraction of polyphenols from defatted fresh and distilled grape marc and its main components skins and seeds. Chem. Eng. Res. Des. 156, 1–12. https://doi.org/10.1016/j.cherd.2020.01.009.

Nazzaro, F., Fratianni, F., De Martino, L., Coppola, R., De Feo, V., 2013. Effect of essential oils on pathogenic bacteria. Pharmaceuticals 6, 1451–1474. https://doi.org/10.3390/ph6121451.

Nor, N.M., Mohamed, M.S., Loh, T.C., Foo, H.L., Rahim, R.A., Tan, J.S., Mohamad, R., 2017. Comparative analyses on medium optimization using one-factor-at-a-time, response surface methodology, and artificial neural network for lysine–methionine biosynthesis by Pediococcus pentosaceus RF-1. Biotechnol. Biotechnol. Equip. 31, 935–947. https://doi.org/10.1080/13102818.2017.1335177.

Nor, O.M., 1999. Volatile aroma compounds in *Citrus hystrix* oil. J. Trop. Agric. Fd. Sc.

Norkaew, O., Pitija, K., Pripdeevech, P., Sookwong, P., Wongpornchai, S., 2013. Supercritical fluid extraction and gas chromatographic-mass spectrometric analysis of terpenoids in fresh kaffir lime leaf oil. Chiang Mai J. Sci. 40, 240–247.

Nwabanne, J.T., 2012. Kinetics and Thermodynamics Study of Oil Extraction from Fluted Pumpkin Seed. Int. J. Multidiscip. Sci. Eng. 3, 11–15.

Obi Reddy, K., Shukla, M., Uma Maheswari, C., Varada Rajulu, A., 2012. Mechanical and physical characterization of sodium hydroxide treated Borassus fruit fibers. J. For. Res. 23, 667–674. https://doi.org/10.1007/s11676-012-0308-7.

Oh, Y., Park, S., Jung, D., Oh, K.K., Lee, S.H., 2020. Effect of hydrogen bond donor on the choline chloride-based deep eutectic solvent-mediated extraction of lignin from pine wood. Int. J. Biol. Macromol. 165, 187–197. https://doi.org/10.1016/j.ijbiomac.2020.09.145.

Okajima, I., Sako, T., 2014. Energy conversion of biomass with supercritical and subcritical water using large-scale plants. J. Biosci. Bioeng. 117, 1–9. https://doi.org/10.1016/j.jbiosc.2013.06.010.

Pandey, A., Pandey, S., 2014. Solvatochromic probe behavior within choline chloride-

based deep eutectic solvents: Effect of temperature and water. J. Phys. Chem. B. https://doi.org/10.1021/jp510420h.

Pandey, A., Rai, R., Pal, M., Pandey, S., 2014. How polar are choline chloride-based deep eutectic solvents? Phys. Chem. Chem. Phys. https://doi.org/10.1039/c3cp53456a.

Pandey, A.K., Kumar, P., Singh, P., Tripathi, N.N., Bajpai, V.K., 2017. Essential oils: Sources of antimicrobials and food preservatives. Front. Microbiol. 7. https://doi.org/10.3389/fmicb.2016.02161.

Park, H.E., Tang, B., Row, K.H., 2014. Application of Deep Eutectic Solvents as Additives in Ultrasonic Extraction of Two Phenolic Acids from Herba Artemisiae Scopariae. Anal. Lett. https://doi.org/10.1080/00032719.2013.874016.

Parthasarathy, P., Narayanan, S.K., 2014. Effect of Hydrothermal Carbonization Reaction Parameters on. Environ. Prog. Sustain. Energy 33, 676–680. https://doi.org/10.1002/ep.

Peleg, M., 1988. An Empirical Model for the Description of Moisture Sorption Curves. J. Food Sci. https://doi.org/10.1111/j.1365-2621.1988.tb13565.x

Pena-Pereira, F., Tobiszewski, M., 2017. The Application of Green Solvents in Separation Processes, The Application of Green Solvents in Separation Processes.

Perez, E.E., Carelli, A.A., Crapiste, G.H., 2011. Temperature-dependent diffusion coefficient of oil from different sunflower seeds during extraction with hexane. J. Food Eng. https://doi.org/10.1016/j.jfoodeng.2011.02.025.

Phanthong, P., Lomarat, P., Chomnawang, M.T., Bunyapraphatsara, N., 2013. Antibacterial activity of essential oils and their active components from Thai spices against foodborne pathogens. ScienceAsia 39, 472–476. https://doi.org/10.2306/scienceasia1513-1874.2013.39.472.

Plaza, M., Marina, M.L., 2019. Pressurized hot water extraction of bioactives. TrAC - Trends Anal. Chem. 116, 236–247. https://doi.org/10.1016/j.trac.2019.03.024.

Plaza, M., Turner, C., 2015. Trends in Analytical Chemistry Pressurized hot water extraction of bioactives. Trends Anal. Chem. 71, 39–54. https://doi.org/10.1016/j.trac.2015.02.022.

Poojary, M.M., Passamonti, P., 2015. Extraction of lycopene from tomato processing waste: Kinetics and modelling. Food Chem. 173, 943–950. https://doi.org/10.1016/j.foodchem.2014.10.127.

Poós, T., Varju, E., 2017. Drying characteristics of medicinal plants. Int. Rev. Appl. Sci. Eng. 8, 83–91. https://doi.org/10.1556/1848.2017.8.1.12.

Pornpunyapat, J., Chetpattananondh, P., Tongurai, C., 2011. Mathematical modeling for extraction of essential oil from . by hydrodistillation and quality of agarwood oil. Bangladesh J. Pharmacol. https://doi.org/10.3329/bjp.v6i1.7902.

Prabha, S.P., Karthik, C., Chandrika, S.H., 2019. Phytol – A biosurfactant from the aquatic weed *Hydrilla verticillata*. Biocatal. Agric. Biotechnol. https://doi.org/10.1016/j.bcab.2019.01.026.

Priyanka, Khanam, S., 2018. Influence of operating parameters on supercritical fluid extraction of essential oil from turmeric root. J. Clean. Prod. 188, 816–824. https://doi.org/10.1016/j.jclepro.2018.04.052.

Procentese, A., Johnson, E., Orr, V., Garruto Campanile, A., Wood, J.A., Marzocchella, A., Rehmann, L., 2015. Deep eutectic solvent pretreatment and subsequent saccharification of corncob. Bioresour. Technol. https://doi.org/10.1016/j.biortech.2015.05.053.

Procentese, A., Raganati, F., Olivieri, G., Russo, M.E., Rehmann, L., Marzocchella, A., 2018. Deep Eutectic Solvents pretreatment of agro-industrial food waste. Biotechnol. Biofuels 11, 1–12. https://doi.org/10.1186/s13068-018-1034-y.

Radivojac, A., Bera, O., Micić, D., Đurović, S., Zeković, Z., Blagojević, S., Pavlić, B., 2020. Conventional versus microwave-assisted hydrodistillation of sage herbal dust: Kinetics modeling and physico-chemical properties of essential oil. Food Bioprod. Process. 123. https://doi.org/10.1016/j.fbp.2020.06.015.

Radošević, K., Ćurko, N., Gaurina Srček, V., Cvjetko Bubalo, M., Tomašević, M., Kovačević Ganić, K., Radojčić Redovniković, I., 2016. Natural deep eutectic solvents as beneficial extractants for enhancement of plant extracts bioactivity. LWT - Food Sci. Technol. 73, 45–51. https://doi.org/10.1016/j.lwt.2016.05.037.

Ramanathan, A., Thangarasu, V., 2019. Effect of high-frequency microwave irradiation on *Aegle Marmelos Correa* oil extraction: Kinetic and thermodynamic study. Energy Procedia 158, 1046–1051. https://doi.org/10.1016/j.egypro.2019.01.253.

Ramawat, K.G., Mérillon, J.M., 2013. Natural products: Phytochemistry, botany and metabolism of alkaloids, phenolics and terpenes, Natural Products: Phytochemistry, Botany and Metabolism of Alkaloids, Phenolics and Terpenes. https://doi.org/10.1007/978-3-642-22144-6.

Raut, J.S., Karuppayil, S.M., 2014a. A status review on the medicinal properties of essential oils. Ind. Crops Prod. 62, 250–264. https://doi.org/10.1016/j.indcrop.2014.05.055.

Raut, J.S., Karuppayil, S.M., 2014b. Bioprospecting of plant essential oils for medicinal uses. Environ. Sustain. Dev. 9788132211, 1–198. https://doi.org/10.1007/978-81-322-1166-2.

Ravber, M., Knez, Ž., Škerget, M., 2015. Simultaneous extraction of oil- and water-soluble phase from sunflower seeds with subcritical water. Food Chem. 166, 316–323. https://doi.org/10.1016/j.foodchem.2014.06.025.

Reyes-Jurado, F., Franco-Vega, A., Ramírez-Corona, N., Palou, E., López-Malo, A., 2014. Essential Oils: Antimicrobial Activities, Extraction Methods, and Their Modeling. Food Eng. Rev. 7, 275–297. https://doi.org/10.1007/s12393-014-9099-

2.

Rezazi, S., Hanini, S., Abdelmalek, S., 2017. Kinetic Modeling and Parameters Identification Based on Metaheuristic Optimization Techniques for Extraction Process of Marrubium vulgare L . Essential Oil. J. Agric. Sci. Technol. 19, 307–322.

Riad, N., Bouzidi, N., Zahi, M.R., Touafek, O., Daghbouche, Y., Piovetti, L., El Hattab, M., 2021. Extraction of the volatile oils of dictyopteris membranacea batters 1902 by focused microwave-assisted hydrodistillation and supercritical carbon dioxide: Empirical kinetic modelling approach, apparent solubility and rate constants. Chem. Biochem. Eng. Q. 35. https://doi.org/10.15255/CABEQ.2020.1885.

Ruberto, G., Baratta, M.T., 2000. Antioxidant activity of selected essential oil components in two lipid model systems. Food Chem. https://doi.org/10.1016/S0308-8146(99)00247-2.

Ruesgas-Ramón, M., Figueroa-Espinoza, M.C., Durand, E., 2017. Application of Deep Eutectic Solvents (DES) for Phenolic Compounds Extraction: Overview, Challenges, and Opportunities. J. Agric. Food Chem. https://doi.org/10.1021/acs.jafc.7b01054.

Şahin, S., Şamli, R., 2013. Optimization of olive leaf extract obtained by ultrasound-assisted extraction with response surface methodology. Ultrason. Sonochem. https://doi.org/10.1016/j.ultsonch.2012.07.029.

Sahin, S., Samli, R., Birteks Z Tan, A.S., Barba, F.J., Chemat, F., Cravotto, G., Lorenzo, J.M., 2017. Solvent-free microwave-assisted extraction of polyphenols from olive tree leaves: Antioxidant and antimicrobial properties. Molecules. https://doi.org/10.3390/molecules22071056.

Sakti, A.S., Saputri, F.C., Mun'im, A., 2019. Optimization of choline chloride-glycerol based natural deep eutectic solvent for extraction bioactive substances from *Cinnamomum burmannii* barks and Caesalpinia sappan heartwoods. Heliyon 5, e02915. https://doi.org/10.1016/j.heliyon.2019.e02915.

Samadi, M., Abidin, Z.Z., Yunus, R., Radiah, D., Biak, A., Yoshida, H., Lok, E.H., 2016. Assessing the kinetic model of hydro-distillation and chemical composition of A*quilaria malaccensis* leaves essential oil Chinese Journal of Chemical Engineering Assessing the kinetic model of hydro-distillation and chemical composition of Aquilaria malacc. Chinese J. Chem. Eng. https://doi.org/10.1016/j.cjche.2016.09.006.

Samadi, M., Zainal Abidin, Z., Yoshida, H., Yunus, R., Awang Biak, D.R., 2020. Towards higher oil yield and quality of essential oil extracted from *Aquilaria malaccensis* wood via the subcritical technique. Molecules 25. https://doi.org/10.3390/molecules25173872.

Samadi, M., Zainal Abidin, Z., Yoshida, H., Yunus, R., Awang Biak, D.R., Lee, C.H., Lok, E.H., 2019. Subcritical water extraction of essential oil from *Aquilaria malaccensis* leaves. Sep. Sci. Technol. 0, 1–20.

https://doi.org/10.1080/01496395.2019.1650768.

Santos, S.B. Dos, Martins, M.A., Caneschi, A.L., Aguilar, P.R.M., Coimbra, J.S.D.R., 2015. Kinetics and Thermodynamics of Oil Extraction from *Jatropha curcas* L. Using Ethanol as a Solvent. Int. J. Chem. Eng. 2015. https://doi.org/10.1155/2015/871236.

Saravana, P.S., Cho, Y.N., Woo, H.C., Chun, B.S., 2018. Green and efficient extraction of polysaccharides from brown seaweed by adding deep eutectic solvent in subcritical water hydrolysis. J. Clean. Prod. 198, 1474–1484. https://doi.org/10.1016/j.jclepro.2018.07.151.

Sarfarazi, M., Jafari, S.M., Rajabzadeh, G., Feizi, J., 2019. Development of an environmentally-friendly solvent-free extraction of saffron bioactives using subcritical water. LWT. https://doi.org/10.1016/j.lwt.2019.108428.

Sauid, S.M., Aswandi, F.A., 2018. Extraction methods of essential oil from kaffir lime (*Citrus hystrix*): A review. Malaysian J. Chem. Eng. Technol. 1, 56–64.

Setiyoningrum, F., Lioe, H.N., Apriyantono, A., Abbas, A., 2018. Drying and pulverization processes affect the physico-chemical properties of kaffir lime leaves (*Citrus hystrix* DC). Int. Food Res. J.

Sharifi-Rad, J., Sureda, A., Tenore, G.C., Daglia, M., Sharifi-Rad, Mehdi, Valussi, M., Tundis, R., Sharifi-Rad, Marzieh, Loizzo, M.R., Oluwaseun Ademiluyi, A., Sharifi-Rad, R., Ayatollahi, S.A., Iriti, M., 2017. Biological activities of essential oils: From plant chemoecology to traditional healing systems, Molecules. https://doi.org/10.3390/molecules22010070.

Shinoda, K., 1977. "Iceberg" formation and solubility. J. Phys. Chem. https://doi.org/10.1021/j100528a016.

Shitu, A., Izhar, S., Tahir, T.M., 2015. Sub-critical water as a green solvent for production of valuable materials from agricultural waste biomass: A review of recent work. Glob. J. Environ. Sci. Manag. https://doi.org/10.7508/gjesm.2015.03.008.

Sidebottom, D.L., 2012. Introduction to phase transitions. Fundam. Condens. Matter Cryst. Phys. 267–288. https://doi.org/10.1017/cbo9781139062077.020.

Singh Chouhan, K.B., Tandey, R., Sen, K.K., Mehta, R., Mandal, V., 2019. Critical analysis of microwave hydrodiffusion and gravity as a green tool for extraction of essential oils: Time to replace traditional distillation. Trends Food Sci. Technol. 92, 12–21. https://doi.org/10.1016/j.tifs.2019.08.006.

Smith, E.L., Abbott, A.P., Ryder, K.S., 2014. Deep Eutectic Solvents (DESs) and Their Applications. Chem. Rev. 114, 11060–11082. https://doi.org/10.1021/cr300162p.

So, G.C., Macdonald, D.G., 1986. Kinetics of oil extraction from canola (rapeseed). Can. J. Chem. Eng. https://doi.org/10.1002/cjce.5450640112.

Solanki, K.P., Desai, M.A., Parikh, J.K., 2019. Improved hydrodistillation process using amphiphilic compounds for extraction of essential oil from java citronella grass. Chem. Pap. 74, 145–156. https://doi.org/10.1007/s11696-019-00861-3.

Solanki, K.P., Desai, M.A., Parikh, J.K., 2018. Sono hydrodistillation for isolation of citronella oil: A symbiotic effect of sonication and hydrodistillation towards energy efficiency and environment friendliness. Ultrason. Sonochem. 49, 145–153. https://doi.org/10.1016/j.ultsonch.2018.07.038.

Sonobe, T., Worasuwannarak, N., 2008. Kinetic analyses of biomass pyrolysis using the distributed activation energy model. Fuel. https://doi.org/10.1016/j.fuel.2007.05.004.

Soto-Armenta, L.C., Sacramento-Rivero, J.C., Acereto-Escoffié, P.O., Peraza-González, E.E., Reyes-Sosa, C.F., Rocha-Uribe, J.A., 2017. Extraction Yield of Essential Oil from *Lippia graveolens* Leaves by Steam Distillation at Laboratory and Pilot Scales. J. Essent. Oil-Bearing Plants. https://doi.org/10.1080/0972060X.2017.1331756.

Soto Ayala, R., Luque de Castro, M.D., 2001. Continuous subcritical water extraction as a useful tool for isolation of edible essential oils. Food Chem. https://doi.org/10.1016/S0308-8146(01)00212-6.

Souza, E.L., Stamford, T.L.M., Lima, E.O., Trajano, V.N., 2007. Effectiveness of Origanum vulgare L. essential oil to inhibit the growth of food spoiling yeasts. Food Control. https://doi.org/10.1016/j.foodcont.2005.11.008.

Sreepian, A., Sreepian, P.M., Chanthong, C., Mingkhwancheep, T., Prathit, P., 2019. Antibacterial activity of essential oil extracted from *Citrus hystrix* (Kaffir lime) peels: An in vitro study. Trop. Biomed. 36, 531–541.

Srifuengfung, S., Bunyapraphatsara, N., Satitpatipan, V., Tribuddharat, C., Junyaprasert, V.B., Tungrugsasut, W., Srisukh, V., 2019. Antibacterial oral sprays from Kaffir lime (*Citrus hystrix* DC.) fruit peel oil and leaf oil and their activities against respiratory tract pathogens. J. Tradit. Complement. Med. https://doi.org/10.1016/j.jtcme.2019.09.003.

Srisukh, V., Tribuddharat, C., Nukoolkarn, V., Bunyapraphatsara, N., Chokephaibulkit, K., Phoomniyom, S., Chuanphung, S., Srifuengfung, S., 2012. Antibacterial activity of essential oils from *Citrus hystrix* (makrut lime) against respiratory tract pathogens. ScienceAsia 38, 212–217. https://doi.org/10.2306/scienceasia1513-1874.2012.38.212.

Stamenković, O.S., Kostić, M.D., Tasić, M.B., Djalović, I.G., Mitrović, P.M., Biberdžić, M.O., Veljković, V.B., 2020. Kinetic, thermodynamic and optimization study of the corn germ oil extraction process. Food Bioprod. Process. 120, 91–103. https://doi.org/10.1016/j.fbp.2019.12.013.

Stefanovic, R., Ludwig, M., Webber, G.B., Atkin, R., Page, A.J., 2017. Nanostructure, hydrogen bonding and rheology in choline chloride deep eutectic solvents as a function of the hydrogen bond donor. Phys. Chem. Chem. Phys. 19, 3297–3306.

https://doi.org/10.1039/c6cp07932f.

Stratakos, A.C., Koidis, A., 2016. Methods for extracting essential oils, Essential Oils in Food Preservation, Flavor and Safety. Elsevier Inc. https://doi.org/10.1016/B978-0-12-416641-7.00004-3.

Takahashi, Y., Inaba, N., Kuwahara, S., Kuki, W., 2003. Antioxidative effect of citrus essential oil components on human low-density lipoprotein I. Biosci. Biotechnol. Biochem. https://doi.org/10.1271/bbb.67.195.

Talebi, A.F., Mohtashami, S.K., Tabatabaei, M., Tohidfar, M., Bagheri, A., Zeinalabedini, M., Hadavand Mirzaei, H., Mirzajanzadeh, M., Malekzadeh Shafaroudi, S., Bakhtiari, S., 2013. Fatty acids profiling: A selective criterion for screening microalgae strains for biodiesel production. Algal Res. https://doi.org/10.1016/j.algal.2013.04.003.

Tang, B., Bi, W., Zhang, H., Row, K.H., 2014. Deep eutectic solvent-based HS-SME coupled with GC for the analysis of bioactive terpenoids in *Chamaecyparis obtusa* leaves. Chromatographia 77, 373–377. https://doi.org/10.1007/s10337-013-2607-3.

Tao, Y., Zhang, Z., Sun, D.W., 2014. Kinetic modeling of ultrasound-assisted extraction of phenolic compounds from grape marc: Influence of acoustic energy density and temperature. Ultrason. Sonochem. 21, 1461–1469. https://doi.org/10.1016/j.ultsonch.2014.01.029.

Tarley, C.R.T., Silveira, G., dos Santos, W.N.L., Matos, G.D., da Silva, E.G.P., Bezerra, M.A., Miró, M., Ferreira, S.L.C., 2009. Chemometric tools in electroanalytical chemistry: Methods for optimization based on factorial design and response surface methodology. Microchem. J. 92, 58–67. https://doi.org/10.1016/j.microc.2009.02.002.

Teo, C.C., Tan, S.N., Yong, J.W.H., Hew, C.S., Ong, E.S., 2010. Pressurized hot water extraction (PHWE). J. Chromatogr. A 1217, 2484–2494. https://doi.org/10.1016/j.chroma.2009.12.050.

Thavara, U., Tawatsin, A., Bhakdeenuan, P., Wongsnkongman, P., Boonruad, T., Bansiddhi, J., Chavalittumrong, P., Komalamisra, N., Siriyasatien, P., Mulla, M.S., 2007. Repellent activity of essential oils against cockroaches (Dictyoptera: Blattidae, Blattellidae, and Blaberidae) in Thailand. Southeast Asian J. Trop. Med. Public Health 38, 663–673.

Tim, T.K., 2012. Edible medicinal and non-medicinal plants: Volume 4, Fruits. Edible Med. Non-Medicinal Plants Vol. 4, Fruits 4, 1–1022. https://doi.org/10.1007/978-94-007-4053-2.

Tisserand, R., Young, R., 2014. Essential oil composition, 2nd ed, Essential Oil Safety. © 2014 Robert Tisserand and Rodney Young. https://doi.org/10.1016/b978-0-443-06241-4.00002-3.

Tisserand, R., Young, R., 2013. Essential Oil Safety: A Guide for Health Care

Professionals: Second Edition, Essential Oil Safety: A Guide for Health Care Professionals: Second Edition. https://doi.org/10.1016/C2009-0-52351-3.

Tongnuanchan, P., Benjakul, S., 2014. Essential oils: extraction, bioactivities, and their uses for food preservation. J. Food Sci. 79, R1231-49. https://doi.org/10.1111/1750-3841.12492.

Utami, R., Kawiji, Khasanah, L.U., Nasution, M.I.A., 2017. Preservative effects of kaffir lime (*Citrus hystrix* DC) leaves oleoresin incorporation on cassava starch-based edible coatings for refrigerated fresh beef. Int. Food Res. J. 24, 1464–1472.

Várhegyi, G., Chen, H., Godoy, S., 2009. Thermal decomposition of wheat, oat, barley, and *brassica carinata straws.* a kinetic study. Energy and Fuels. https://doi.org/10.1021/ef800868k.

Vera Candioti, L., De Zan, M.M., Cámara, M.S., Goicoechea, H.C., 2014. Experimental design and multiple response optimization. Using the desirability function in analytical methods development. Talanta 124, 123–138. https://doi.org/10.1016/j.talanta.2014.01.034.

Vetal, M.D., Lade, V.G., Rathod, V.K., 2013. Extraction of ursolic acid from *Ocimum sanctum* by ultrasound: Process intensification and kinetic studies. Chem. Eng. Process. Process Intensif. 69, 24–30. https://doi.org/10.1016/j.cep.2013.01.011.

Vetal, M.D., Lade, V.G., Rathod, V.K., 2012. Extraction of ursolic acid from *Ocimum sanctum* leaves: Kinetics and modeling. Food Bioprod. Process. 90, 793–798. https://doi.org/10.1016/j.fbp.2012.07.003.

Vilková, M., Płotka-Wasylka, J., Andruch, V., 2020. The role of water in deep eutectic solvent-base extraction. J. Mol. Liq. 304. https://doi.org/10.1016/j.molliq.2020.112747.

Vining, G., 2011. Technical advice: Residual plots to check assumptions. Qual. Eng. https://doi.org/10.1080/08982112.2011.535696.

Vladić, J., Canli, O., Pavlić, B., Zeković, Z., Vidović, S., Kaplan, M., 2017. Optimization of *Satureja montana* subcritical water extraction process and chemical characterization of volatile fraction of extracts. J. Supercrit. Fluids 120, 86–94. https://doi.org/10.1016/j.supflu.2016.10.016.

Vogt, W., 2011. Dictionary of Statistics & Methodology, Dictionary of Statistics & Methodology. https://doi.org/10.4135/9781412983907.

Wagner, W., Cooper, J.R., Dittmann, A., Kijima, J., Kretzschmar, H.J., Kruse, A., Mareš, R., Oguchi, K., Sato, H., Stöcker, I., Šifner, O., Takaishi, Y., Tanishita, I., Trübenbach, J., Willkommen, T., 2000. The IAPWS industrial formulation 1997 for the thermodynamic properties of water and steam. J. Eng. Gas Turbines Power. https://doi.org/10.1115/1.483186.

Waikedre, J., Dugay, A., Barrachina, I., Herrenknecht, C., Cabalion, P., Fournet, A., 2010. Chemical composition and antimicrobial activity of the essential oils from

New *Caledonian Citrus macroptera* and *Citrus hystrix*. Chem. Biodivers. https://doi.org/10.1002/cbdv.200900196.

Wesołowski, M., Konieczyński, P., 2003. Thermal decomposition and elemental composition of medicinal plant materials - Leaves and flowers: Principal component analysis of the results. Thermochim. Acta 397, 171–180. https://doi.org/10.1016/S0040-6031(02)00319-2.

Wongpornchai, S., 2012. Kaffir lime leaf, in: Handbook of Herbs and Spices: Second Edition. https://doi.org/10.1533/9780857095688.319.

Wongsariya, K., Phanthong, P., Bunyapraphatsara, N., Srisukh, V., Chomnawang, M.T., 2014. Synergistic interaction and mode of action of Citrus hystrix essential oil against bacteria causing periodontal diseases. Pharm. Biol. 52, 273–280. https://doi.org/10.3109/13880209.2013.833948.

Xu, G.C., Ding, J.C., Han, R.Z., Dong, J.J., Ni, Y., 2016. Enhancing cellulose accessibility of corn stover by deep eutectic solvent pretreatment for butanol fermentation. Bioresour. Technol. https://doi.org/10.1016/j.biortech.2015.11.002.

Xu, H., Kong, Y., Peng, J., Song, X., Che, X., Liu, S., Tian, W., 2020a. Multivariate analysis of the process of deep eutectic solvent pretreatment of lignocellulosic biomass. Ind. Crops Prod. 150, 112363. https://doi.org/10.1016/j.indcrop.2020.112363.

Xu, H., Kong, Y., Peng, J., Song, X., Liu, Y., Su, Z., Li, B., Gao, C., Tian, W., 2021. Comprehensive analysis of important parameters of choline chloride-based deep eutectic solvent pretreatment of lignocellulosic biomass. Bioresour. Technol. 319, 124209. https://doi.org/10.1016/j.biortech.2020.124209.

Xu, H., Peng, J., Kong, Y., Liu, Y., Su, Z., Li, B., Song, X., Liu, S., Tian, W., 2020b. Key process parameters for deep eutectic solvents pretreatment of lignocellulosic biomass materials: A review. Bioresour. Technol. 310, 123416. https://doi.org/10.1016/j.biortech.2020.123416.

Yadolah, D., 2008. The Concise Encyclopedia of Statistics, The Concise Encyclopedia of Statistics. https://doi.org/10.1007/978-0-387-32833-1.

Yahya, A., Amadi, I., Hashib, S.A., Mustapha, F.A., 2018. Influence sample sizing of C*itrus hystrix* essential oil from hydrodistillation extraction. IOP Conf. Ser. Mater. Sci. Eng. 334. https://doi.org/10.1088/1757-899X/334/1/012065.

Yang, H., Yan, R., Chen, H., Lee, D.H., Zheng, C., 2007. Characteristics of hemicellulose, cellulose and lignin pyrolysis. Fuel. https://doi.org/10.1016/j.fuel.2006.12.013.

Yanishlieva, N. V., Marinova, E., Pokorný, J., 2006. Natural antioxidants from herbs and spices. Eur. J. Lipid Sci. Technol. https://doi.org/10.1002/ejlt.200600127.

Yu, G.W., Cheng, Q., Nie, J., Wang, X.J., Wang, P., Li, Z.G., Lee, M.R., 2018. Microwave Hydrodistillation Based on Deep Eutectic Solvent for Extraction and

Analysis of Essential Oil from Three Amomum Species Using Gas Chromatography–Mass Spectrometry. Chromatographia 81, 657–667. https://doi.org/10.1007/s10337-018-3482-8.

Yu, W., Wang, C., Yi, Y., Wang, H., Zeng, L., Li, M., Yang, Y., Tan, Z., 2020. Comparison of Deep Eutectic Solvents on Pretreatment of Raw Ramie Fibers for Cellulose Nanofibril Production. ACS Appl. Mater. Interfaces. https://doi.org/10.1021/acsomega.0c00506.

Zainal-Abidin, M.H., Hayyan, M., Hayyan, A., Jayakumar, N.S., 2017. New horizons in the extraction of bioactive compounds using deep eutectic solvents: A review. Anal. Chim. Acta 979, 1–23. https://doi.org/10.1016/j.aca.2017.05.012.

Zainan, N.H., Sapardi, M.A.M., Ho, B.C.H., Siajam, S.I., Kamal, S.M.M., Danquah, M.K., Harun, R., 2019. Kinetic and thermodynamic characterization of amino acids generation via subcritical water reaction of microalgae *Nannochloropsis* sp. biomass. Biomass Convers. Biorefinery. https://doi.org/10.1007/s13399-019-00538-7.

Zakaria, S.M., Kamal, S.M.M., 2016. Subcritical Water Extraction of Bioactive Compounds from Plants and Algae: Applications in Pharmaceutical and Food Ingredients. Food Eng. Rev. 8, 23–34. https://doi.org/10.1007/s12393-015-9119-x.

Zhang, H., Lang, J., Lan, P., Yang, H., Lu, J., Wang, Z., 2020. Study on the Dissolution Mechanism of Cellulose by ChCl-Based Deep Eutectic Solvents 1–12.

Zhang, J., Wen, C., Zhang, H., Duan, Y., Ma, H., 2020. Recent advances in the extraction of bioactive compounds with subcritical water: A review. Trends Food Sci. Technol. 95, 183–195. https://doi.org/10.1016/j.tifs.2019.11.018.

Zhang, Q., De Oliveira Vigier, K., Royer, S., Jérôme, F., 2012. Deep eutectic solvents: Syntheses, properties and applications. Chem. Soc. Rev. 41, 7108–7146. https://doi.org/10.1039/c2cs35178a.

Zhao, Y., Wang, P., Zheng, W., Yu, G., Li, Z., She, Y., Lee, M., 2019. Three-stage microwave extraction of cumin (*Cuminum cyminum* L.) Seed essential oil with natural deep eutectic solvents. Ind. Crops Prod. 140, 111660. https://doi.org/10.1016/j.indcrop.2019.111660.