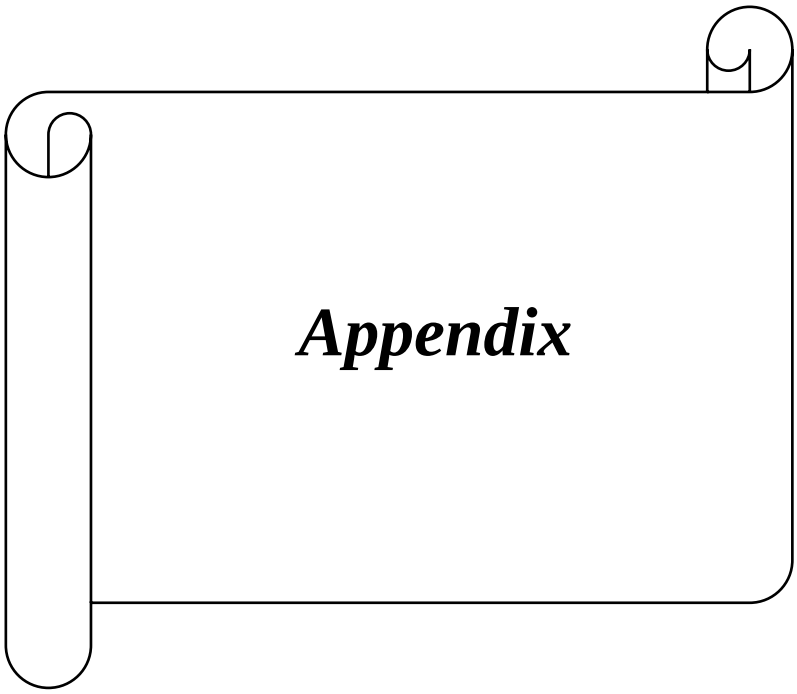
Appendix

List of Publications

1. Jha, A. K., & Sit, N. (2020). Drying characteristics and kinetics of colour change and degradation of phytocomponents and antioxidant activity during convective drying of deseeded *Terminalia chebula* fruit. *Journal of Food Measurement and Characterization*, *14*(4), 2067-2077.
2. Jha, A. K., & Sit, N. (2021). Comparison of response surface methodology (RSM) and artificial neural network (ANN) modelling for supercritical fluid extraction of phytochemicals from *Terminalia chebula* pulp and optimization using RSM coupled with desirability function (DF) and genetic algorithm (GA) and ANN with GA. *Industrial Crops and Products*, *170*, 113769.
3. Jha, A. K., & Sit, N. (2021). Extraction of bioactive compounds from plant materials using combination of various novel methods: A review. *Trends in Food Science & Technology*.
4. Jha, A. K., & Sit, N. (2023). Effect of ultrasound, microwave and enzymatically pre-treated *Terminalia chebula* pulp on extraction of bioactive compounds using supercritical CO_2. *Sustainable Chemistry and Pharmacy*.
5. Jha, A. K., & Sit, N. (2023). Phytochemicals from *Terminalia chebula* and their application: A review, *Food and Humanity*, (Under review).

Participation in National/International Conference

1. Jha, A. K. and Sit, N. Implications of various pre-treatments and their combinations on supercritical fluid extraction of bioactive compounds from *Terminalia chebula* pulp. Sustainable Approaches in Food Engineering and Technology (SAFETy-2022), organized by Tezpur University, Assam and Sultan Qaboos University, Oman, 19-20th October, 2022.
2. Jha, A. K. and Sit, N. Extraction of bioactive compounds from *Terminalia chebula* (haritaki) using novel technologies and development of functional food (yoghurt) using encapsulated powder. Sustainable Approaches in Food Engineering and Technology (SAFETy-2021), organized by Tezpur University, Assam and University of Georgia, USA, 24-25th June, 2021 (Best oral presentation).
3. Jha, A. K. and Sit, N. Supercritical fluid extraction of bioactive compounds from Haritaki (*Terminalia chebula*). 27th Indian Convention of Food Scientists and Technologists

(ICFoST). At Department of FET, Tezpur University, Assam, 30 January -1st February, 2020.

4. Jha, A. K. and Sit, N. A comparative study of bioactive compounds and antioxidant activities of different varieties of *Terminalia chebula* pulp and seed. National Symposium on "Probiotics and Functional Foods on Health Management" (PFFHeM-2019). At Department of FET, Tezpur University, Assam, 4 -5th March, 2019.
5. Jha, A. K. and Sit, N. A study on drying behavior and degradation kinetics of bioactive compounds and antioxidant capacity of *Terminalia chebula* during tray drying at different temperatures. Technological Innovations for Integration of Food and Health: A focus on North-Eastern India (TiiFH-2019), Tezpur University, Assam, 14 -16th February, 2019.
6. Jha, A. K. and Sit, N. Studies on drying behavior and antioxidant activity of Haritaki (*Terminalia Chebula*) at different temperatures. International Conference on Recent Advances in Food Processing Technology (iCRAFPT). At IIFPT, Thanjavur, Tamilnadu, 17 -19th August, 2018.

Journal of Food Measurement and Characterization
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ORIGINAL PAPER

Drying characteristics and kinetics of colour change and degradation of phytocomponents and antioxidant activity during convective drying of deseeded *Terminalia chebula* fruit

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Abstract
Terminalia chebula Retizus fruit contains phytochemicals like phenols including flavonoids which are responsible for hypocholesterolaemic, anti-inflammatory, anti-allergic, antimicrobial, antioxidative properties. In the present study the effect of drying temperatures (40–80 °C) on drying kinetics during convective drying of deseeded *T. chebula* fruit was investigated. The data from the drying experiments were fitted into seven different drying models and the best model was selected by comparing the coefficient of determination (R^2) and root mean square error (RMSE). Degradation kinetics for vitamin C, antioxidant activity (DPPH radical scavenging activity), total phenol content (TPC) and total flavonoid content (TFC) was evaluated at 60, 70 and 80 °C. Change in colour at these temperatures were also observed. From the results it was found that an increase in the temperature increased the drying rate and the drying time was reduced, and the mathematical model for drying which best fitted the experimental data was 'Approximation of diffusion' model. The degradation of the phytochemicals and change in colour followed the first order kinetics. The rate at which vitamin C degraded was found to be higher than the other components for all temperatures. The rate of change in total colour difference (ΔE*) decreased with increasing temperature.

Keywords *Terminalia chebula* fruit · Drying kinetics · Degradation kinetics · Phytochemicals · Colour

Introduction

Terminalia chebula Retizus (Combretaceae) is widely cultivated in South East Asia including India. It is commonly known as 'chebulic myrobalan', and in India it is known as 'Harad' in Hindi and 'Haritaki' in Sanskrit. From ancient times it is believed as the 'King of Medicine' for its extraordinary healing properties and has been listed at the top of the list in 'Ayurvedic Materia Medica' [1]. However, origin of this fruit is the northern light rainfall forests of India, in present-day Uttar Pradesh and West Bengal and is common crop in Tamil Nadu, Karnataka and Southern Maharashtra. Since the ancient era, it is used as a medicine to cure diseases. The flowers appear in April–August and fruiting starts in September while maturity takes place from October to January. The fruit is drupe-like, having length of 2–4.5 cm and breadth of 1.2–2.5 cm with tinge of black or yellowish-brown spot and have five longitudinal ridges. The fruit is starchy, fibrous with an astringent, sour and sweet taste [2].

T. chebula has been reported to have various theraupetic properties which include hypocholesterolaemic, anti-inflammatory, anti-allergic, antimicrobial, antioxidative etc.[3, 4]. These properties are due to presence of phytochemicals in the fruit mainly phenolics including flavonoids [4]. The total phenol content, total flavonoid content and vitamin C contents of *T. chebula* were reported to be 14.03 mg GAE, 12.69 mg QE and 1.12 mg respectively per g fresh weight of the fruit [5]. Therefore, various researchers have shown interest to use *T. chebula* as a phytotherapy agent for its antioxidative properties which can protect against oxidative stress. Since *T. chebula* is seasonal, so drying plays a major role and acts as an alternative method of preservation and increase the shelf life of the fruit [6].

Drying is an unit operation where heat and mass transfer take place simultaneously and is an important preservation method, occurring between the inside the material

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Comparison of response surface methodology (RSM) and artificial neural network (ANN) modelling for supercritical fluid extraction of phytochemicals from *Terminalia chebula* pulp and optimization using RSM coupled with desirability function (DF) and genetic algorithm (GA) and ANN with GA

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ARTICLE INFO

Keywords:
Terminalia chebula
Supercritical fluid extraction
Modelling and optimization
Response surface methodology
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Genetic algorithm

ABSTRACT

In the present study supercritical fluid extraction parameters for extraction of phytochemicals from *Terminalia chebula* (Haritaki) pulp were optimized using different approaches and compared. A central composite rotatable design (CCRD) was employed with four numerical factors viz. temperature, pressure, time and co-solvent flow rate. The responses were total phenol content (TPC), total flavonoid content (TFC) and antioxidant activity (2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity) of the extracts. Two different methods viz. response surface methodology (RSM) and artificial neural network (ANN) were used for modelling from the same set of experiments. Subsequently, optimization was carried by three different approaches viz. RSM coupled with numerical optimization by desirability function (RSM-DF), RSM coupled with genetic algorithm (RSM-GA) and ANN coupled with genetic algorithm (ANN-GA). Statistical analyses indicated that the models derived using both the methods i.e., RSM and ANN can be used to predict the response precisely, but RSM ($R^2 = 0.9987$) method was somewhat found to be superior compared to ANN model ($R^2 = 0.9973$). When comparing the optimization approaches, it was observed that results obtained from all the approaches were close to each other, but RSM-GA and RSM-DF approaches provided higher values of TPC, TFC and DPPH radical activity compared to ANN-GA approach. The values of TPC (mg GAE/mL), TFC (mg QE/mL) and DPPH (%) for RSM-GA were 428.03, 136.58, 92.63 respectively, for RSM-DF were 432.28, 137.36, 92.54 respectively and for ANN-GA were 414.25, 135.55, 91.32 respectively. From the present study it can be concluded that both RSM and ANN can be used for modelling of the processes with good predictability and optimization can be done using different approaches which will depend upon the specific process or the problem.

1. Introduction

In developing nations, access to health care originating from the significant expenses of medications, health services and diagnostics, has become a significant matter of concern. *Terminalia chebula Retz. (T. chebula)* commonly known as haritaki in Sanskrit native to South Asia, is considered as a source of nutrients having medical advantage is found in the tropical territories of the world referred to as *Chebulae Fructus* (Hezi) in China (Prado and Thibaut, 2008). It has traditionally been utilized for its therapeutic properties in various bioactive compounds since ancient times to fix geriatric diseases and to improve memory (Avula et al., 2013). It has been accounted that haritaki organic products are highly rich in phytochemicals. To get a high return of phenolic components from haritaki, it is essential to build up a reliable extraction method. Currently, natural herbal antioxidants from various fruits are gaining attention for their potential helpfulness. The bioactive compounds from *T. chebula* may be obtained by an extraction procedure for potential use in functional foods or nutraceuticals. A few extraction procedures have been utilized for the extraction of phenolic mixes from haritaki, such as, reflux framework blended with water-ethanol and water-propylene glycol, and subcritical water extraction (Rangsriwong et al., 2009). In any case, because of high temperature and long treatment periods, the

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Extraction of bioactive compounds from plant materials using combination of various novel methods: A review

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ARTICLE INFO

Keywords:
Extraction
Bioactive compounds
Novel technologies
Combined methods
Supercritical fluid extraction

ABSTRACT

The first step in the isolation and purification of bioactive compounds from plant material is extraction. Extraction of secondary metabolites such as phenolic acids and flavonoids is difficult due to their insoluble nature. While conventional extraction methods such as Soxhlet, heat reflux, and maceration are successful procedures in the extraction of bioactive compounds and the equipment involved in these methods are distinct from each other. An appropriate extraction technique that balances product quality, process efficiency, production costs, and environmentally acceptable methods should be used for the extraction of bioactive compounds from plant tissues. The application of innovative extraction methods in the food industries has been extensively investigated, due to increased consumer expectations for greener options that do not include hazardous chemicals, as well as industry concerns about sustainable, nontoxic extraction techniques. Innovative technologies, such as high hydrostatic pressure (HHP), ultrasound (US), pulsed electric field (PEF), supercritical fluid (SF), and others, are increasingly replacing the conventional methods. The use of novel and combined novel technologies increases extractability, resulting in yields with higher extraction rates. It also yields lower impurities in the final extract and preserves thermo-sensitive compounds, uses different inorganic solvents, and consumes low energy. The purpose of the present review is to evaluate the efficiency of the different conventional, novel, and combined novel technologies involved in the extraction of bioactive compounds from plant materials.

1. Introduction

Primary and secondary metabolites form the biological system of plants. Carbohydrates, amino acids, and proteins are primary metabolites that are used largely throughout the developing and maturing phases of plant tissues. Secondary metabolites are produced during the developmental cycle to assist plants in surviving and overcoming natural obstacles (Azmir et al., 2013). Bioactive compounds can be found in a variety of plant items and are classified into various classes including terpenoids, alkaloids, nitrogen-containing compounds, organosulfur compounds, and phenolics (Liu et al., 2014; Altemimi et al., 2017). Terpenoids, which include tocotrienol, tocopherols, carotenoids, limonoids, and phytosterols, are well-known antioxidants (Dillard & German, 2000). α-Carotene, β-carotene, β-cryptoxanthin, lutein, and carotenoid are also members of this class. Alkaloids may be classified into groups based on a combination of the following traits: morphine, strychnine, atropine, colchicine, ephedrine, quinine, nicotine, acridine, imidazole, carbazole, indole, isoquinoline, lycopodium, pyrrolidine, pyrrolizidine, quinoline, quinolizidine, and steroids. The abovementioned bioactive compounds have been reported to have certain health benefitting attributes like anti-inflammatory, anti-cancerous, anti-diabetic, improves blood circulation, improves digestion, and so on (Zhang et al., 2016).

Extraction is influenced by solubility in conjunction with other solutes, various compounds in the plant matrix, and the solvent employed to solubilize the active ingredients (Berk, 2018). To increase the extraction rate, the plant tissue should be thoroughly homogenised before being extracted (Sasidharan et al., 2011). Bioactive compounds are derived from various natural sources including plants, microorganism, animals and marine organism (Swamy & Akhtar, 2019). The amount of bioactive natural products in natural sources is always fairly low and present in plant matrix (Patel et al., 2019). All plant components, such as leaves, roots, barks, tubers, woods, gums or oleoresin, exudates, fruits, figs, flowers, rhizomes, berries, twigs, and the whole plant, produces active chemicals in smaller quantities and at variable concentrations. Thus, selection of the right extraction process is crucial to maximize the extract from tissues (Joana Gill-Chavez et al., 2013; Tiwari, 2015). The extraction efficiency is governed by several critical

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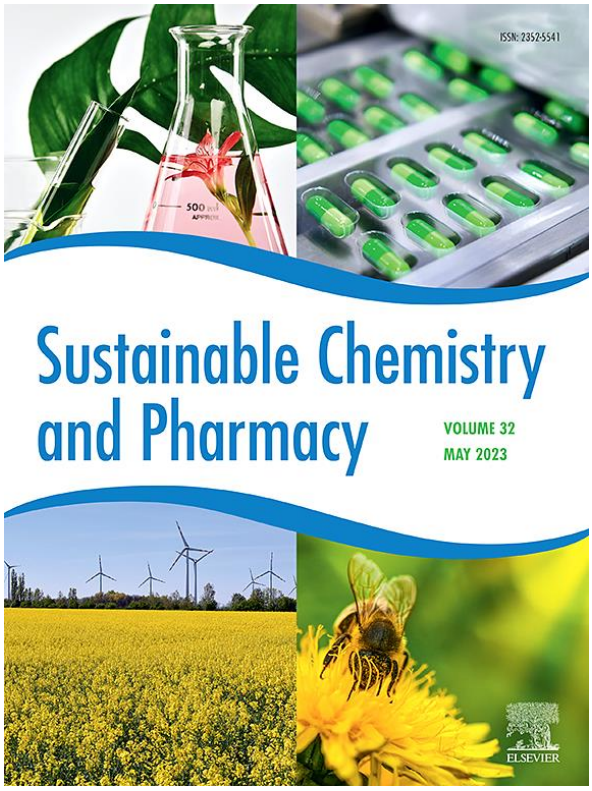

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Effect of ultrasound, microwave, and enzymatically pre-treated Terminalia chebula pulp on extraction of bioactive compounds using supercritical CO2

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Corresponding author	Nandan Sit
First author	Avinash Kumar Jha
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Poster Presentation Certificate

This is to certify that the following **Poster** was presented at the **International Conference on Recent Advances in Food Processing Technology** organised by **Indian Institute of Food Processing Technology (IIFPT)** during **17th – 19th August 2018** at IIFPT, Thanjavur.

Title: Studies on drying behaviour and antioxidant activity of Haritaki at different temperatures

Author(s): **Jha AK**, Sit N

Dr. V.R. Sinija

Dr. K. Suresh Kumar

Dr. C. Anandharamakrishnan
Chairman, iCRAFPT

IIFPT/iCRAFPT/2018/P-043

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on

Technological Innovations for Integration of Food and Health: A Focus on North-Eastern India

(TiiFH-2019)

Certificate

This is to certify **Avinash Kumar Jha** has participated as **Poster Presenter** at TiiFH-2019, organized by the Department of Food Engineering and Technology in Association with AFSTI during 14th-16th February, 2019 at Tezpur University, Tezpur, India.

Title: A study on drying behaviour and Degradation kinetics of bioactive compounds and antioxidant capacity of (*Terminalia chebula*) during tray drying at different temperatures

Author(s): Avinash Kumar Jha, Nandan Sit

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National Symposium on "Probiotics and Functional Foods on Health Management"

PFFHeM2019

CERTIFICATE

This is to certify that ~~Dr./Mr./Ms.~~ Avinash Kumar Jha has participated as ~~Oral Presenter~~/Poster Presenter at the National Symposium (PFFHeM2019), organized by the Department of Food Engineering and Technology during 4th to 5th March, 2019 at Tezpur University, Tezpur, India.

Title: A comparative study of bioactive compounds and antioxidant activities of different varieties of haritaki (Terminalia chebula) pulp and seed

Author(s): Avinash Kumar Jha and Nandan Sit

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27th Indian Convention of Food Scientists and Technologists

"Raising Agro-processing & Integrating Novel technologies for Boosting Organic Wellness" (RAINBOW)

30th January 2020 -1st February 2020 @ Tezpur University, Tezpur, Assam

Poster Presentation Certificate

This is to certify that the following **POSTER** was presented at **27th ICFoST** organized by AFST(I)-HQ and Tezpur Chapter during 30th January 2020 -1st February 2020 at Tezpur University, Tezpur, Assam.

Title : Supercritical fluid extraction of bioactive compounds from Haritaki (Terminalia chebula)

Author (s): **Mr Avinash Kumar Jha**, Nandan Sit, Food Engineering and Technology, Tezpur University, Tezpur, Assam

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on
Sustainable Approaches in Food Engineering and Technology (SAFETy-2021)
24th-25th June, 2021

CERTIFICATE

This is to certify that the following paper has been awarded **FIRST POSITION** in the **Technical Session on Functional, Nutraceutical and Health Foods** at SAFETy-2021 organized by the Department of Food Engineering & Technology, Tezpur University, Assam, India, and Department of Food Science & Technology, University of Georgia, Georgia (US) in association with AFST(I) Tezpur Chapter.

Title: Extraction of bioactive compounds from Terminalia chebula (Haritaki) using Novel technologies and Development of functional food (yoghurt) using encapsulated powder

Authors: Jha, A.K. & Sit, N.

Dr. Amit Baran Das	Dr. Abhinav Mishra	Prof. Nandan Sit	Prof. Manpreet Singh
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19th - 20th october, 2022

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OF PARTICIPATION

This is to certify that Dr./Mr./Ms. AVINASH KUMAR JHA has participated in SAFETy-2022 organized by the Department of Food Engineering & Technology, Tezpur University, Assam, India, and Department of Soils, Water & Agricultural Engineering, Sultan Qaboos University, Oman in Association with AFST(I) Tezpur Chapter.

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