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ORIGINAL ARTICLE

Empirical modeling of drying kinetics and microwave assisted extraction of bioactive compounds from *Adathoda vasica* and *Cymbopogon citratus*

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Abstract To highlight the shortcomings in conventional methods of extraction, this study investigates the efficacy of Microwave Assisted Extraction (MAE) toward bioactive compound recovery from pharmaceutically-significant medicinal plants, *Adathoda vasica* and *Cymbopogon citratus*. Initially, the microwave (MW) drying behavior of the plant leaves was investigated at different sample loadings, MW power and drying time. Kinetics was analyzed through empirical modeling of drying data against 10 conventional thin-layer drying equations that were further improvised through the incorporation of Arrhenius, exponential and linear-type expressions. 81 semi-empirical Midilli equations were derived and subjected to non-linear regression to arrive at the characteristic drying equations. Bioactive compounds recovery from the leaves was examined under various parameters through a comparative approach that studied MAE against Soxhlet extraction. MAE of *A. vasica* reported similar yields although drastic reduction in extraction time (210 s) as against the average time of 10 h in the Soxhlet apparatus. Extract yield for MAE of *C. citratus* was higher than the conventional process with optimal parameters determined to be 20 g sample load, 1:20 sample/solvent ratio, extraction time of 150 s and 300 W output power. Scanning Electron Microscopy and Fourier Transform Infrared Spectroscopy were performed to depict changes in internal leaf morphology.

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Nomenclature

a, a_1, b, b_1, c, g, k, k_1, k_2, n, n_1	empirical coefficients
D_{eff}	effective moisture diffusivity ($m^2\ s^{-1}$)
D_o	pre-exponential factor ($m^2\ s^{-1}$)
E_a	activation energy ($W\ g^{-1}$)
k_o	pre-exponential factor (min^{-1})
L	half the thickness of the sample (m)
m	sample mass (g)
M	number of mathematical models used for empirical modeling
MC_i	moisture content at specific time (g water/g dry solids)
MC_o	moisture content at initial time (g water/g dry solids)
MR	moisture ratio
N	number of model constants
P	microwave output power (W)
R^2	coefficient of determination
E_{RMS}	root mean square error
RSS	residual sum of squares
t	drying time (min)
W_c	weights of the crude extract (g)
W_o	weight of dry powdered sample (g)

Greek letters

α	constant ($min^{-1}\ m^{-2}\ s^{-1}$)
χ^2	chi-square

Subscripts

o	initial
i	specific time
th	theoretical

1. Introduction

Auto-oxidation of food during transportation, storage and processing is the primary mechanism for its physical (taste, color) and nutritional deterioration [12]. There is growing interest in the food science community on bioactive components such as natural antioxidants and their potential to replace synthetic compounds[1] in various food applications. Since time immemorial, we have looked toward plants as a source of inspiration and for harnessing their medicinal properties; indeed, their contributions toward improving human health have been substantial [24]. In this vein, both *Adathoda vasica* and *Cymbopogon citratus* are well-recognized plants in the Indian system of oriental medicine [8,3]. The contemporary remedial applications of *A. vasica* include the treatment of asthma, chronic bronchitis, rheumatic inflammatory swellings, antispasmodics, piles, cold [6,14]. Identified *A. vasica* alkaloids, primarily, vasicine and vasicinone have been acknowledged to be bioactive with their combination producing both in vitro and in vivo bronchodilatory activity commensurate to that of theophylline [2,29]. Likewise, *C. citratus* (lemongrass) has been used in various pharmaceutical applications as spasmolytics, analgesics, antipyretics, and diuretics and in tranquilizers. Essential oil extract from lemongrass leaves has high citral content and is utilized as a raw material in the production of vitamin A, beta carotene, ionone, etc. [20].

In lieu of the shortcomings of conventional methods[2] toward bioactive component recovery from plants, research effort has been directed toward the applicability of newer techniques that utilize enzymes, microwaves, supercritical fluids and ultrasounds for assisting the extraction. In addition to their high safety-low cost aspect these processes also benefit from allowing extraction to occur without affecting the quality of the final product or degrading unsaturated compounds in the extract [4]. Particularly, Microwave Assisted Extraction (MAE) has shown promise with several studies demonstrating its feasibility for the extraction of compounds from medicinal plants [15,5,7]. MAE enhances traditional solvent extraction by subjecting the solvent to rapid heat generation and direct interaction with electromagnetic radiation. The process results in the creation of a high pressure difference that causes the plant cellular structure to break and the solvent to penetrate within its matrix [22].

A comprehensive understanding of both, the drying and extraction steps is necessary to design the extraction process, avoid the denaturation of the product and determine feasible operating parameters. Given the limited availability of this literature for *A. vasica* and *C. citratus*, this study investigates the effect of various process parameters on the leaf extraction yield of bioactive compounds therein. An empirical correlation was developed for the examined drying parameters by improvising upon a selected conventional drying model. A comparative experimental procedure was followed to distinguish conventional Soxhlet extraction and MAE which were performed following the microwave drying of the leaves.

2. Materials and methods

Fresh *A. vasica* and *C. citratus* leaves were sourced from the VIT University campus at Vellore, India (12°55′12.79″N – 79°7′59.9″E; 216 m above sea level). The leaves were washed with distilled water and stored at *ca* 10 °C. Both plant specimens were validated by the Plant Biotechnology Division[3] at VIT University, Vellore, India. Ten replicated measurements were performed to determine the leaf thickness using a micrometer (Leica stage micrometer-MA285, Germany) and initial moisture content by standard vacuum drying method. Leaf thickness was found to be 0.5 mm and 0.75 mm and moisture content was 70.72% and 68.75% (w.b.), for *A. vasica* and *C. citratus* respectively. All solvents and chemicals used in the study were purchased from SD Fine Chemicals, Mumbai, India, and were of analytical grade.

[1] *Inter alia*, synthetic antioxidants such as butylated hydroxyanisole have been banned in Japan and *tert*-butyl hydroquinone is no longer allowed for food applications in the EU and Canada.

[2] Such as hydrodistillation, enfleurage, maceration, pressing and distillation.

[3] http://www.vit.ac.in/academics/schools/sbst