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Evaluation of drying methods with respect to drying kinetics, mineral content and colour characteristics of rosemary leaves

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Abstract

Rosemary leaves (*Rosmarinus officinalis* L., Lamiaceae) were dried by using sun, oven (50 °C) and microwave oven (700 W, 2450 MHz) drying methods. Microwave oven drying shortened the drying time more than 99% when compared to the sun and oven drying methods. K, Ca, Na, Mg and P were the most abundant elements in the rosemary samples. The mineral content of oven dried rosemary leaves was higher than that of the sun and microwave dried samples. The logarithmic and Midilli and Küçük models were shown to give a good fit to the sun and oven drying. The Page, Modified Page and Midilli and Küçük models have shown a better fit to the experimental microwave oven drying data of rosemary leaves. Microwave oven drying revealed optimum colour values. Oven drying resulted in a considerable decrease in the colour quality of the rosemary leaves.

Keywords: Drying kinetics; Sun; Oven; Microwave; Rosemary; Mineral; Colour

1. Introduction

Rosemary (*Rosmarinus officinalis* L., Lamiaceae) is an aromatic, evergreen, shrubby herb indigenous to most European countries bordering on the Mediterranean Sea, which is widely used in pharmaceutical products and folk medicine [1–3]. It bears linear, leathery dark green, needle like leaves and light, sky blue flowers. When dried, the leaves become rolled in appearance and dark green to brownish green in colour. Dried rosemary leaves or one of its extractives are used to season fried chicken, salad croutons, baked products, confections, non-alcoholic beverages, condiments, perfumes, eau de cologne and soaps. Several extracts, essential oils and chemical constituents isolated from this species demonstrated a number of interesting biological activities such as mainly antioxidant activity [4–9].

Medicinal and aromatic plants contain a high level of moisture and micro-organisms. Therefore, immediate drying is the most important operation in post harvest processing to avoid losses of the valuable, but perishable crops [10]. Furthermore, the high temperature and/or intensive solar radiation adversely affects quality, causing vitamin and essential oil losses or colour changes in dried crops [11].

Apart from their rich contents of vitamin C and beta carotene, herbs are an excellent source of mineral constituents whose importance in the human diet is indisputable. Some of them, such as potassium, sodium, phosphorus, calcium, magnesium or iron, are indispensable in sustaining human health. Others, such as copper or zinc, are equally indispensable, but in this case, the interval between acceptable and toxic levels is limited [12,13]. In recent years, there has been a growing interest in mineral concentrations of foods, as the basic source of minerals for humans [14].

In recent years, the drying behaviours of different aromatic plants and culinary herbs have been studied by many

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Nomenclature

a, b, c	empirical constants in drying models	N	positive integer
k, k_0, k_1	empirical constants in drying models	RMSE	root mean square error
MR	moisture ratio (dimensionless)	r^2	coefficient of determination
M	moisture content at any time	SSE	sum square error
M_e	equilibrium moisture content	t	drying time (h)
M_0	initial moisture content	y	empirical constant in drying models

investigator, parsley [15], laurel [16], bay leaves [17], dill [18], mint [19,20], verbena [21], St. John's Wort [22], thyme [23], black tea [24], ginseng [25] and purslane [26]. However, studies on the drying characteristics of rosemary are scarce in the literature, particularly the traditional sun drying properties as well as microwave drying properties of aromatic plants are not adequately investigated.

The aim of the work was to determine the sun, oven and microwave drying characteristics of rosemary and to compare traditional sun drying and conventional oven drying methods to the microwave drying method, which reduces drying time considerably, and to determine the effects of these different drying techniques on some properties of rosemary, such as the mineral contents and colour values.

2. Materials and methods

2.1. Material

Fresh rosemary (*Rosmarinus officinalis* L.) leaves were purchased from a local market in Konya, Turkey. The rosemary leaves were kept in cooled bags while being transporting to the laboratory. The moisture content of the leaves was immediately measured on arrival. The HNO_3 used in the mineral assay was of analytical grade (Merck, Germany). Prior to each of the drying experiments, the thick stems of the herbs were separated.

2.2. Methods

2.2.1. Drying of the mint herbs

Oven drying: Rosemary leaves were distributed uniformly as a thin layer on the trays and dried in an oven at 50 °C for 12 h [23].

Sun drying: Rosemary leaves were distributed uniformly as a thin layer on the trays and dried under direct sunlight at temperatures between 20 and 30 °C for 13 h in August in Konya, Turkey [23].

Microwave oven drying: A programmable domestic microwave oven (Arçelik ARMD 580, Turkey) with maximum output of 700 W and 2450 MHz was used for the drying experiments. Fifty grams of rosemary leaves were spread evenly on a glass microwave oven plate and processed until the leaves were completely dried.

The mass of the sample was measured every 1 hour during oven and sun drying [17,27] and every 15 s during microwave oven drying [15,28] using a digital balance, measuring to an accuracy of 0.001 g [29].

The moisture content of the leaves was measured by drying in an oven at 105 °C for 24 h. The initial moisture content of the leaves was determined as 13.20 kg water/kg dry solids (dry weight basis). The experiments were repeated three times, and mean values were used.

2.2.2. Mathematical modelling of drying curves

For mathematical modelling, the equations in Table 1 were tested to select the best model for describing the drying curve equation of rosemary leaves during drying. The moisture ratio of the rosemary leaves during drying was calculated using the equation; $MR = (M - M_e)/(M_0 - M_e)$ [30].

The regression was performed in the Statistica computer program (Statistica for Windows 5.0). The coefficient of determination (r^2), sum square error (SSE) and root mean square error (RMSE) were calculated in order to evaluate the goodness of fit of the models. The lower the SSE and RMSE values and the higher the r^2 values indicate the high fit of the model [31].

Table 1
Mathematical models applied to the drying curves

Model no.	Equation	Model name	References
1	$MR = \exp(-kt)$	Lewis	[39]
2	$MR = \exp(-kt^y)$	Page	[40]
3	$MR = \exp(-(kt)^y)$	Modified Page	[41]
4	$MR = a\exp(-kt)$	Henderson and Pabis	[42]
5	$MR = a\exp(-kt) + c$	Logarithmic	[43]
6	$MR = a\exp(-k_o t) + b\exp(-k_1 t)$	Two-term model	[44]
7	$MR = a\exp(-kt^n) + bt$	Midilli and Kucuk	[45]