Industrial Crops and Products 61 (2014) 193–201

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Drying of kaffir lime leaves in a fluidized bed dryer with inert particles: Kinetics and quality determination

S.M. Tasirin [a], I. Puspasari [b,*], A.W. Lun [a], P.V. Chai [a], W.T. Lee [a]

[a] Department of Chemical and Process Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia
[b] Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia

ARTICLE INFO

Article history:
Received 14 February 2014
Received in revised form 21 June 2014
Accepted 1 July 2014
Available online 20 July 2014

Keywords:
Citronellal
Effective diffusivity
Essential oil
Fluidized bed drying
Kaffir lime leaves

ABSTRACT

Kaffir lime (*Citrus hystrix* D.C.) leaves are widely used as aromatic herb and food ingredient. Drying process is required to preserve this product. In the present study, drying behavior of kaffir lime leaves was investigated in a fluidized bed dryer with sand as inert particles under different superficial air velocities (0.6, 0.7 and 0.8 m/s) and mass ratios of kaffir lime leaves to sand (without inert, 0.04, 0.02 and 0.01) at a constant temperature of 50 °C. Effects of air velocity and mass ratio of kaffir lime leaves to sand were studied. The results showed that the rate of drying increased with increasing superficial air velocity. It was found that the presence of inert particles enhanced the drying rate. However, the rates of drying decreased when higher ratios of kaffir lime leaves to sand were used. Page model was the most suitable model to represent the drying kinetics experimental results with the highest r^2 and the lowest RMSE values compared to the other drying models. The effective moisture diffusivity was found to increase with the increase in air velocity. Within the range of variables used, the values were reported to be varied from 2.61×10^{-11} to 9.24×10^{-11} m^2/s. Comparison was made for the products dried using different drying methods (fluidized bed, sun and oven) in terms of color, composition of essential oil and vitamin C and A contents. No significant loss in the composition of essential oil, vitamin C and A contents and the color of kaffir lime leaves when drying in the fluidized bed dryer.

1. Introduction

Drying has been well-known method for food preservation. The main reason of drying in the food industry is to inhibit microorganisms and bacteria growth. Without the existence of water, the growth of those bacteria can be control and hence the food can be stored longer. Despite the importance of drying process in preserving food products, high temperatures and long drying times required to remove the water from the food material in convection air drying may cause serious damage in flavor, color and nutrients of the dried product (Lin et al., 1998). The development of drying strategy at low air temperature and short drying times with low economic cost becomes the popular research topic in the food industry.

Kaffir lime (*Citrus hystrix* D.C.) is a tropical plant grown in the Asian countries such as Laos, Indonesia, Malaysia, Vietnam and Thailand. The leaves are widely used as aromatic herb to add a distinctive aroma and flavor to food. Kaffir lime leaves are important ingredient in many Thai dishes such as soups and curries. In soupy dishes, whole leaves or leaves torn into smaller pieces are added, and especially, hot and sour shrimp soup (Tom Yum Kung) is the most popular of all Thai soups (Raksakantong et al., 2012).

Kaffir lime leaves can be used fresh or dried as a spice. However, the fresh leaves have very short postharvest life of 3–4 days, causing a depreciation in market price (Raksakantong et al., 2012). Dried kaffir lime leaves are popular as a medical spice and useful as a preserved food. It is normally tray dried and packaged in plastic film (Phoungchandang et al., 2008). As it is quite useful, the dried kaffir lime is of interest and has been exported to many countries such as United States of America, United Kingdom and Australia (Raksakantong et al., 2012).

Traditional method of kaffir lime leaves drying by using sun light brings up problems of sanity and quality of the products. Hence, many researches have been conducted on drying of kaffir lime leaves in various types of dryers to overcome these problems. Among those are hot-air drying, low relative humidity air drying and far-infrared radiation drying (Raksakantong et al., 2012) and tray drying and heat pump dehumidified drying (Phoungchandang et al., 2008). One of the commercially used dryer is fluidized bed dryer. Fluidized bed dryer has high thermal efficiency and low

* Corresponding author. Tel.: +60 389216425.
E-mail address: ifa.puspasari@ukm.edu.my (I. Puspasari).

http://dx.doi.org/10.1016/j.indcrop.2014.07.004

Nomenclature

a, b, c, g, k, n model parameters
B average mL of sample blank titrate, mL
D_{eff} effective diffusion coefficient, m^2/s
E mass of the sample, mg
F mg of ascorbic acid corresponds to 1 mL indophenols standard solution, mg
L half thickness, m
L^*, a^* and b^* color parameters
m weight of sample, kg
MR moisture ratio
N number of observations
r^2 coefficient of determination
RMSE root mean square error
t drying time, s
V initial solution volume, mL
W g sample/mL solution
X moisture content, kg water/kg dry solid
x average mL of sample titrate, mL
Y titrated sample volume, mL
z number of constants in the models
ΔE^* color difference

Subscript
d dry weight
eq equilibrium
exp experimental
o initial
pre predicted
t at specific time

Symbol
χ^2 reduced chi-square

capital cost so that it is suitable to be used in many fields and applications (Puspasari et al., 2012, 2013; Yang, 2003). Furthermore, the existence of inert material will increase the fluidization behavior of the drying products (Souraki and Mowla, 2008; Tasirin et al., 2014). Inert materials act as heat carrier and it transfers the air from the air into the products. Thus, by drying the products in a fluidized bed dryer with the presence of inert materials, it is expected to produce superior quality of products compared to sun drying.

Sand is typically used as an inert material to facilitate the fluidization of difficult-to-fluidize materials (Cui and Grace, 2007). Ajbar et al. (2011) showed that the addition of appropriate small proportions of inert group A particles such as sand may be advantageous in improving the fluidization of nano-powders compared to the application of energy intensive sound vibration. The addition of sand particles in the fluidization of rice husk and sand mixtures was found to improve the bed behavior due to the reduced inter-particle friction forces of rice husk (Karmakar et al., 2013). Oliveira et al. (2013) investigated the fluid dynamic behavior of binary mixtures of biomass and sand in a fluidized bed. They concluded that the diameter ratio inert/biomass affected segregation; more pronounced bed segregation was accomplished with a higher ratio. Rao and Bheemarasetti (2001) also studied the fluidization of biomass/sand mixtures. The biomass constituted 2%, 5%, 10% and 15% by weight of the mixtures. They found that the minimum fluidization velocity increased with increasing biomass weight fraction, as well as with increasing sand density and particle size.

The objective of this study was to investigate the drying characteristics of kaffir lime leaves in a fluidized bed dryer with sand as inert particles. Apart from that, the drying impact on the color of the final product, retention of chemical constituents, and vitamin C and vitamin A contents were also reported.

Table 1
Experimental parameters for kaffir lime leaves drying in fluidized bed dryer.

Set	Air velocity, u (m/s)	m_{sample}/m_{inert}
A1	0.6	Without inert
A2	0.6	0.04
A3	0.6	0.02
A4	0.6	0.01
A5	0.7	Without inert
A6	0.7	0.04
A7	0.7	0.02
A8	0.7	0.01
A9	0.8	Without inert
A10	0.8	0.04
A11	0.8	0.02
A12	0.8	0.01

2. Materials and methods

2.1. Equipment

A fluidized-bed dryer (rapid dryer model TG 100, Retsch GmbH & Co., Germany) was used for the drying experiments. This fluidized bed column is cylindrical in shape with approximately 18 cm in diameter and 22 cm high.

2.2. Material preparation

Fresh kaffir lime leaves (*C. hystrix* D.C.) used in this study were purchased from local market in Kajang, Selangor, Malaysia. Fresh leaves contained about 69% w.b. moisture content. Prior to use, the leaves were washed, drained and cut to the rectangle-shaped slices with dimensions of 5 mm × 5 mm using scissor. Sand with a particle density of 2400 kg/m^3 was used as inert particles. It was obtained from a beach and then dried in an oven at 105 °C for 1 day to remove any moisture content. Then it was sieved using sieving machine model Endecotts EFL 2000/2 (CSC Scientific Company Inc.) for 10 min to obtain samples with size ranges between 100 μm and 300 μm.

2.3. Experimental methods

For each drying experiment, 20 g of kaffir lime leaves were used. The sand was weighed according to the required mass ratio. Hot air was circulated for 10 min to ensure that the required experimental conditions were established. Afterwards, the kaffir lime leaves and sand mixture was then placed into the fluidized bed bin for the start of the experiment and the mass was recorded every minute. During the weighing procedure, the kaffir lime leaves were sieved out and separated from the sand. This was to ensure that the weight and moisture recorded was only for the kaffir lime leaves sample. The drying air temperature was set at 50 °C following the work of Raksakantong et al. (2012) to retain the essential constituents. The variable parameters in the experiment were air velocity and sample to sand mass ratio. Table 1 summarizes the experimental runs for this study. The kaffir lime leaves were also dried at natural condition under the sun and in an oven at 60 °C to see whether any significant difference of quality occurs in drying with fluidized bed dryer.

2.4. Thin layer drying models

The experimental results from this work are presented as drying curve and drying rate curve. Drying curve was constructed from the