Available online at www.sciencedirect.com
SCIENCE DIRECT®
International Journal of Pharmaceutics 299 (2005) 115–126
international journal of pharmaceutics
www.elsevier.com/locate/ijpharm

Technical aspects of the production of dried extract of *Maytenus ilicifolia* leaves by jet spouted bed drying

Daniel S. Cordeiro, Wanderley P. Oliveira *

Universidade de São Paulo, Faculdade de Ciências Farmacêuticas de Ribeirão Preto, Via do Café s/nº, 14040-903, Ribeirão Preto, SP, Brazil

Received 6 August 2004; received in revised form 10 December 2004; accepted 2 May 2005
Available online 22 June 2005

Abstract

This work presents an evaluation of the performance of jet spouted bed with inert particles for production of dried extracts of *Maytenus ilicifolia* leaves. The development of the extraction procedure was carried-out with the aid of three factors and three levels Box–Behnken design. The effects of the extraction variables, temperature (T_{ext}); stirring time (θ); and the ratio of the plant to solvent mass (m_p/m_s) on the extraction yield were investigated. The drying performance and product properties were evaluated through the measurement of the product size distribution, loss on drying (U_p), flavonoid degradation (D) and, process thermal efficiency (η). These parameters were measured as a function of the inlet temperature of the spouting gas (T_{gi}), the feed mass flow rate of the concentrated extract relative to mass flow rate of the spouting gas (W_s/W_g), the ratio between the feed flow rate of spouting gas relative to feed flow rate at a minimum spouting condition (Q/Q_{ms}) and the static bed height (H_0). A powder product with a low degradation of active substances and good physical properties were obtained for selected operating conditions. These results indicate the feasibility of this drying equipment for the production of dried extracts of *M. ilicifolia* Martius ex Reiss leaves.

Keywords: Drying; Jet spouted bed; Dried extract; *Maytenus ilicifolia*; Medicinal plants; Experimental design

1. Introduction

Currently, the worldwide interest in herbal or medicinal plant products has increased significantly. According to a World Health Organization survey, about 70–80% of the world's population relies on non-conventional medicine for their primary health-care. This strategy is mostly based on the use of medicinal plant products know as botanicals, herbal medicines or phytomedicines (Akerele, 1993; Calixto, 2000; Chan, 2003). Herbal medicines are composed of plant parts or plant materials in either the crude or processed state as active ingredients and may contain inert excipients (Busse, 2000).

Herbal products are in general used as raw materials for the extraction of active substances or chemical

* Corresponding author. Tel.: +55 16 602 4185; fax: +55 16 633 1941.
E-mail address: wpoliv@fcfrp.usp.br (W.P. Oliveira).

0378-5173/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.ijpharm.2005.05.002

Nomenclature

C_s	solid content (% g/g)
C_{pg}	specific heat (J/kg K)
d_p	powder product diameter (μm)
d_{p0}	mean diameter of teflon beads (mm)
d'_{pp}	powder product diameter corresponding to the cumulative fraction undersize of 0.632 (μm)
D	flavonoid degradation (% g/g)
H_0	static bed height (cm)
m_{et}	ethanol mass (g)
m_i	sample mass before desiccation (g)
m_f	sample mass after desiccation (g)
m_p	plant mass (g)
m_{p0}	mean mass of teflon beads (mg)
m_s	solvent mass (g)
m_w	water mass (g)
P	pressure (Pa)
P_{at}	pressure of atomizing gas (kPa)
P_m	maximum pressure (Pa)
P_s	mean spouting pressure (Pa)
Q	spouting gas flow rate (m^3/min)
Q_{ms}	spouting gas flow rate at minimum spouting condition (m^3/min)
S	specific surface (cm^2/g)
T_{ext}	extraction temperature (°C)
T_f	flavonoid content (mg/g)
T_{gi}	inlet temperature of the drying gas (°C)
T_{go}	outlet temperature of the drying gas (°C)
V	variable (−)
V_c	coded variable as defined by Eq. (1) (−)
W_{at}	flow rate of atomizing gas (L/min)
W_s	feed flow rate of extract (kg/min)
W_g	feed flow rate of drying gas (kg/min)
U_p	loss on drying (% g/g)
X	cumulative frequency (−)

Greek symbols

α	significance level (%)
Δ	difference (−)
γ	conical base angle (°)
ϕ	shape factor (−)
η	thermal efficiency (−)
λ	latent heat of vaporization of water (kJ/kg)
θ	extraction time (h)
ρ_e	density of the extractive solution (g/cm^3)
ρ_{p0}	density of the teflon beads (g/cm^3)

Superscript

−	mean value (−)

precursors and mainly for the production of teas, home-made-remedies, fluid extracts and also powders resulting from dried and comminuted plants or from the drying of an extract (Runha et al., 2001). The advantages of the dried extract over conventional liquid forms are lower storage costs and a higher concentration and stability of active substances. These attributes, however, are not independent of the processing steps during production.

In scientific literature there are several references concerning the production of dried extracts of medicinal plants (Teixeira, 1996; Senna et al., 1997; Runha et al., 2001). Spray dryers have been the most commonly used equipment in the dehydration step. Currently, the Research Group on Agglomeration and Drying of Pharmaceuticals at the Faculty of Pharmaceutical Sciences of Ribeirão Preto at São Paulo University/Brazil, is investigating the feasibility of the spouted bed drying for the production of dried extracts of medicinal plants as an alternative process.

The spouted bed with inert particles has been mostly used for the drying of liquid materials such as pastes, suspensions and solutions including heat-sensitive biological and chemical products (Barret and Fane, 1990; Markowski, 1992, 1993; Oliveira, 1996; Ormós and Blickle, 1980; Pham, 1983; Runha et al., 2001). The suitability of this process for heat-sensitive materials is attributed to the short residence time of the material in the equipment and the low bed annulus temperatures compared to the inlet air temperature (Oliveira, 1996). This equipment has low installation and operating costs and has high heat and mass transfer rates, resulting in higher drying rates, emerging as an alternative to spray drying.

The aim of this work was to study the feasibility of the jet spouted bed dryer (JSB) for the production of dried extract of the *Maytenus ilicifolia* leaves, and to evaluate the drying characteristics and the product

quality. The description of the principles of JSBs, its basic hydrodynamic and drying characteristics, and their application to the drying of some bio-products, can be found elsewhere (Markowski and Kaminski, 1983; Markowski, 1992, 1993).

M. ilicifolia was used in this study due to its widespread use in Brazilian folk medicine. It is a small medicinal evergreen shrub tree growing to 5 m in height with leaves and berries that resemble holly. It is native to many parts of South America and southern Brazil and is commonly known as espinheira santa, cancerosa, cangorosa, maiteno and espinheira divina. Infusion of the plant leaves is used in the treatment of ulcers, indigestion, chronic gastritis and dyspepsia. The tea leaf is also applied topically to wounds and rashes and also to treat skin cancer (Taylor, 1996).

2. Materials and methods

2.1. Material

Dried and crushed leaves of *M. ilicifolia* Martius ex Reiss (Elly Martins S.A., Ribeirão Preto, Brazil) and ethanol–water solutions were used in the preparation of the hydro-alcoholic extracts. Methanol, aluminum chloride, pyridine, glacial acetic acid, dimetyl sulfoxid (DMSO) and chloroform (Labsynth, Vinhedo—Brazil) and rutin (Sigma Aldrich) were used as analytical reagents and as reference substance. All chemicals were at least of analytical grade.

2.2. Equipment

The jet spouted bed dryer consists of a conical base, which has an inlet orifice diameter of 60 mm, included angle of 38° and upper diameter of 340 mm. All the parts are made of stainless steel. Fig. 1 shows the scheme of the experimental rig. Teflon® beads of concave-cylindrical shape with mean diameter of 5.45 mm and density of 2.16 g/cm^3 were used as inert material. Table 1 summarizes some physical properties of the beads. Teflon was selected due to its inert nature, high thermal stability, low coefficient of friction, insolubility and lack of toxicological effects.

The main components of the system are a blower of 7.5 HP; a flow meter; a rotameter; an electric heater, with total power of 5000 W; a voltage regulator, an

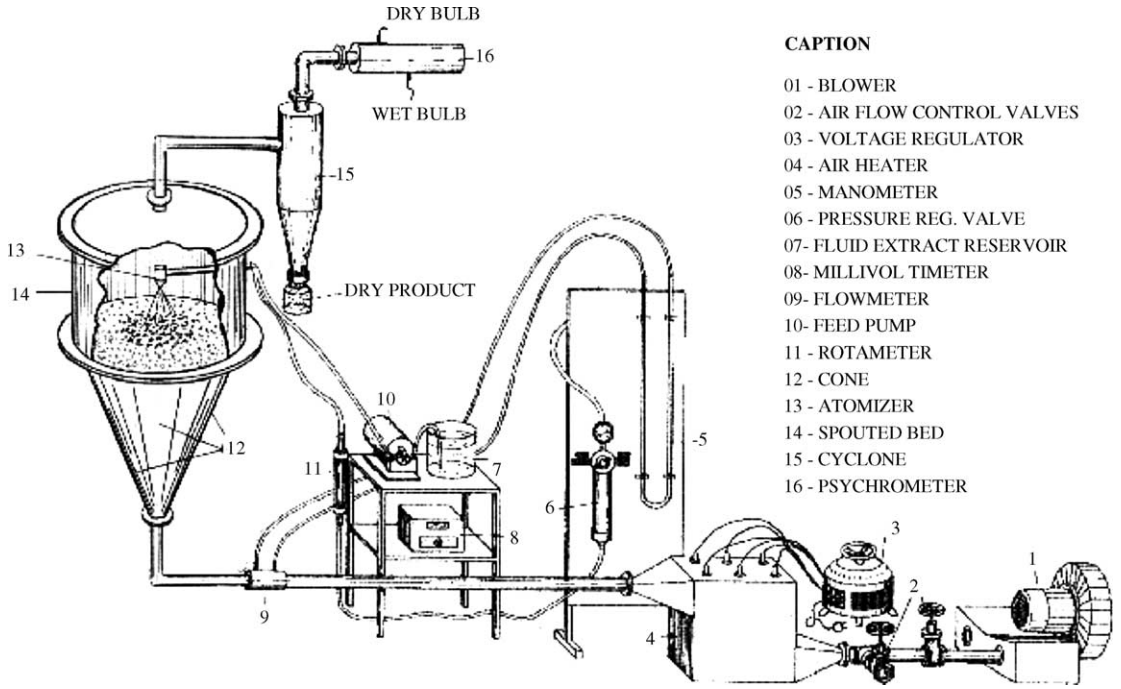

Fig. 1. Schematic diagram of the jet spouted bed dryer.

Table 1
Physical properties of the teflon particles

m_{p0} (mg)	183.0
d_{p0} (mm)	5.45
ρ_{p0} (g/cm^3)	2.16
S (cm^2/g)	5.27
ϕ (−)	0.96

extract reservoir system; a LAPPLE cyclone to collect the dry product; an acquisition data system (PCL 711-S ADVANTECH acquisition board and a PCL 789D temperature reading board), connected to a personal computer running the software LABTECH; and a psychrometer, for the measurement of the humidity of the effluent gas. The other devices used were a pycnometer, an analytical balance (Mettler Tolledo AG204, Switzerland), a vacuum pump, a drying and sterilization oven (Fanem Model 315 SE—Brazil), a vacuum filtration system, a rotary evaporator, mechanical and magnetic stirrers (Fisatom model 713 and 753—Brazil), a spectrophotometer (HP8453 UV–vis) and a centrifuge (Fanem Excelsa II, Model 206 BL—Brazil).

2.3. Methods

2.3.1. Preparation of the hydro-alcoholic extracts

The effects of the extraction variables, including the temperature (T_{ext}), stirring time (θ), and the ratio of the plant to solvent mass (m_p/m_s), on the extraction yield were investigated with the aid of three factors and three levels Box–Behnken design (Box and Behnken, 1960; Tox et al., 1978). This design allows the construction of a second order polynomial model to characterize or to optimize a process with a small number of experiments. This model includes at least one intermediate level, established for each factor combination. In this work, the factors were coded in low, intermediate and high level, established as −1.0, 0.0 and +1.0, through the following equation

$$V_c = \frac{V - \overline{V}}{\Delta V/2} \quad (1)$$

In Eq. (1), V is the factor level, $\overline{V}$ is the mean value of the factor and ΔV is the level interval. Table 2 presents the factors and the levels investigated.

The extraction of the active substances was performed by placing dried and milled *M. ilicifolia* leaves in contact with water:ethanol solutions (m_w/m_{et} = 1/2) for different time periods (1, 2 and 3 h). The extraction system consisted of a jacketed stirred vessel connected to a thermostatized bath with controlled temperature (30, 50 and 70 °C). The extracts were filtered in a vacuum filtration system and concentrated two to three times in a rotary evaporator. Water and ethanol were used as solvents to facilitate the extraction of the polar and non-polar substances, including the condensed tannins, pertaining to the catechin group, to which the anti-ulcer activity is attributed (Martins et al., 2003; Carlini and Braz, 1988; Carvalho, 1997).

Table 2
Factors and levels studied

Factors	Levels		
Temperature (°C)	30	50	70
Agitation time (h)	1	2	3
Ratio plant to solvent mass (g/g)	0.1	0.15	0.2

2.3.2. Quantification of the total flavonoid content

Determination of the total flavonoid content in the extracts was used as a marker to evaluate the process yield. The procedure used for the quantification of total flavonoid content is based on the reaction between the flavonoids and aluminum chloride forming a complex with a yellow color that can be measured in a spectrophotometer at a wavelength of 420 nm (Costa, 1994). The calibration curve, relating absorbance to the total flavonoids concentration was constructed using rutin as a reference substance. Five miligrams of rutin standard were dissolved in 10 mL of methanol. Four aliquots of this solution were taken: 0.25; 0.5; 1.0 and 1.5 mL (corresponding to 0.125; 0.25; 0.5 and 0.75 mg of rutin, respectively). Each aliquot was diluted with methanol to 2 mL. Ten millilitres of a reagent (pyridine:water:aluminum chloride 17:80:3, v/v), 12.4 mL of a solution constituted by water and dimetyl sulfoxid (1:1) and 0.6 mL of glacial acetic acid were added completing the volume to 25 mL.

For the quantification of the flavonoid content in the hydro-alcoholic extract, aliquots of 2 mL of hydro-alcoholic extracts were diluted 10 times with methanol. Five millilitres of this diluted solution were taken with a pipette and 3 mL of distilled water and 5 mL of chloroform were added to the solution in order to perform the “clean-up”, removing compounds, such as chlorophyll, that can cause interference in the readings. The resulting solution was centrifuged for

5 min at 4000 rpm. A small quantity of glacial acetic acid was added in order to increase the solubility of the flavonoids present in the aqueous phase. Two millilitres of the aqueous phase was diluted to 25 mL with 10 mL of the reagent (pyridine, distilled water and aluminum chloride solution 17:80:3, v/v), 12.4 mL of a solution composed of water and dimetyl sulfoxid (1:1, v/v) and 0.6 mL of glacial acetic acid and, was measured at a wavelength 420 nm. The construction of the calibration curve and the preparation of the sample solutions of the hydro-alcoholic extracts for reading were done in triplicate.

2.3.3. Physical characterization of the hydro-alcoholic extracts

The hydro-alcoholic extracts were characterized by the density and total solid content, C_s. The density was determined by pycrometry. The solids content was measured by storing a predefined mass of the material in an oven at 102 °C until constant mass (oven drying method).

2.3.4. Fluid-dynamic characterization of the jet spouted bed

The fluid-dynamic characterization of the equipment was carried-out by determining the minimum spouting velocity (U_{ms}), maximum pressure drop (ΔP_m) and the mean spouting pressure drop (ΔP_s). For the determination of these parameters, data of the pressure drop in the system as a function of the gas flow rate introduced into the system were collected with the aid of the acquisition data system. These data were obtained for the static bed heights of 7 and 14 cm.

2.3.5. Drying analysis

The drying operation started with the introduction of a given load of inert material to the equipment, in order to maintain the static bed height, H_0, at 7 or 14 cm. Spouting occurs by injecting air at the base of the bed. With the establishment of the spout, the heating of the air was commenced. When the air reached the desired temperature, the feed of the concentrated extract, with a preset flow rate together with the atomizing air, were introduced into the system. Measurements of the inlet temperature, T_{gi}, and of the temperature of the effluent gas, T_{go}, were taken at regular intervals in order to detect when the process reached the steady state (5 to 10 min from the beginning of the drying).

During the drying, samples of the dried product were collected to determinate the process performance and the product properties. These responses were evaluated through the measurement of the loss on drying of the dried product (U_p), product size distribution, flavonoid degradation (D), and the thermal efficiency of the dryer (η), as a function of the inlet temperature of the spouting gas (T_{gi}), the feed mass flow rate of the concentrated extract relative to flow rate of the spouting gas (W_s/W_g), the ratio between the feed flow rate of spouting gas relative feed flow rate at minimum spouting condition (Q/Q_{ms}) and the static bed height (H_0). The feed rate of the atomization air (W_{at}) was maintained at 15 L/min at a pressure of 147.1 kPa. Table 3 shows the variables and the operational ranges studied. The total flavonoid content was used as chemical marker to evaluate the effect of the drying on product degradation. Colloidal silicon dioxide at concentration of 15.82% (corresponding to 40% of solids present in the extract) was added to the concentrated extract before drying to improve the dryer performance.

2.3.5.1. Loss on drying of the dried product, U_p. The loss on drying of the dried extract was determined by the oven drying method (WHO, 1998). Powder samples with a pre-defined mass, m_i, were placed in an oven heated at 102 °C until constant mass, m_f. The percentage of loss on drying was estimated by the following equation

$$U_p\,(\%) = 100\frac{(m_i - m_f)}{m_f} \tag{2}$$

2.3.5.2. Flavonoid degradation rate. The flavonoid degradation rate was assumed as the percent ratio between the difference of the total flavonoid content in the concentrated and in the dried extracts by the flavonoid content in the concentrated extract (dry basis).

Table 3
Parameters and operating ranges used in the drying tests

Parameter	Range	Unit
W_s/W_g	0.0056–0.0119	–
Q/Q_{ms}	1.40–1.85	–
H_0	7–14	cm
T_{gi}	80–150	°C
P_{at}	147.1	kPa
γ	38	°

2.3.5.3. Product size distribution. The size distribution of dried product was determined by optical microscopy and image analysis. A powder sample was dispersed on the surface of a microscopic lamina. Images of the powder were obtained with the aid of an Olympus microscope (model BX60MIV), connected to an analogue camera. The images obtained were analyzed with an image Analysis System (Image Pro-plus, 1999).

2.3.5.4. Process thermal efficiency. The drying thermal efficiency, defined as a ratio between the heat effectively used to the total heat supplied to the dryer, was obtained by mass and energy balance in the system. The total heat supplied was assumed as the enthalpy variation between the inlet gas and the outlet drying gas fed to the equipment. The heat used in the process was assumed as the heat used for the solvent removal from the concentrated extracts atomized into the dryer. This was estimated by the evaporation rate times the latent heat of water evaporation, since the concentrated extract presented low ethanol content (≤15%). Thus, the thermal efficiency was estimated by the following simplified equation:

$$\eta = \frac{W_s(1 - C_s - C_s U_p)\lambda}{W_g C_{pg}(T_{gi} - T_{go})} \quad (3)$$

The specific heat of the drying gas, C_{pg}, as determined at the average bed temperature, defined as the arithmetic mean between the inlet and outlet temperatures of the drying gas.

3. Results and discussion

3.1. Preparation of the hydro-alcoholic extracts

Table 4 presented the experimental results of the total flavonoids content, solids concentration and density of the hydro-alcoholic extracts. Seeking to identify the variables presenting significant effects on the extraction process, a variance analysis on the experimental data presented in Table 4, was performed. Tables 5 and 6 show the variance analysis results, respectively for the flavonoid contents and solids concentration in the hydro-alcoholic extract. These results revealed that the ratio between the plant mass to solvent mass, m_p/m_s, and the extraction temperature, T_{ext}, were statistically significant at α level lower than 10%, for both responses. Second order polynomial models relating the total flavonoids content and the solids content with the investigated variables were fitted to the experimental data, in order to optimize the extraction procedure. Considering only the significant terms, the resulting models are the

Table 4
Variables studied and the results of the total flavonoids content, solids concentration and density of the hydro-alcoholic extracts

Run	Variable			Results[a]		
	m_p/m_s (−)	T_{ext} (°C)	θ (h)	C_s (%)	ρ_e (g/cm^3)	T_f (mg/g$_{ext}$)
1	0.20	70	2	5.85	1.025	0.750
2	0.10	70	2	2.29	1.001	0.560
3	0.15	50	2	2.55	1.009	0.840
4	0.10	50	1	2.27	1.027	0.581
5	0.20	50	3	4.18	1.052	0.621
6	0.15	70	1	3.28	1.037	0.856
7	0.15	70	3	5.38	0.994	0.905
8	0.15	30	1	2.27	1.024	0.396
9	0.10	50	3	1.96	1.006	0.404
10	0.20	50	1	3.94	1.043	0.966
11	0.15	30	3	2.47	1.030	0.489
12	0.15	50	2	2.51	1.019	0.792
13	0.15	50	2	3.15	1.050	0.977
14	0.20	30	2	3.12	1.020	0.429
15	0.10	30	2	2.17	1.009	0.318

[a] Average values of three determination.

Table 5
Variance analysis for the flavonoid content in the hydro-alcoholic extracts

Variable	Sum of squares	Degrees of freedom	Mean square	F_{calc}
T_{ext}	0.3636	2	0.182	9.371[a]
$T_{ext(l)}$	0.2588	1	0.259	13.326[a]
$T_{ext(s)}$	0.1048	1	0.105	5.395[b]
θ_{ext}	0.076	2	0.038	1.964
$\theta_{ext(l)}$	0.0181	1	0.018	0.929
$\theta_{ext(s)}$	0.0058	1	0.006	0.300
m_p/m_s	0.2310	2	0.116	5.954[a]
$m_p/m_{s(l)}$	0.1019	1	0.102	5.247[b]
$m_p/m_{s(s)}$	0.1291	1	0.129	6.645[a]
Interation effects				
$T_{ext(l)}$ $\theta_{ext(l)}$	0.0005	1	0.025	0.025
$T_{ext(l)}$ $m_p/m_{s(l)}$	0.0016	1	0.080	0.080
$\theta_{ext(l)}$ $m_p/m_{s(l)}$	0.0071	1	0.363	0.363
Error	0.0971	5	0.019	–
Total	0.7030	14	–	–

[a] Term is significant ($\alpha = 5\%$).
[b] Term is significant ($\alpha = 10\%$).

following (coded variables):

$$T_f = 0.8697 + 0.1799 \times T_{ext} + 0.1129\left(\frac{m_p}{m_s}\right) - 0.1685 \times T_{ext}^2 - 0.1870\left(\frac{m_p}{m_s}\right)^2 \quad (4)$$

$$C_s = 3.07 + 0.846 \times T_{ext} + 1.05\left(\frac{m_p}{m_s}\right) \quad (5)$$

Figs. 2 and 3 present comparisons between the experimental values of the flavonoids content and of the solid concentration in the hydro-alcoholic extract with estimates obtained by Eqs. (4) and (5). From these figures it is possible to observe the optimal agreement between the experimental and the estimated values of T_f and C_s. Fig. 2 shows that the flavonoid content in the extract rise with increase in the extraction temperature

Table 6
Variance analysis for the solids concentration in the hydro-alcoholic extract

Variable	Sum of squares	Degrees of freedom	Mean square	F_{calc}
T_{ext}	6.009	2	3.005	5.670[c]
$T_{ext(l)}$	5.729	1	5.729	10.835[b]
$T_{ext(s)}$	0.280	1	0.280	0.528
θ_{ext}	0.622	2	0.311	0.588
$\theta_{ext(l)}$	0.622	1	0.622	1.176
$\theta_{ext(s)}$	0.000092	1	0.000092	0.00018
m_p/m_s	8.821	2	4.411	8.337[b]
$m_p/m_{s(l)}$	8.820	1	8.820	16.681[a]
$m_p/m_{s(s)}$	0.0006	1	0.0006	0.001
Interation effects				
$T_{ext(l)}$ $\theta_{ext(l)}$	0.903	1	0.903	1.707
$T_{ext(l)}$ $m_p/m_{s(l)}$	1.703	1	1.703	3.221
$\theta_{ext(l)}$ $m_p/m_{s(l)}$	0.076	1	0.076	0.144
Error	2.643	5	0.529	–
Total	20.776	14	–	–

[a] Term is significant ($\alpha = 1\%$).
[b] Term is significant ($\alpha = 5\%$).
[c] Term is significant ($\alpha = 10\%$).

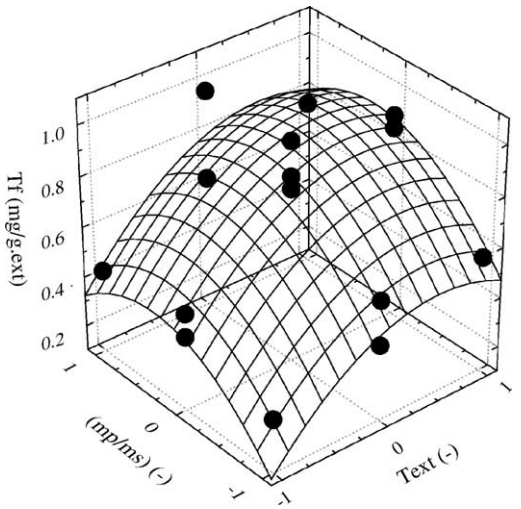

Fig. 2. Response surface relating the flavonoid concentration in the hydro-alcoholic extract as a function of the extraction temperature and of the ratio between the plant mass and the solvent mass.

and the ratio between the plant mass to solvent mass; presenting, however, a region of maximum (ideal value). Fig. 3 shows that the solid content in the extract increases with the increase in the extraction temperature and the ratio plant to solvent mass. From the analysis presented, the conditions of the hydro-alcoholic extract preparation that gives the best yield (highest

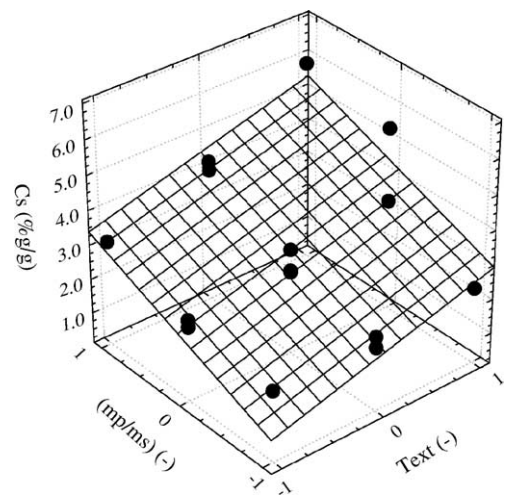

Fig. 3. Response surface relating the solid content in the hydro-alcoholic extract as a function of the extraction temperature and of the ratio between the plant mass and the solvent mass.

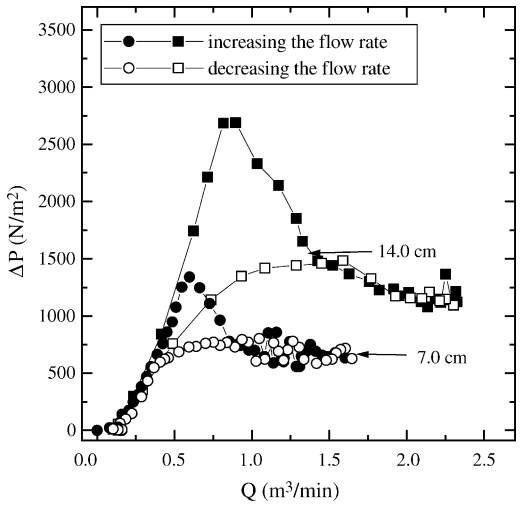

Fig. 4. Pressure drop (ΔP) as a function of the gas flow rate (Q) introduced into the system for static bed heights of 7 and 14 cm.

total flavonoids content and solid concentration) were selected: $m_p/m_s = 0.16$; $T_{ext} = 60.2\,^{\circ}C$ and $\theta = 2$ h.

3.2. Fluid-dynamic characterization of the jet spouted bed

Fig. 4 shows the plots of the pressure drop as a function of the air flow rate introduced into the jet spouted bed, obtained for static bed heights of 7 and 14 cm. From these graphs, values of the minimum spouting flow rate (Q_{ms}), the maximum pressure drop (ΔP_m) and the pressure drop of stable spouting (ΔP_s) were determined. As expected, the highest values of maximum pressure drop, the pressure drop stable spouting and of the air flow rate at the minimum spouting condition were obtained for the static bed height of 14 cm.

3.3. Drying analysis

Samples of the dried product were collected during the drying operation in order to determine the physical and chemical properties of the dried product and to evaluate the dryer performance. The dried product was characterized through determinations of the loss on drying (U_p), of the product size distribution and of the flavonoids degradation rate (D). The drying performance was analyzed by the estimation of the thermal

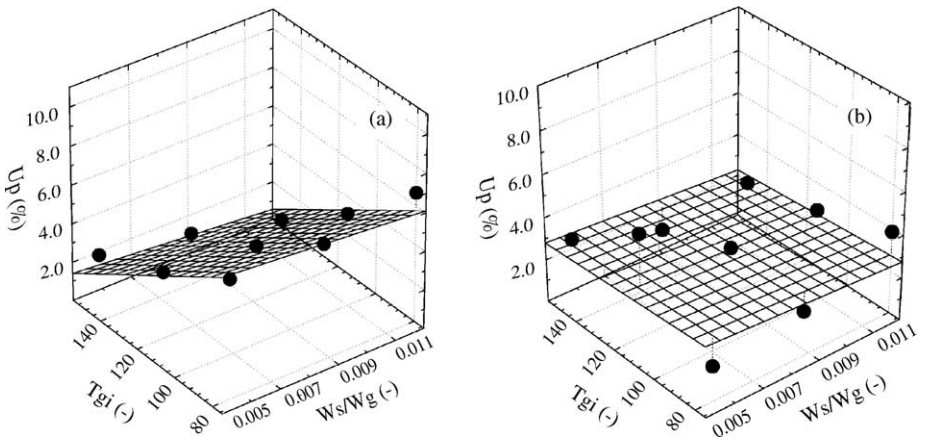

Fig. 5. Response surface relating the product loss on drying as a function of T_{gi} and of the ratio W_s/W_g. (a) $H_0 = 7$ cm; $Q/Q_{ms} = 1.85$ and (b) $H_0 = 14$cm; $Q/Q_{ms} = 1.85$.

efficiency of the dryer (η). The results are described below.

3.3.1. Loss on drying

Fig. 5a and b show typical results of the loss on drying of the product as a function of the inlet temperature of the drying gas, T_{gi}, and the relation between the feed flow rate of extract by the feed flow rate of drying gas, W_s/W_g, respectively for the static bed heights of 7 and 14 cm (data obtained at Q/Q_{ms} of 1.85). Similar results were obtained for Q/Q_{ms} of 1.4. The lowest values of the loss on drying were obtained at high temperatures of the drying gas. These are expected results since the energy introduced into the system is directly proportional to the inlet gas temperature. The parameter Q/Q_{ms} show little effect on loss on drying values for the static bed height of 14 cm. However, the loss on drying decreases conversely with Q/Q_{ms} for $H_0 = 7$ cm. Low values of the loss on drying were obtained for drying with a static bed height of 14 cm.

3.3.2. Flavonoids degradation rate

The flavonoids degradation rate was assumed as the percent ratio between the difference of the total flavonoids content in the concentrated and in the dried extracts by the flavonoids content in the concentrated extract (dry basis). A variance analysis was done in order to evaluate the influence of the drying parameters cause on the flavonoids compounds degradation. From the results, it was verified that only the variable H_0 (static bed height of the inert particles), influenced significantly the flavonoid degradation rate at $\alpha = 1\%$. Fig. 6a and b show typical response surfaces obtained for the flavonoids degradation rate as a function of the inlet drying gas temperature and of the W_s/W_g ratio, respectively, for static bed heights of 7 and 14 cm ($Q/Q_{ms} = 1.85$). The same behavior was obtained at $Q/Q_{ms} = 1.4$. The flavonoids degradation rate tends to increase with the static bed height increment.

During the drying operation, a significant quantity of the atomized extract fed into the system in the upper part of the dryer, coats the surface of inert bodies forming a thin layer. This layer dries during the passage of the coated particle through the spouted bed zones became fragile and, when brittle enough is knocked off the host particles and carried out of the dryer by the spouting gas as a fine powder (Schneider and Bridgwater, 1990). However, a fraction of the atomized extract dries by spray drying effect without coat the inert particles, being fast removed with the drying gas. Increasing the static bed height, the importance of this effect possibly could decrease, since the distance between the feed atomizer and particles present in the fountain of the jet spouted bed dryer is reduced, facilitating the beads coating. Consequently, for H_0 of 14 cm, the concentrated extract will suffer the drying effects for more time, leading to an increase in the flavonoids degradation and a reduction of the product loss on drying, as well.

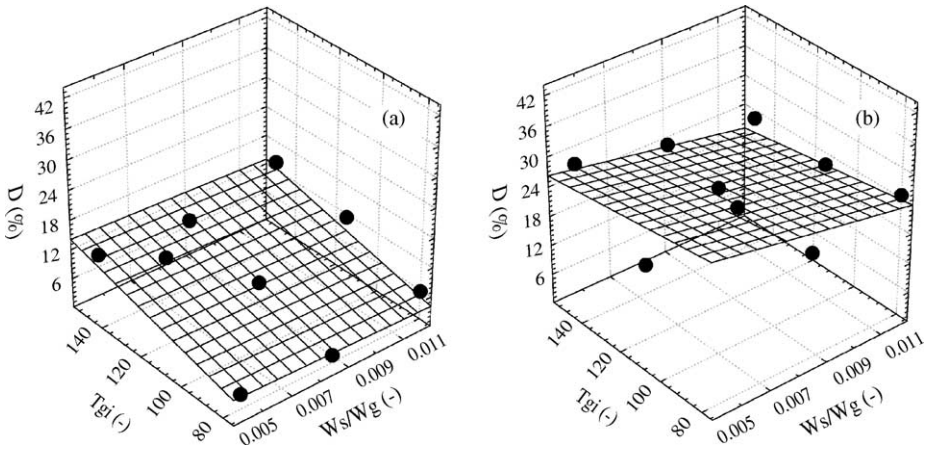

Fig. 6. Response surface relating the flavonoid degradation as a function of T_{gi} and of the ratio W_s/W_g. (a) $H = 7$ cm; $Q/Q_{ms} = 1.85$ and (b) $H = 14$ cm; $Q/Q_{ms} = 1.85$.

Although the variable Q/Q_{ms} has caused some influence on the flavonoids degradation rate, this effect was not detected in the statistical analysis. The flavonoids degradation rate was slightly bigger for $Q/Q_{ms} = 1.85$. The inlet temperature of the drying gas, T_{gi}, and the relation between the feed flow-rate of extract by the feed flow rate of drying gas, W_s/W_g, did not presented significant effect on the flavonoids degradation rate.

3.3.3. Product size distribution

A dried product with a wide size distribution was obtained for all experimental runs, with diameters ranging from 2 to 40 μm. Fig. 7a and b show typical results of the accumulated size distribution as a function of the relation between the feed flow-rate of extract by the feed flow rate of drying gas, W_s/W_g, and of the inlet gas temperature, T_{gi}, figures (a) and (b) respectively (data obtained for H_0 of 7 cm and Q/Q_{ms} of 1.4). Similar results were found H_0 of 14 cm and for Q/Q_{ms} equal 1.85. These findings revealed that the product size distribution were practically insensitive to the jet spouted bed drying operating parameters. The experimental size distribution results were well correlated by the Rosin–Rammler distribution model, presenting an average regression coefficient higher than 0.97. The Rosin–Rammler model is described by

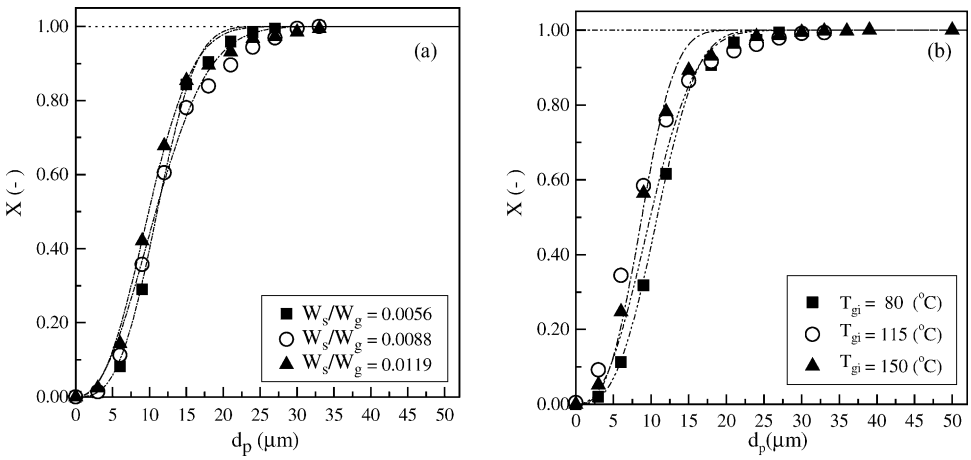

Fig. 7. Typical results of the accumulated size distribution as a function of the relation between the feed flow-rate of extract by the feed flow rate of drying gas, W_s/W_g, and of the inlet gas temperature, T_{gi}, Figures (a) and (b), respectively ($H_0 = 7$ cm, $Q/Q_{ms} = 1.4$).

the following equation

$$X = 1 - e^{-(d_{pp}/d'_{pp})^M} \quad (6)$$

where X is the cumulative frequency, d_{pp} is the particle diameter, d'_{pp} the diameter corresponding to the cumulative fraction undersize of 0.632 (adopted as 6.8 μm for all size distributions), and M is a constant. This is an expected result since the Rosin–Ramler expression has been found useful to describe size distribution of powders produced by collision and obtained from atomizing nozzles, which have widespread applications in spray and spouted bed drying operations (Runha et al., 2001; Djamarani and Clark, 1997). These processes occur simultaneously inside the jet spouted bed during the drying of liquid materials, producing skewed size distributions of the powder product suitable to be correlated by the Rosin-Rammler expression.

3.3.4. Process thermal efficiency

The jet spouted bed drying operation showed experimental thermal efficiencies around 0.7, for all operating parameters, indicative of good thermal insulation of the equipment. Increases in the feed flow-rate of the concentrated extract to the bed and/or the reduction in the inlet drying gas temperature lead to an augment in the thermal efficiency.

3.4. Antiulcerogenic activity of the jet spouted bed dried extract

The "in-vivo" evaluation of the antiulcerogenic activity of the dried extract of *M. ilicifolia* leaves produced by methodology described in this paper was reported recently by Tabach and Oliveira (2003). The authors conducted pharmacologic tests with samples of the dried extract prepared in the following drying conditions: inlet temperature of the drying gas, T_{gi}, of 150 °C; relation between the feed flow rate of extract by the feed flow rate of drying gas, W_s/W_g, of 0.0088; static bed height, H_0, of 7 cm and relation between the flow-rate of the spouting gas relative to flow rate at minimum spouting condition, Q/Q_{ms}, of 1.85. These operating conditions generate a product with low thermal degradation rate of the total flavonoid content (less than 10%) and low value of the loss on drying (less than 2%). The tests were carried-out on Wistar rats (albino, males, with an age of 3–4 months). The results indicated a significant reduction in the ulceration index, as well as a significant increase of the volume and of the pH of the gastric secretion for the different doses administrated (140 mg/kg, 280 mg/kg and 420 mg/kg), confirming the viability of the jet spouted bed for the production of dried extracts of *M. ilicifolia* leaves.

4. Conclusions

The feasibility of the jet spouted bed drying for the production of dried extracts of *M. ilicifolia* leaves has been demonstrated in this paper. A product with low thermal degradation of the chemical marker (flavonoid content), low loss on drying values and with pharmacologic efficacy was obtained. The correct selection of the operating conditions used in the extractive process (T_{ext}, θ and m_p/m_s) and, also, in the drying stage (T_{gi}, W_s/W_g, H_0 and Q/Q_{ms}), has significant effect on the product properties, as proved by the statistical analyses performed.

These results show strong evidence of the viability of the jet spouted bed drying (JSB) for the production of dried extract of the *M. ilicifolia* Martius ex Reiss leaves, emerging as an alternative to spray drying.

Acknowledgements

We would like to express our gratitude to FAPESP for a fellowship granted to the first author and for the financial aid.

References

Akerele, O., 1993. Summary of WHO guidelines for the assessment of herbal medicines. HerbalGram 28, 13–19.

Barret, N., Fane, A., 1990. Drying liquid materials in a spouted bed. In: Mujumdar, A.S., Roques, M.A. (Eds.), Drying' 89, vol. B. Hemisphere Pub. Co., New York, pp. 415–420.

Box, G.E.P., Behnken, D.W., 1960. Some a new three level designs for the study of quantitative variables. Technometrics 2, 455–475.

Box, G.E.P., Hunter, W.G., Hunter, J.S., 1978. Statistics for Experimenters: An Introduction to Design, Data Analysis, and Model Building. John Wiley, New York.

Busse, W., 2000. The significancy of quality for efficacy and safety of herbal medicinal products. Drug Inf. J. 34, 15–23.

Calixto, J.B., 2000. Efficacy, safety, quality control, marketing and regulatory guidelines for herbal medicines (phytotherapeutic agents). Braz. J. Med. Biol. Res. 33, 179–189.

Carlini, E.A., Braz, S. 1988. Efeito protetor do extrato liofilizado obtido do abafado de *Maytenus* sp. (espinheira-santa) contra a úlcera gástrica experimental em ratos. In: Carlini, E.L.A., Coord. Estudo da ação antiúlcera gástrica de plantas brasileiras (*Maytenus ilicifolia* "espinheira-santa" e outras), CEME/AFIP, Brasília, Brasil, pp. 21–35 (in Portuguese).

Carvalho, E.L.S., 1997. Desenvolvimento de produto seco nebulizado de *Maytenus ilicifolia* Martius ex. Reiss (espinheira-santa). PPGCF/UFRGS, Porto Alegre, Brasil (M.Sc. Thesis, in Portuguese).

Chan, K., 2003. Some aspects of toxic contaminants in herbal medicines. Chemosphere 52, 1361–1371.

Costa, A.F., 1994. Farmacognosia, 3. Fundação Calouste Gulbenkian, Lisboa.

Djamarani, K.M., Clark, I.M., 1997. Characterization of particle size based on fine and coarse fractions. Powder Technol. 93, 101–108.

Image Pro-Plus, Reference Guide, 1999. Medya Cybernetics, Georgia EUA, p. 506.

Markowski, A.S., 1992. Drying characteristics in a jet-spouted bed dryer. Can. J. Chem. Eng. 70, 938–944.

Markowski, A.S., 1993. Quality interaction in a jet spouted bed dryer for bio-products. Drying Technol. 11, 369–387.

Markowski, A.S., Kaminski, W., 1983. Hydrodynamic characteristics of jet-spouted beds. Can. J. Chem. Eng. 61, 377–381.

Martins, A.G., Guterres, S.S., Ortega, G.G., 2003. Anti-ulcer activity of spray-dried powders prepared from leaf extracts of *Maytenus ilicifolia* Martius ex. Reiss. Acta Farm. Bonaerense 22, 39–44.

Oliveira, W.P., 1996. Estudo da Secagem de Pastas em Leito de Jorro Cônico, PPGEQ/UFSCar, São Carlos, Brasil (D.Sc. Thesis, in Portuguese).

Ormós, Z., Blickle, T., 1980. Drying of pastes in fluidized bed. In: Drying 80, vol. 1. Developments in Drying. Hemisphere Publ. Corp., New York McGraw-Hill Int. Book Comp., pp. 200–204.

Pham, Q.T., 1983. Behavior of a conical spouted bed dryer for animal blood. Can. J. Chem. Eng. 61, 426–434.

Runha, F.P., Cordeiro, D.S., Pereira, C.A.M., Vilegas, J., Oliveira, W.P., 2001. Production of dry extracts of medicinal Brazilian plants by spouted bed process: development of process and evaluation of thermal degradation during the drying operations. Trans IchemE 79, 160–168, Part C.

Schneider, T., Bridgwater, J., 1990. Drying of solutions and suspensions in spouted beds. In: Drying'89. Hemisphere Publ. Co., New York, USA, pp. 421–425.

Senna, E.L., Petrovick, P.R., Ortega, G.G., Bassani, V.L., 1997. Preparation and characterization of spray dried powders from *Achyrocline satureioides* (Lam) DC extracts. Phyt. Res. 11, 123–127.

Tabach, R., Oliveira, W.P., 2003. Evaluation of the anti-ulcerogenic activity of a dry extract of *Maytenus ilicifolia* Martius Ex Reiss produced by a jet spouted bed dryer. Pharmazie 58, 573–576.

Taylor, L., 1996. Wealth of the rainforest, Pharmacy to the World, Copyrighted 1996–2000 by Raintree Nutrition, Inc. Austin, TX. Online at: http://www.rain-tree.com, accessed in 20 July 2004.

Teixeira, H.F., 1996. Avaliação da influência de adjuvantes farmacêuticos sobre as características físicas, químicas, tecnológicas e farmacológicas de extratos secos nebulizados de Achyrocline satureioides (Lam.) DC. Compositae, macela. PPGCF/UFRGS, Porto Alegre, Brasil (M.Sc. Thesis, in Portuguese).

WHO, 1998. Quality Control Methods for Medicinal Plant Materials. Geneve, Switzerland.