EVALUATION OF THE USE OF THE SOLAR DRYER IN THE DRYING OF MINT AND PARSLEY LEAVES[1]

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SUMMARY: the objective is to evaluate the kinetics of drying of leaves of mint and parsley, dehydrated in a solar dryer exposed directly to the sun and adjust the mathematical models of Page, Newton, Thompson, Henderson and Pabis, Midilli, Two-term and Approximation of Diffusion to the experimental data obtained and to characterize the two samples studied, regarding parameters of water content, total solids, water activity and color (L*, a* and b*). The dryer is made of wood, on the top of the dryer there is a glass sheet for the entrance of the solar rays. During the drying of the leaves the solar dryer was exposed directly to the sun, these data being used to determine the drying kinetics. The water content and total solids were determined by kiln drying at 105 ± 1 °C, the water activity was determined by direct measurement in Aqualab meter and the color was determined by direct reading in the sample using a spectrophotometer. Analyzing the results it was verified that the solar dryer had an internal temperature higher than the external temperature in the drying of mint and parsley, obtaining the maximum value at 14 hours, and that the drying kinetics of the leaves can be represented by the Midilli model with good precision.

KEYWORDS: Vegetables, mathematical models, solar drying.

AVALIAÇÃO DO USO DO SECADOR SOLAR NA SECAGEM DE FOLHAS DE HORTELÃ E SALSA

RESUMO: objetivou-se avaliar a cinética de secagem de folhas de hortelã e salsa, desidratadas em secador solar exposto diretamente ao sol e ajustar os modelos matemáticos de Page, Newton,

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Thompson, Henderson e Pabis, Midilli, Dois termos e Aproximação da difusão aos dados experimentais obtidos e caracterizar as duas amostras estudadas, quanto aos parâmetros de teor de água, sólidos totais, atividade de água e cor (L*, a* e b*). O secador é feito de madeira, na parte superior do secador há uma placa de vidro para a entrada dos raios solares. Durante a secagem das folhas o secador solar ficou exposto diretamente ao sol, sendo estes dados utilizados para se determinar as cinéticas de secagem. O teor de água e os sólidos totais foram determinados por secagem em estufa à temperatura de 105 ± 1 °C, a atividade de água foi determinada por medida direta em medidor Aqualab e a cor foi determinada por leitura direta na amostra utilizando-se espectrofotômetro. Analisando os resultados verificou-se que o secador solar apresentou uma temperatura interna maior que a temperatura externa na secagem de hortelã e salsa, obtendo o valor máximo às 14 horas, e que a cinética de secagem das folhas pode ser representada pelo modelo Midilli com ótima precisão.

PALAVRAS-CHAVE: Hortaliças, modelos matemáticos, secagem solar.

INTRODUCTION

Vegetable consumption has been increasing, as well as consumers' demand; thereby there is a need to maintain its yearly supply in adequate quantity and quality, free of preservatives (Gualberto et al., 2009).

These vegetables have been grown in the last years by family farmers in order to supply *in natura* products for supermarkets, street markets, vegetable stands and restaurants throughout the region. However, once harvested, culinary herbs may decrease in quality due to both marketing delay or by the lack of conservation methods (Carvalho et al., 2010). One alternative which can be implemented, for the small producers, in order to add value to the spice and eliminate overproduction waste would be the drying of plant materials for posterior selling. Drying is the process used to ensure quality and stability, considering that the decrease in water content reduces biological activity and physical-chemical changes, which occur during storage (Ullmann et al., 2010).

Advantages of the drying process are practicality, low costs and reduction of transport volume, while increasing shelf life and keeping the plants fresh and healthy during storage (Recci et al., 2012).

Agricultural commodities drying can be performed in two ways: natural or artificial. Solar dryer involves the solar energy harnessing, which is free and renewable. Furthermore, it presents low operation costs, no need of specialized labor, protection against insects and dust and it can be built in the farm, thus, addressing small producers (Martins et al., 2002; Togrul & Pehlivan, 2002). Several researchers (Sales & Suzuki, 2013; Santos & Sales, 2014; Amanlou et al., 2015; Mendonça et al., 2015) used solar dryer, highlighting its importance and efficiency.

Therefore, the aim of this study was to evaluate and build drying kinetics of mint and parsley leaves solar drying in solar dryer exposed to sunlight.

MATERIAL AND METHODS

The study was carried out in Food Technology Laboratory of the Academic Unity of Development Technology from the Federal University of Campina Grande (UFCG), *Campus* Sumé and in the Agricultural Commodities Storage and Processing Laboratory (LAPPA) of the Agricultural Engineering Department from Campina Grande.

Leaves of mint (*Mentha x villosa*) and parsley (*Petroselinum crispum* Mill.) plants were taken to the Food Technology Laboratory where we performed the removal of any damaged or sick leaves, other plant parts and foreign materials. Leaves were washed in running water to remove surface dirt, followed by immersion in sodium hypochlorite solution (100 ppm). Subsequently, leaves were rewashed in running water to remove solution excess, and placed in stainless steel trays and exposed to air for surface water evaporation.

The dryer is made of wood (Figure 1), presenting a glass plate on top in order to allow solar radiation to enter the system, and contains two pillars in the back so that the dryer leans forward. The dryer is 70-cm long, 47.2-cm wide and 18-cm high. The products were arranged in trays over a mesh.

Prior to the solar drying process, leaf water content was determined according to the methodology described in the Adolfo Lutz Institute Manual (Lutz, 2008), in which the samples, in triplicates, were placed into an oven at 105 ± 1 °C, until reaching constant weight.

Leaves which were dehydrated in the solar dryer were weighted in semi-analytical balance (precision: ± 0.01 g), placed into screened baskets and taken to the solar dryer afterwards. Dehydrated samples were withdrawn and placed into a desiccator until room temperature was reached. Subsequently, the samples were packed into low-density polyethylene bags, closed using a sealer.

During mint and parsley leaves drying process, the solar dryer was directly exposed to sunlight, using these data to determine drying kinetics. Data of drying kinetics were obtained weighting the trays with the samples, during drying events until constant weight was reached, in regular intervals. After data collection, values of moisture ratio were calculated (Equation 01).

$$RX = \frac{X - S_1}{X_0 - X_e} \qquad (1)$$

where,

RX – moisture ratio (dimensionless)

X – moisture content (% dry basis)

X_e – equilibrium water content (% dry basis)

X_0 – initial moisture content (% dry basis)

Mathematical models from Table 1 were fitted to experimental data from the solar drying process of dehydrated leaves, using Statistic 5.0 software by analyzing them through non-linear regression (Quasi-Newton method).

In order to evaluate the model that produced the best results, coefficient of determination (R^2) and root-mean-square deviation (Equation 02) were used as parameters.

$$RMSD = \sqrt{\frac{\sum(RX_{pred} - RX_{exp})^2}{n}} \qquad (2)$$

where,

RMSD – root-mean-square deviation

RX_{pred} – model-predicted moisture ratio

RX_{exp} – experimental moisture ratio

n – number of observations

Water content and total solids were oven dried at 105 ± 1°C until reaching constant weight, expressed in percentage (%), according to the method described in the Adolfo Lutz Institute Manual (Lutz, 2008). Water activity was determined through direct measurements using Aqualab, model 3TE, manufactured by Decagon Devices at the temperature of 25°C.

Color was determined by direct reading of the sample using a spectrophotometer MiniScan HunterLab XE Plus, with a Cielab color system. The device, equipped with illuminant D65/10°, was calibrated with standard white and black calibration plates (X = 80.5, Y = 85.3, Z = 90.0), in accordance with manufacturer's instructions. The following parameters were determined: L* which represents the luminosity, white (0) to black (100) transition; a* which represents green (-a*) to red (+a*); and b*, blue (-b*) to yellow (+b*) transition.

RESULTS AND DISCUSSION

It can be depicted from Figure 2 the graphic of moisture ratio (dimensionless) as a function of drying time (min). Analyzing the figure, there has been a greater weight loss for mint samples in the period from 0 to 200 minutes, then the weight was practically stable until 300 minutes. On the other hand, parsley samples reached their stability at 360 minutes, confirming that they have lost water slowly than mint leaves.

Table 2 illustrates physical-chemical parameters of mint and parsley leaves, respectively, where leaf water content mean value for mint was 82.05 % and total solids was 17.95 %, while for parsley leaves those values were 80.11 % and 19.89 %, respectively. These results show that both products are perishable, where drying process turns out to be essential for leaf conservation. Observing luminosity (L*), red intensity (a*) and yellow intensity (b*) values of dried samples, it was verified that the negative value of the parameter a* indicates green as the main leaf color and parameter b* indicates yellow for mint leaves. However, for parsley samples, it was verified that the positive value of the parameter a* indicates red as the main leaf color and, for b* parameter, yellow.

According to Gasparin et al. (2014), when studying peppermint (*Mentha x Piperita*. L) leaf drying in a fixed bed dryer, observed a luminosity (L*) of 36.59, red intensity (a*) of 0.66 and yellow intensity (b*) of 7.96 at the temperature of 50 ºC and wind speed of 0.5 m s^{-1}.

Tables 3 and 4 show the values for Page, Newton, Thompsom, Henderson and Pabis, Midilli, Two-term and Diffusion approximation models, fitted to drying kinetics experimental data of both leaves, the coefficients of determination (R^2) and the root-mean-square deviation (RMSD). It was observed that some of models presented coefficients of determination (R^2) greater than 0.90. According to the values of coefficients of determination (R^2) and RMSD, the mathematical model which presented the best result for both mint and parsley drying was Midilli's model, with the following values: R^2 = 0.9879 and 0.9983, and RMSD = 0.0476 and 0.0152, respectively.

Saeed (2010) verified R^2 values greater than 0.99 when fitting Diffusion Approximation, Midilli and Page model to data from the drying of *Hibiscus sabdariffa* L. in a solar dryer. Reis et al. (2011), studying mathematical modelling of Cumari do Pará pepper, used several mathematical models; however, they concluded that Midilli's model was the best fit for experimental data, with values of R^2 greater than 0.99.

CONCLUSION

Most of mathematical models successfully represented drying kinetics of mint and parsley in solar dryer with coefficients of determination (R^2) greater than 0.90 and low values of root-mean-square deviation (RMSD).

Among the models fitted to the drying kinetics data of mint and parsley leaves in a solar dryer, Midilli's equation presented the greater values of coefficient of determination and the lowest root-mean-square deviations.

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Table 1. Mathematical models to describe the process of drying mint and parsley.

MODEL	EQUATION
Page	$RX = \exp(-k.t^{n})$
Newton	$RX = \exp(-kt)$
Thompson	$RX = \exp((-a-(a^{2}+4bt)^{0,5})2.b)$
Henderson e Pabis	$RX = a\exp(-kt)$
Midilli	$RX = a.\exp(-k.t^{n}) + b.t$
Two-term	$RX = a.\exp(-k_0.t)+b.\exp(-k_1.t)$
Diffusion Approximation	$RX = a\exp(-kt) + (1 - a)\exp(-kbt)$

where, RX – moisture content (dimensionless), k, k_0, k_1 – drying coefficients (s^{-1}); a, b, c e n – model constants.

Figure 1. Image of the solar dryer.

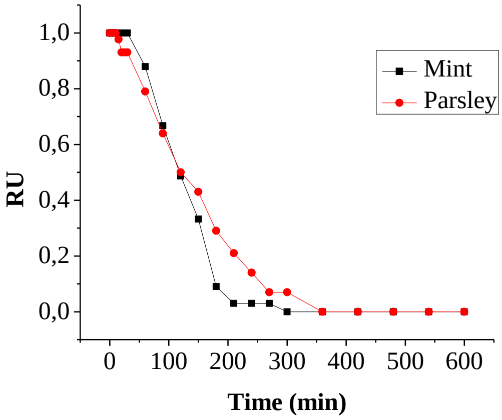

Figure 2. Moisture ratio graph of mint and parsley leaves.

Table 2. Mean values of the physical-chemical parameters of mint and parsley leaves.

Parameters	Mean ± Standard deviation	
	Mint	Parsley
Water content (% b.u.)	82.05 ± 0.10	80.11 ± 0.11
Total solids (%)	17.95 ± 0.10	19.89 ± 0.11
Water activity (a_w)	0.469 ± 0.001	0.458 ± 0.001
Luminosity (L*)	37.57 ± 0.275	35.19 ± 0.057
Red intensity (a*)	-0.74 ± 0.05	1.43 ± 0.03
Yellow intensity (b*)	10.71 ± 0.136	23.80 ± 0.172

Table 3. Values of parameters, coefficients of determination (R²) and the root-mean-square deviation (RMSD) the models studied (mint).

Model	Parameters				R^2	DQM
Page	**k**		**n**		0.9753	0.0667
	0.0004		1.5843			
Newton	**k**				0.8976	0.1358
	0.0072					
Thompson	**a**		**b**		0.8976	0.1358
	-3671.15		2.5797			
Henderson e Pabis	**a**		**k**		0.9329	0.1099
	1.1449		0.0085			
Midilli	**a**	**k**	**b**		0.9879	0.0476
	1.0468	0.0003	-0.0002			
Two-term	**a**	**k_o**	**b**	**k_1**	0.9329	0.1099
	0.5725	0.0085	0.5725	0.0085		
Diffusion Approximation	**a**	**k**	**b**		0.9858	0.0505
	-549.771	0.01863	0.9975			

Table 4. Values of parameters, coefficients of determination (R²) and the root-mean-square deviation (RMSD) the models studied (parsley).

Model	Parameters				R^2	DQM
Page	**k**		**n**		0.9976	0.0182
	0.0007		1.4383			
Newton	**k**				0.9647	0.0704
	0.0064					
Thompson	**a**		**b**		0.9647	0.0704
	-3392.63		2.3317			
Henderson e Pabis	**a**		**k**		0.9789	0.0543
	1.0820		0.0070			
Midilli	**a**	**k**	**b**		0.9983	0.0152
	1.0144	0.0010	-0.0001			
Two-term	**a**	**k_o**	**b**	**k_1**	0.9789	0.0544
	0.5414	0.0070	0.5414	0.0071		
Diffusion Approximation	**a**	**k**	**b**		0.9968	0.0209
	-120.86	0.013	0.9920			