Drying kinetics and microbiological quality of green onions[1]

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ABSTRACT

Green onion (*Allium fistulosum* L.) is widely consumed and traded in Brazil as condiment. Because of the high yields in the region of Volta Redonda - RJ and the alternative of drying as a method for preserving the excess production, the objective of this study was to evaluate the drying process of green onions, considering the microbiological quality, and to develop the mathematical modeling of this process. Mathematical models to describe the drying of agricultural products were used to predict the phenomenon. The modified Page equation gave the best fit to the data. Microbiological quality was evaluated using the analysis of aerobic mesophilic bacteria, molds and yeasts. Dehydration at 60 ºC was the most indicated for green onions, with assured microbiological quality.

Key words: *Allium fistulosum* L.; mathematical modeling; dehydration; microbiology.

RESUMO

Cinética de secagem de folhas de cebolinha e avaliação da qualidade microbiológica

A cebolinha (*Allium fistulosum* L.) possui amplo consumo e comercialização no Brasil como condimento. Devido à alta produtividade na região de Volta Redonda/RJ e a alternativa da aplicação do processo de secagem como método de conservação para o excesso da produção, o objetivo do presente trabalho foi avaliar o processo de secagem de folhas de cebolinha, levando em consideração a qualidade microbiológica vegetal, assim como realizar a modelagem matemática do processo. Para predizer o fenômeno, foram utilizados modelos matemáticos utilizados para representação da secagem de produtos agrícolas. A equação de Page Modificada foi a que melhor se ajustou aos dados observados. A qualidade microbiológica das plantas foi avaliada por meio de análises de bactérias aeróbias mesófilas, bolores e leveduras. A temperatura de 60 ºC foi a mais indicada para a desidratação da cebolinha, resultando em um produto com qualidade microbiológica assegurada.

Palavras-chave: *Allium fistulosum* L.; modelagem matemática; desidratação; microbiologia.

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INTRODUCTION

The use of spices or condiments has appeared throughout human history and these natural plant products have been used as ingredients of recipes, beverages, embalming formulas, as well as to modify the taste and odor of food. Spices are part of the rich Brazilian cuisine and are used both in homes and restaurants and companies in the gastronomy sector. Gastronomy is a field that has been gaining market share and new adherents because of the socioeconomic changes in the country, which provided the population's access to the Brazilian and international gourmet market, with dishes of different flavors and vast use of the spice species.

Green onion (*Allium fistulosum* L.), originally from Siberia, is a spice species much appreciated by Brazilians and commonly grown in their homes. It is rich in vitamins C and A, in addition to calcium, niacin and phosphorus. Its essential oil contains volatile constituents such as ajoene, allicin and alliin. Green onions are marketed both in fresh and dried forms and may appear alone or together with parsley (*Petroselinum crispum* Mill.), forming the popularly known "cheiro-verde" (smell-green). Green onion is digestive and diuretic and it is used in traditional medicine to treat hypertension, disorders of the digestive system, intestinal parasites, edema, thrombosis, skin and mucosal infections, in the macerated form or as tea or syrup (Lorenzi & Matos, 2002; Heredia *et al*., 2003; Cardoso *et al*., 2005).

When harvested, spice plants may lose quality during drying and storage, which are fundamental processes to keep the product final quality (Carvalho, 2010).

Drying is one of the most commonly used methods for preserving condiment quality. It removes much of the water from the plant soon after physiological maturity, aiming to reach the moisture content ideal for long-term storage.

Post-harvest conservation by drying relies on the fact that microorganisms, enzymes, and the entire metabolic mechanism require a certain amount of water to perform their activities. Reducing the water available in the plant will consequently reduce water activity, the rate of chemical reactions, the enzymatic degradation, and the microorganism growth (Christensen & Kaufmann, 1974; Hansen *et al*., 1993). However, due to undesirable changes in the quality of products dried with the pre-treatments and drying conditions, this process needs further studies (Maskan, 2000).

Mathematical simulation can be used to study drying systems, their design, optimization and determination of the feasibility of their commercial application. For the simulation, which is based on the drying of successive thin layers of the product, it is used a mathematical model that represents satisfactorily the moisture loss of the product during the drying process. Thin layer drying is described as that with a thickness of only one product unit. The thin layer drying equation combined with equations representing other specific product physical properties forms a set of mathematical relationships that help in the calculation and understanding of the thick-layer drying processes. A thick layer consists of a succession of superimposed thin layers. These models are generally based on variables which are external to the product such as temperature and relative humidity of the drying air (Hall, 1980; Berbert *et al*., 1995; Resende *et al*., 2008).

Drying of perishable products with high initial moisture contents has advantages of maintaining mineral constituents, inhibiting microorganism action, reducing transport costs, handling, storage and alternative for waste, disposal and pollution problems (Alessi *et al*., 2013).

The quality of the procedures along the production and marketing chain is decisive in the final quality of the product. When these conditions are unsuitable, products will have poor quality, and among other problems, they can transport several microorganisms to consumers (Elpo *et al*., 2001).

In Brazil, according to data from the Epidemiological Analysis of Outbreaks of Foodborne Diseases between 2000 and 2015, there were 10,666 outbreaks of food-borne diseases, with 209,240 patients and 155 deaths. Of these, 58.5% of the cases had the etiological agents not identified. Spices, industrialized sauces and similar products, vegetables and mixed foods totaled 15.9% of the cases, and 51% of the foods blamed for the outbreaks were not identified (Brazil, 2015).

To assure the quality and safety of foods, the Resolution of the Collegiate Board (RDC) No. 12 of January 2, 2001 of the National Agency of Sanitary Surveillance - ANVISA established a number of microbiological standards regarding *Salmonella* sp. and coliforms thermotolerant at 45ºC, which are microorganisms commonly associated with raw and/or dried vegetables (Brazil, 2001). The legislation, however, does not advocate maximum permissible values for molds and yeasts and aerobic mesophiles.

Teixeira-Loyola *et al*. (2014) emphasized that the limited legal requirement in the Brazilian legislation for microbiological control in spices is worrying, since these products can be ingested by children, the elderly and even by immunocompromised and immunosuppressed patients; it can cause illnesses and worse the clinical picture of the patient, therefore, it is not recommended to use these products in hospitals.

Furlaneto & Mendes (2004) pointed out that spices are added to other preparations and if they are contaminated, they can contaminate other foods, increasing their microbial load. The authors emphasized the concern with the hygiene of manipulators, utensils and equipment that come in contact with the product, as well as the storage conditions, because pathogenic microorganisms pose a great risk to health and may cause foodborne toxinfections.

In this context, the present study aimed to evaluate the microbiological quality of green onions before and after convective drying and to fit mathematical models to the resulting drying curves.

MATERIALS AND METHODS

The spice species used in the experiments was provided by farmers from the municipality of Volta Redonda / RJ. After harvesting, before starting the drying process, the material was transported to a processing room where the leaves were selected, discarding those unfit for consumption. After the selection, the leaves were cut transversely into 5-cm-long segments and placed in stainless steel perforated trays for drying. The experiments were arranged in a completely randomized design, with three replications. Samples of fresh leaves were randomly selected for determining moisture content and microbiological analysis, as described later.

Drying was carried out at the Laboratory of Post-harvest and Pre-Processing of Agricultural Products of the Universidade Federal Fluminense (UFF), campus Volta Redonda/RJ. The electric hot-air dryer used in the study has a blower for upflow air drying and three screened-bottom trays horizontally disposed. The drying process finished when the product reached moisture content around 0.11 d.b. (dry base). The moisture content of the samples was determined by the gravimetric method recommended by ASAE Standards (2000).

Different air temperatures (40, 50 and 60 °C) were tested to provide the shortest drying time and assure microbiological quality. Temperature and relative air humidity were monitored using a digital thermohygrometer with sensor placed in the drying chamber of the dryer.

The drying curves were obtained by calculating the loss of water during the drying by the mass differences, weighing the trays at regular intervals until the product reached the final moisture content. The fit of the drying curves was obtained with the equations in Table 01.

Table 1: Nonlinear regression models used to predict the phenomenon of thin layer drying

Model name	Model
Newton	$RU = \exp(-k.t)$
Page	$RU = \exp(-k.t^n)$
Modified Page	$RU = \exp[-(k.t)^n]$
Verna	$RU = a.\exp(-k.t)+(1-a).\exp(-k_1.t)$
Wang & Sing	$RU = 1+a.t+b.t^2$

RU - Moisture Ratio; t - time; a, b, c, k, k_o, k_1, n - Model constants. Source: Madamba *et al*, 1996; Mohapatra & Rao, 2005.

The moisture ratio (MR) of the product during drying in the different air conditions was calculated with the following equation:

$$RU=\frac{U-U_e}{U_i-U_e} \quad (1)$$

where:

RU - moisture ratio (dimensionless);

U - moisture content, decimal (d.b.);

U_e – equilibrium moisture content, decimal (d.b.);

U_i - initial moisture content, decimal (d.b.).

The fit of the mathematical models of drying and hygroscopic equilibrium to the experimental data was performed with the non-linear regression analysis using the Gauss-Newton method. The degree of fit of the model to the experimental data was evaluated by the coefficient of determination (R^2), the relative mean error (P) and the estimated mean error (SE) as described below (Madamba *et al*., 1996, Afonso Jr & Corrêa, 1999; Mohapatra & Rao, 2005).

$$SE = \sqrt{\frac{\sum_{i=n}^{n}(Y-Y_0)^2}{DFM}} \quad (2)$$

$$P=\frac{100}{n}\sum_{i=1}^{n}\frac{|Y-Y_0|}{Y} \quad (3)$$

where:

n - number of observations;

Y - experimental observation;

Y_0 – model estimate;

DFM - degrees of freedom of the model.

The microbiological evaluation of fresh and dry green onions was carried out according to the Normative Instruction No. 62 of August 26, 2003 of the Ministry of Agriculture, Livestock and Supply (MAPA, Brazil, 2003). The presence of aerobic mesophilic bacteria, molds and yeasts was determined.

The culture media used to grow microorganisms and determine the microbiological quality were Plate Count Agar (PCA) for aerobic mesophilic bacteria and Sabouraud Agar for molds and yeasts. After inoculation into plates containing the Sabouraud and PCA medium, the plates were incubated at 30 °C for 48 to 72 hours. Microorganism counts were carried out only on plates with less than 300 colony forming units (CFU) (Silva *et al*., 2007).

RESULTS AND DISCUSSION

Table 2 shows the coefficient of determination (R²), the mean relative error (P), and the mean error of the estimation (SE) for the mathematic models fitted to the experimental data using nonlinear regression, for each treatment.

Among the models tested to predict the drying phenomenon, the Modified Page equation gave the best fit to the moisture ratio data. In addition to the lowest P and SE values, the equation had high R^2 values, which were above 98% for all temperatures, meaning, according to Madamba *et al*. (1996), a good fit of the model to represent the drying phenomenon. Similarly, Rocha *et al*. (2012) found that the experimental drying data of thyme (*Thymus vulgaris* L.) were fitted best to the Modified Page model at 40, 50, 60, 70 and 80 °C. Likewise, Demir *et al*. (2004) found that the Modified Page model gave the best fit for the drying process of laurel (*Laurus nobilis* L.)

Table 3 shows the Modified Page model constants at different drying temperatures.

According to Madamba *et al*. (1996), the drying constant (k) can be used as an approximation to describe the effect of the drying temperature and is related to the effective diffusivity of drying in the falling-rate period, in which the liquid diffusion controls the drying process. Table 03 shows that constant "k" for the Modified Page model increased with the drying temperature, representing the effect of the external drying conditions. Temperature and relative humidity are examples of external factors influencing the drying process during any phase of water diffusion, since the water removal of the product depends on the difference between the characteristics of the drying air and the drying product. These results corroborate Barbosa *et al*. (2007) for drying lemon balm (*Lippia alba* Mill N. E. Brown).

Constant "n" values increased with the increase in drying air temperature. Misra & Brooker (1980) discussed that "n" depends on the agricultural product and the drying conditions, reflecting the extent of its internal resistance to drying in certain external conditions, thus explaining the water gradients within the product during the process in the rate at which it occurs.

Figure 01 shows the drying curves of green onions based on the experimental data and estimates of moisture content using the Modified Page equation at different temperatures.

The moisture contents of fresh green onions were 9.48; 10.11 and 10.11 d.b. The plot shows that there was a reduction in the drying time with the increase in the drying temperature. The mean drying time at 40 °C was 4290 minutes; with increase of 10 °C, this time fell to 1390 minutes, reducing 67.6% of the drying time. Consequently, with a further 20 °C in the initial drying temperature, the drying time was reduced to 1045 minutes, reducing 75.6% of the total drying time. These results are in agreement with those obtained by Radünz *et al*. (2010) who analyzed the drying kinetics of sage (*Salvia officinalis* L.) from 40 to 90 °C and found a 9.8-fold reduction in the drying time when the temperature increased from 40 to 70 °C and up to 13 times when it increased to 90 °C. Oliveira *et al*. (2011) analyzed the drying kinetics of *Pectis brevipedunculata* (Gardner) Sch. Beep. ("alecrim bravo") and reported a 10-fold reduction in drying time by increasing the drying temperature from 30 to 50 °C.

Table 03: Modified Page model constants for drying of green onions leaves (*Allium fistulosum*) at different temperatures

Drying temperature (°C)	Modified Page Model Constants	
	k	n
40	0.000017	0.692398
50	0.000047	0.897648
60	0.000053	1.034895

Table 2: Coefficient of determination (R^2), mean relative error (P) and mean error of the estimate (SE) of the mathematical models at each drying temperature for green onions

Mathematical Model	T (°C)	R^2 (%)	P (%)	SE
	40	96.18	31.61	0.065
Newton	50	99.57	10.81	0.024
	60	99.75	47.52	0.020
	40	99.70	16.01	0.018
Page	50	99.72	25.78	0.019
	60	99.09	76.77	0.037
	40	98.89	28.90	0.035
Modified Page	50	99.89	15.23	0.012
	60	99.85	30.76	0.015
	40	98.07	22.99	0.048
Verna	50	99.85	9.76	0.014
	60	99.67	22.75	0.022
	40	82.26	91.03	0.141
Wang & Singh	50	95.36	66.01	0.077
	60	98.64	28.90	0.045

Table 4 shows the microorganism count in the fresh and dried green onions at the temperatures evaluated.

The RDC No. 12/2001 by ANVISA does not establish maximum permissible counts for molds, yeasts and aerobic mesophiles for microbiological control of intact and ground spices such as seeds, leaves, roots, or other parts of the plant, separated or in mixture (Brazil, 2001).

In this study, the drying process reduced mold and yeast contamination, varying from 5.93 x 10^5 CFU/g in fresh leaves to 0 CFU/g in leaves dried at 60 °C (Table 4). Because there is no established standard in Brazil for the presence of these microorganisms in vegetables and condiments such as green onions, for comparison purposes, it was used the acceptable limits recommended by the World Health Organization (WHO) for medicinal/spice plants, which establishes the maximum acceptable count of 10^3 CFU/g (WHO, 1998). The results showed that only the plants dried at 60 °C had counts below this limit and were suitable for consumption. The high occurrence of molds and yeasts is likely due to poor hygienic condition at any stage of the production chain and requires attention, as they can produce mycotoxins and accelerate food deterioration.

Table 4 shows the mean counts of 3.00 x 10^7, 1.67 x 10^5, 2.34 x 10^4, and 1.09 x 10^4 CFU/g for aerobic mesophilic microorganism contamination for fresh leaves and leaves dried at 40, 50 and 60 °C, respectively. The World Health Organization establishes the acceptable limit of 10^5 CFU/g for these microorganisms (WHO, 1998). Thus, it was found that the fresh samples and the samples dried at 40 °C are not within the limit acceptable for consumption. Similarly, Silva & Rosa (2003) found microorganism loads greater than 10^6 CFU/g of aerobic mesophylls in "cheiro-verde" (smell-green) purchased in retail stores in the city of Piracicaba/SP and Zaroni *et al*. (2004) found levels of contamination above legal standards for consumption in 45.83% of the studied samples of medicinal plants grown in the state of Paraná. According to Souza *et al*. (2004), the analysis of viable facultatively aerobic and/or anaerobic mesophilic bacteria indicate the sanitary quality of the food and high loads of these microorganisms can cause organoleptic changes in the product, if there are favorable conditions for bacterial growth.

The standardization of procedures aiming at maintaining the microbiological quality of the product throughout cultivation and post-harvest of spice species is required to assure food safety. A well-managed drying process carried out at the ideal temperature for microorganism control and maintenance of the sensorial characteristics of the product would be an alternative of processing for dried condiments.

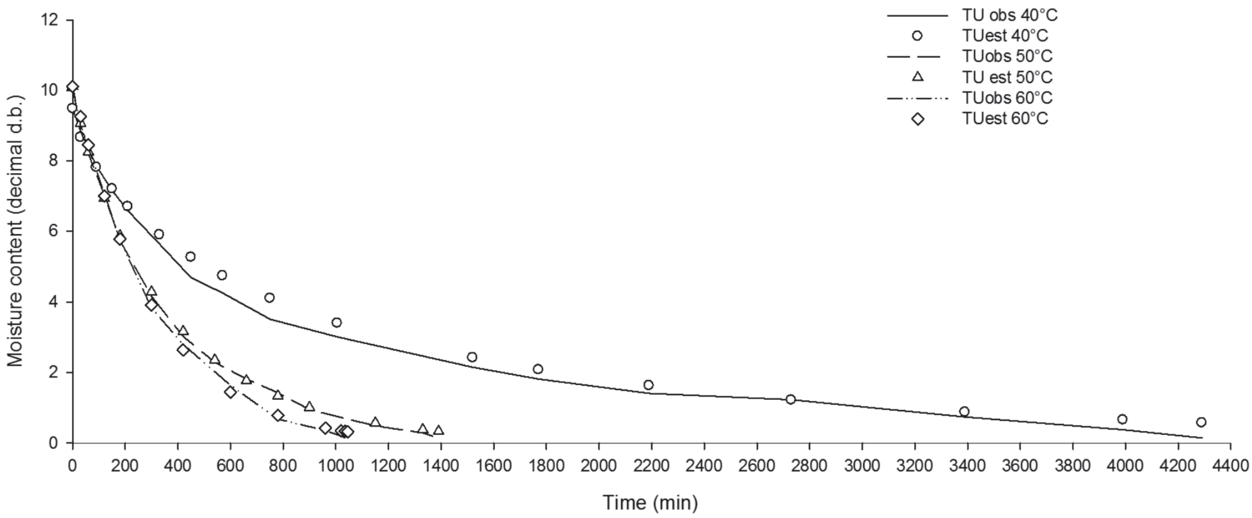

Figure 01: Moisture content (TU) observed and estimated by the Modified Page equation for drying of green onions (*Allium fistulosum*) at 40, 50 and 60 °C.

Table 4: Microorganism counts in leaves of green onions (*Allium fistulosum*) for the treatments analyzed, as CFU/g

Microorganisms	**Treatments**			
	Fresh plant	**Temperature of drying air (°C)**		
		40	**50**	**60**
Molds and Yeasts	5.93 10^5	2.72 10^4	0.61 10^4	Absent*
Aerobic mesophilic	3.00 10^7	1.67 10^5	2.34 10^4	1.09 10^4

*No counting.

CONCLUSIONS

Considering the coefficients of determination and the standard errors of fit, the Modified Page model showed the best fit to describe the drying kinetics of green onions at 40, 50 and 60 °C.

The microbiological analyses showed that drying green onion leaves at 60 °C provided the best results, since the sanitary characteristics of the product meet the requirements of the current legislation.

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