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Physico-chemical characterization and kinetics of drying of organic yellow bell pepper (*Capsicum annuum* L.)

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The bell pepper has many qualities, but it has a high water content, favoring the occurrence of deteriorating reactions and the growth of microorganisms; however, it is possible to use drying as a conservation method. The objective of this study is to perform the kinetics of organic yellow bell pepper drying at different drying air temperatures, to adjust the data obtained to the empirical models and to evaluate the effect of the applied temperatures on its physicochemical characteristics. The fruits were subjected to drying under the temperatures of 50, 60, 70 and 80°C. In order to understand the drying process, kinetics and modeling were applied using Henderson and Pabis, Lewis, Page, Peleg, Silva et al. and Wang and Singh models. The physical-chemical characterization was performed in the *in natura* samples and after drying. The Page model was the one that best described the drying kinetics at all applied temperatures. The effectiveness of the drying process in the reduction of water activity and in the increase of the ash concentration in all treatments was verified. The samples dried at 50°C presented the highest values for protein content, vitamin C and phenolic compounds.

Key words: Conservation, dehydration, organic vegetables, quality.

INTRODUCTION

The cultivation of organic vegetables has prospered all over the world, because this system of production provides benefits to the producer, consumer and the environment. Organic fertilization expands productivity, minimizes the occurrence of corrosive processes in the soil, allows greater aggregation of particles, provides more nutrients and allows the increase of water and phosphorus contents, resulting in obtaining a product of high quality and nutrient-rich (Sediyama et al., 2014; Celestrino et al., 2017; Salles et al., 2017).

The bell pepper (*Capsicum annuum* L.), belonging to the family Solanaceae originated in Central America and was one of the first seasonings used to provide foods with more attractive color, aroma and flavor. In the sixteenth century an expansion of its cultivation became popular in practically all the continents (Hachmann et al., 2017). In Brazil, the pepper has high economic value, standing out as one of the ten vegetables most consumed in the national territory. The existing cultivars have different shapes, sizes and colors that are correlated to the maturation stage (Lahbib et al., 2017). The green peppers are characterized by being harvested before reaching full maturity, presenting slight bitterness. The yellow and orange chilies have intermediate maturation, whereas the red chilies are harvested at full maturity, presenting sweet taste (Trecha et al., 2017).

The peppers are part of the gastronomy of several countries, and can be consumed *in natura*, in the preparation of salads or used industrially as raw material in the production of sauces, condiments, colorings or concentrated aromas (Bogusz Júnior et al., 2015). Besides the aroma, pungency and attractive color, the pepper pericarp has several nutrients that are beneficial to human health, such as calcium, phosphorus, iron, B vitamins, carotenoids and flavonoids that are substances associated with the prevention of diseases such as cancer (Lahbib et al., 2017; Trecha et al., 2017).

In spite of the innumerable qualities previously reported, the *in natura* pepper has a high water content, which is one of the parameters responsible for the occurrence of deteriorating reactions and the development of microorganisms, resulting in a short shelf life. However, the viability of using the drying process as a conservation method, which consists in the removal of water from the product and aims to reduce losses related to the post-harvest stages, development of a product with higher added value and reducing weight and volume, implying less need for spaces for transportation, storage, and reduction in packaging costs (Alves and Nicoleti, 2016). The drying process entails in the product variations that are observed in the texture, taste, aroma, color and reduction of the nutritional quality. Substances are degraded by light, oxygen and high temperatures. Carrying out studies on drying processes and systems, through mathematical modeling, enables the design, optimization and evaluation of the application of the commercial scale drying process. It is possible to observe a higher quality final product (Hernandez-Carrion et al., 2013) by means of the physical-chemical parameters.

In this context, the objective of this study is to carry out drying kinetics of organic yellow pepper at different drying air temperatures, to adjust the data obtained to the empirical models and to evaluate the effect of the applied temperatures on its physicochemical characteristics.

MATERIALS AND METHODS

The organic yellow bell peppers (*C. annuum* L.) were purchased at a fair of organic products located at the Federal University of Campina Grande, in the city of Campina Grande, Paraiba, Brazil. The work was developed in the Laboratory of Storage and Processing of Agricultural Products of the Federal University of Campina Grande.

Kinetics of drying

The yellow peppers were selected, sanitized and cut manually into thin slices; then the initial water content of the product was determined according to the methodology proposed by AOAC (2005). The drying was performed in air circulation oven with air velocity of 2.0 ms^{-1}, Tecnal brand TE-394/4, at temperatures of 50, 60, 70 and 80°C, in which the samples were uniformly distributed in trays, forming a layer of approximately 0.5 cm thickness. The experimental data were expressed in terms of the water content ratio (X*), given by the relationship between the water content differences in time, t, and equilibrium water content ($X(t) - X_{eq}$) of initial and equilibrium water (X_i-X_{eq}). As described in Equation 1:

$$X^*(t) = \frac{X(t) - X_{eq}}{X_i - X_{eq}} \quad (1)$$

Where: X^* = ratio of water content (dimensionless); X_{eq} = equilibrium water content (dry basis); X (t) = water content (dry basis); X_i = initial water content (dry basis).

The six empirical functions *f*(t,a,b) presented in Table 1 were fitted to the experimental data sets using nonlinear regression with the LAB Fit Curve Adjustment Software (Silva and Silva, 2008). The results from the empirical models were evaluated through the statistical indicators chi-square, χ^2 and coefficient of determination, R^2 (Bevington and Robinson, 1992; Da Silva et al., 2008; Taylor, 1997; Silva et al., 2018a).

Physical-chemical characterization and thermosensitive compounds

The determinations of moisture, ash, lipid and protein contents were performed according to the methodology described by AOAC (2005). Water activity (Aw) was determined using the Decagon® Aqualab CX-2T device at 25°C; the total carbohydrate content was calculated by difference to obtain 100% of the total composition

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Table 1. Empirical models to describe drying kinetics.

Model name	Empirical expression	Reference
Handerson and Pabis	$X^* = ae^{-bt}$	Diamante et al. (2010)
Lewis	$X^* = e^{-at}$	Kaleta and Górnicki (2010)
Page	$X^* = e^{-at^b}$	Diamante et al. (2010)
Peleg	$X^* = t(a + bt)$	Mercali et al. (2010)
Silva et alii	$X^* = e^{-at-b\sqrt{t}}$	Silva et al. (2013)
Wang and Singh	$X^* = 1 + at + bt^2$	Kaleta and Górnicki (2010)

(FAO, 2003). The content of ascorbic acid (Vitamin C) was determined according to the methodology proposed by the Institute Adolfo Luttz (Brazil, 2008) and the results were expressed as mg of ascorbic acid/100 g sample. Total phenolic compounds were quantified using the Folin-Ciocalteau method described by Waterhouse (2006), using gallic acid as standard and water as solvent. The calculations performed for the determination of the phenolic compounds were based on a standard curve with gallic acid and the spectrophotometer readings at 765 nm with the results expressed in $mg.100g^{-1}$ of gallic acid.

Statistical analysis

The results were submitted to analysis of variance (ANOVA), Tukey's test of means comparison at the 5% level of significance, with the aid of the statistical program SAS 9.0 (Statistical Analysis System®) (SAS, 1999).

RESULTS AND DISCUSSION

Table 2 shows the results obtained for the empirical models applied to the drying kinetics of yellow pepper, as well as the statistical indicators, chi-square and coefficient of determination. According to the statistical indicators, all proposed models presented a coefficient of determination (R^2) of more than 0.99 (R^2> 0.99) at all temperatures applied, representing satisfactorily the drying process studied. In the chi-square (χ2) analysis, it can be observed that the Wang and Singh model presented the highest values, ranging from 1.2389 to 4.7295×10^{-2} when the air temperature of drying ranged from 50 to 80°C. The Page model was considered as the lowest values for the same function with a variation of 0.3399 to 0.5183×10^{-2} between the applied temperatures, being the model chosen to represent the drying process. The Peleg model also presented high R^2 and low χ2, according to Silva et al. (2018b), it can be interpreted as an equation resulting from the law of second-order drying rate, which allows to give a physical meaning to the parameters obtained by adjusting curves (Pan et al., 2011; Tao et al., 2014).

It was also observed that the parameter "a" of the empirical shifts tended to increase with increase of drying air temperature, except for the models of Handerson and Pabis, Lewis, Wang and Singh that decreased with the increase in temperature; and the Silva et al. model that did not show direct relation with the air temperature if drying. A similar pattern was observed for parameter "b" where it increased as the drying air temperature increased; however, only the Wang and Singh model showed different behavior.

Derlan et al. (2013), when evaluating the drying process of cambuci pepper at 40, 50 and 60°C, determined that the Midili model was the best fit for the experimental data. Silva et al. (2018b) found that the Handerson and Pabis model best described the drying process of peppers at temperatures of 60 to 80°C. Figure 1 shows the Page model as the one that best described the drying kinetics of yellow pepper to the drying air temperatures applied. The increase in drying air temperature reduced the drying time of the yellow pepper, whose times were equal to 690, 630, 570 and 450 min, respectively. According to Melo et al. (2015), this behavior is due to the fact that the higher water removal rates of the product occur at higher temperatures, which reduce drying time. Table 3 shows the mean values and standard deviations of the physical-chemical characterization and thermosensitive compounds of yellow pepper (*C. annuum*, L.) *in natura*. The mean moisture content for *in natura* yellow pepper was lower than those obtained by Machado et al. (2017) for yellow pepper (92.40%), as well as those obtained by Oliveira et al. (2016) for green pepper (93.79%), eggplant (93.61%) and chuchu (95.26%). It is worth mentioning that in chilies these moisture values decrease with the maturation stage.

According to Fellows (2006), the *in natura* yellow pepper is classified as a food of high water activity (A_w> 0.90), which justifies drying as an option to the conservation of this product due to its high perishability and susceptibility to attack of microorganisms. Values close to the present study were observed by Meneses et al. (2018) for different fruit residues being 0.985, 0.902 and 0.971 for mango, guava and acerola residues, respectively.

The yellow pepper *in natura* had 0.87% ash content, 1.67% proteins and 0.39% lipids; however, Nascimento et al. (2018) when analyzing fresh green peppers obtained lower levels for ashes (0.4%), proteins (1.5%) and lipids (0.2%). Higher values obtained in the present work are related to the maturation stage, since the green

Table 2. Results obtained for the models.

Model	**T (°C)**	***a***	***b***	***R²***	**χ² x 10⁻²**
Handerson and Pabis	50	1.004	0.5597×10^{-2}	0.9984	0.5552
	60	1.003	0.5584×10^{-2}	0.9983	0.5102
	70	1.003	0.5569×10^{-2}	0.9982	0.4730
	80	1.001	0.5507×10^{-2}	0.9981	0.3402
Lewis	50	0.5560×10^{-2}	-	0.9985	0.5646
	60	0.5550×10^{-2}	-	0.9984	0.5178
	70	0.5539×10^{-2}	-	0.9982	0.4786
	80	0.5495×10^{-2}	-	0.9981	0.3410
Page	50	0.4880×10^{-2}	1.0256	0.9988	0.5183
	60	0.4949×10^{-2}	1.0225	0.9987	0.4826
	70	0.5028×10^{-2}	1.0191	0.9986	0.4523
	80	0.5359×10^{-2}	1.0050	0.9989	0.3396
Peleg	50	1.607×10^{2}	0.7328	0.9978	0.6888
	60	1.6338×10^{2}	0.7190	0.9982	0.5252
	70	1.6622×10^{2}	0.7035	0.9985	0.3808
	80	1.7026×10^{2}	0.6796	0.9985	0.2681
Silva et alii	50	0.5698×10^{-2}	-0.1603×10^{-2}	0.9984	0.5482
	60	0.5670×10^{-2}	-0.1377×10^{-2}	0.9983	0.5059
	70	0.5636×10^{-2}	-0.1114×10^{-2}	0.9982	0.4710
	80	0.5501×10^{-2}	-0.6958×10^{-4}	0.9981	0.3410
Wang and Singh	50	-0.3860×10^{-2}	0.3662×10^{-5}	0.9900	4.7295
	60	-0.4011×10^{-2}	0.4040×10^{-5}	0.9917	3.4837
	70	-0.4160×10^{-2}	0.4456×10^{-5}	0.9929	2.5803
	80	-0.4493×10^{-2}	0.5568×10^{-5}	0.9949	1.2389

pepper appears as a stage inferior to the yellow pepper. In relation to the total carbohydrate content, the yellow pepper *in natura* presented low value, since the material presented higher moisture content and consequently high water activity (A_w).

High percentages of ascorbic acid (Vitamin C) in sweet peppers (234.64 mg of ascorbic acid/100 g sample), as well as moderate total phenolic compounds content (38.49 mgGAE.100g^{-1}) were quantified. Pereira et al. (2016) quantified ascorbic acid content of 22.29, 5.13 and 5.00 mg of ascorbic acid/100g sample for chard, lettuce and cabbage leaves, respectively. Table 4 shows the mean values of the physico-chemical and thermosensitive compounds for yellow pepper convectively dehydrated in an air circulation oven at temperatures of 50, 60, 70 and 80 °C, respectively.

The moisture content in the samples submitted to drying showed statistically significant variations for all evaluated temperatures, and the higher the drying temperature, the lower the final moisture content of the product. However, the final moisture content of each treatment was satisfactorily met by the Brazilian legislation that establishes a maximum of 15% (Brazil, 2005). Meneses et al. (2018) obtained moisture content of 13.42, 6.09 and 11.31% for mango, guava and acerola residues, respectively, dehydrated at 55°C. As can be seen in Table 4 the drying process was effective in reducing Aw in all evaluated conditions. The lowest Aw (0.189) was obtained with the highest temperature (80°C) applied in the process; however, it is convenient to evaluate factors such as energy expenditure in the conservation process and nutrient degradation since the milder temperatures obtained satisfactory results. Santos et al. (2017) obtained water activity between 0.353 and 0.318, when drying pitaya shells at temperatures between 50 and 70°C.

In the analysis of the ash content, there was a significant increase from 0.87 to 9.26% when the *in natura* chili was subjected to drying between temperatures of 50 to 80 ºC. This behavior must have occurred due to the decrease of the humidity of the samples, consequently causing an increase in the ashes.

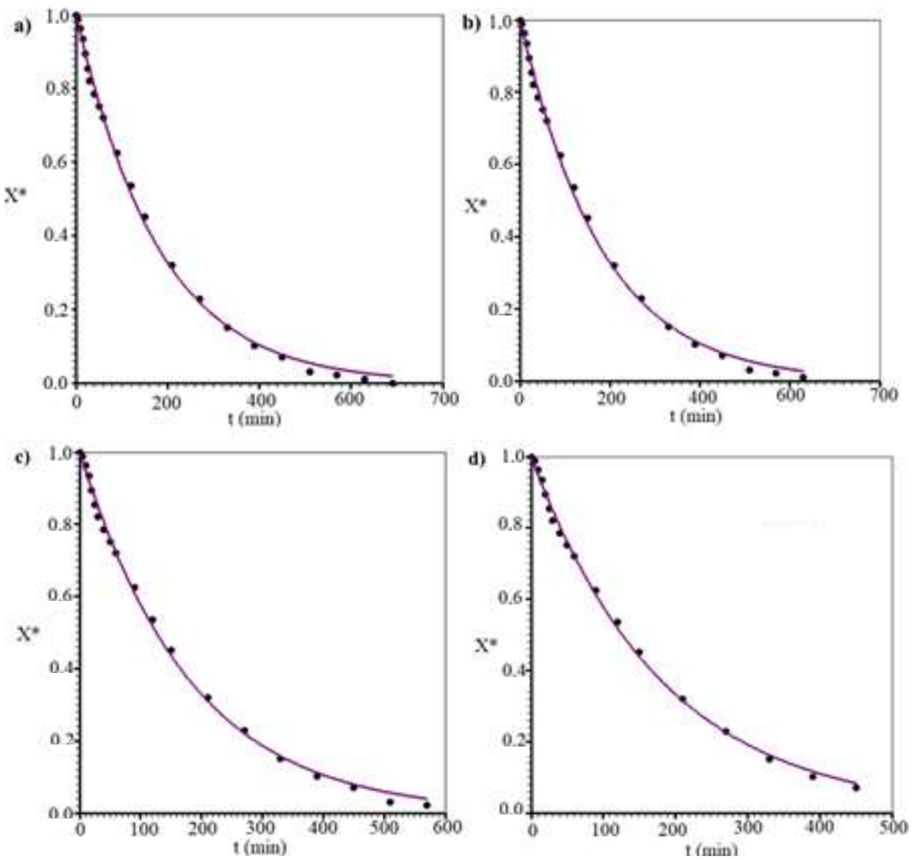

Figure 1. Drying kinetics simulations using the empirical model page at temperature T: (a) 50°C; (b) 60°C; (c) 70°C; (d) 80°C.

Table 3. Physical-chemical characterization and thermosensitive compounds of yellow pepper before drying.

Parameter	Mean and standard deviation
Moisture[1] (%, u.b)	90.88 ± 0.155
A_w	0.982 ± 0.006
Ashes (%)	0.87 ± 0.041
Proteins (%)	1.67 ± 0.053
Lipidis (%)	0.39 ± 0.031
Carbohydrates (%)	6.19 ± 0.135
Vitamin C (mg of ascorbic acid/100g sample)	234.64 ± 0.546
Total phenolic compounds (mgGAE.100g^{-1})	38.49 ± 2.491

[1] umid base.

Chouaibi et al. (2019) quantified ash contents of 3.05% in red pepper seeds. The temperatures obtained for the temperatures of 70 and 80°C do not present statistical difference, as well as those obtained for the temperatures of 50 and 60°C.

In the quantification of the protein content, it was verified that the highest protein content was obtained for the dried pepper at 50°C; and that temperatures above 60°C caused degradation of this. Although there was a variation between the *in natura* pepper and the drying temperatures, this parameter presented similar behavior to the ash content, in which the temperatures of 50 and 60°C; 70 and 80°C did not differ statistically from each other. Silva et al. (2018) in green pepper studies obtained

Table 4. Physico-chemical characterization and thermosensitive compounds of dehydrated peppers.

Parameter	Temperatures (°C)				CV (%)
	50	60	70	80	
Moisture (%, d.b[1])	13.69^{a}	10.95^{b}	8.98^{c}	7.90^{d}	1.50
A_w	0.388^{a}	0.302^{b}	0.284^{b}	0.189^{c}	3.04
Ashes (%)	7.63^{b}	8.45^{b}	9.84^{a}	10.13^{a}	4.64
Proteins (%)	2.15^{a}	2.10^{a}	1.96^{b}	1.84^{b}	2.35
Lipids (%)	4.59^{b}	4.85^{a}	4.88^{a}	4.33^{c}	1.16
Carbohydrates (%)	71.94^{c}	73.65^{b}	74.34^{b}	75.80^{a}	0.62
Vitamin C (mg of ascorbic acid/100g sample)	220.89^{a}	218.36^{b}	214.57^{c}	209.63^{d}	0.18
Total phenolic compounds (mgGAE.100g^{-1})	34.68^{a}	32.20^{b}	31.19^{bc}	30.79^{c}	1.64

[1]Dry base; Letter superscripts equal in the same line do not present significant difference at the 5% probability level. CV: Coefficient of variation.

protein contents ranging from 2.36 to 2.46% when the drying air temperature ranged from 60 to 80°C. Considering the dehydrated material, it is possible to observe that the milder temperatures resulted in better values for this parameter, evidencing that the use of high temperatures in the drying process, can cause a degradation of the proteins.

Regarding the lipid content, the treatments at 60 and 70°C presented the highest values for this parameter, followed by treatments of 80 and 50°C, respectively. The choice of drying method should be well studied since the use of temperatures higher than 50°C and high pressures can degrade important components of the product. For example, drying with greenhouse, which uses heating for a longer time, can modify the physical and chemical properties of the material, especially the ability to retain lipids, which interferes with the quality of the final product (Fornaiser et al., 2018).

In relation to the total carbohydrate content, it was observed that the increase was directly proportional to the temperature increase and inversely proportional to the water content, since these did not suffer thermal degradation and increased with the least amount of water available in the material. Carbohydrate values for the treatments at 60 and 70 °C did not differ statistically from each other. According to Fennema et al. (2010), carbohydrates, alongside water, are more abundant and better distributed in foods of plant origin, and can vary widely among them, and besides their nutritional value help to make food palatable and more pleasant looking.

Higher percentages of Vitamin C were quantified in the pepper of the lower temperature treatment, and for all temperatures, there were significant differences between them. The increase of the drying temperature caused a reduction of 25.01% of the ascorbic acid. Agostini-Costa et al. (2017) quantified ascorbic acid levels for yellow japonica pepper ranging from 136 to 222 mg of ascorbic acid/100g sample. According to Rebouças et al. (2013) and Silva et al. (2018a) vitamins are very sensitive compounds and can be degraded by several factors, such as temperature, oxygen presence, light, humidity, pH, duration of treatment to which the food was submitted, among others.

The highest index of total phenolic compounds was presented in the chili peppers submitted to the lowest temperatures until the highest temperature (80°C), which presented lower value (30.79 mgGAE.100g^{-1}), since drying promotes degradation of the components thermosensitive food. The values of the treatments 60 and 70°C did not present significant differences among themselves, as well as between 70 and 80°C. Lahbib et al. (2017) quantified in the pericarp of 11 different pepper cultivars levels of total phenolic compounds ranging from 6.82 to 4.06 mgGAE.100g-1.

Conclusion

In all applied temperatures, the proposed models presented determination coefficients superior to 0.99, representing adequately the drying process studied. Page's model was the one that best described the drying kinetics of yellow pepper for the drying treatments applied. The chili *in natura* presented high moisture content and high water activity, higher values for protein content, vitamin C and total phenolic compounds. The treatment of 80°C presented lower moisture content, low water activity, high ash content and carbohydrates, also causing a degradation of Vitamin C and total phenolic compounds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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