Advance Journal of Food Science and Technology 15(SPL): 21-27, 2018
DOI:10.19026/ajfst.15.5868
ISSN: 2042-4868; e-ISSN: 2042-4876

Submitted: September 9, 2017 Accepted: October 31, 2017 Published: July 10, 2018

Research Article

Evaluation of the Kinetics of Drying Sweet Chili (*Capsicum annuum*) in a Tray Dryer

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Abstract: This study establishes the kinetics regarding the drying process of sweet chili (*Capsicum annuum*), in order to obtain flour through a tray dryer. The sweet chili samples of 9±0.2° Brix, humidity 91.18% and green coloration were adapted to 2.3×2.3 cm dimensions, dried at 50, 60 and 70°C temperatures on a tray dryer with forced air at 2.7m/s, continual weight. The drying curves were adjusted to 12 mathematical models, determined through adjusted R^2 and the Sum of Squared Errors (SSE) that the Midilli and Kucuk model best describe the drying process at a 50°C temperature (R^2 of 0.9976 and SSE of 0.012), at 60°C (R^2 of 0.9972 SSE of 0.011) and 70°C (R^2 of 0.9960 SSE of 0.012).

Keywords: Drying kinetics, drying temperatures, mathematical models, sweet chili, tray dryers

INTRODUCTION

Sweet chili (*Capsicum annuum*) is a product typically cultivated in Colombia informally; this subsector is poorly structured, with the possibility of technification due to the low production costs and the profitability it has, mainly in Valle del Cauca and Cordoba department (Asohofrucol, 2013). Regarding the Caribbean region, sweet chili production is very important and it is considered a main component in the food manufacturing like stews, sauces, soups and canned products because of its peculiar flavor and scent. The variety of uses of sweet chili, favors the fact that it is considered an added value, developing products like chili flour for later commercialization as condiment, guaranteeing with its preservation a more stable market against the ever-changing prices due to the supply and demand (Asohofrucol, 2013).

Drying is one of the oldest methods for food preservation; nowadays it serves that purpose along with ensuring the food quality and a commercial alternative for markets (Estrada Velázquez, 2006). Dehydrated products, compared to fresh ones, offer great advantages because of their larger life span due to the reduction of water conteined which also favors the microorganism reduction and the enzymatic activity (González *et al*., 2008). The study of temperature, time and drying speed variables, are determined by the quality of the product; therefore, an excess of drying air exposure would deteriorate the sweet chili flour while low exposure would neglect the correct dehydration. In both situations the organoleptic characteristics would be altered (Krokida and Maroulis, 2001 quoted by Vega *et al*., 2005; Colina, 2010).

The following investigation is oriented to determine the kinetics regarding the drying process of sweet chili (*Capsicum annuum*), in order to obtain flour through a forced air tray dryer.

MATERIALS AND METHODS

Obtaining prime materials and adequacy of the sample: The chili was obtained at a public market of the city of Monteria, with a green coloration, fresh and uniform with a 9-10 °Brix and 91-92% humidity, apt for processing and consumption, sane with the absence of damages caused by bumps, microorganisms or insects. Samples of chili were superficially washed with drinking water, the seeds inside were taken out through a parallel cut and samples of approximately 0.1 cm thickness, 2.3 cm length and 2.3 cm width were obtained.

Determination of the humidity content and initial water activity (aw): Previous to the drying trials, initial humidity of the fresh sweet chili was established using the described method on the (AOAC, 2003). With the obtained value, the dry weight of the sample was calculated for each temperature. In addition, the aw of

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Table 1: Mathematical models for drying adjustment

Name of the mathematical model	Equation of the mathematical model
Newton	$MR = (e^{-kt})$
Page	$MR = (e^{-kt^{y}})$
Page (Modified)	$MR = e^{\lfloor(-kt)^{y}\rfloor}$
Henderson and Pabis	$MR = a[e^{-kt}]$
Logarithmic	$MR = a[e^{-kt}] + C$
Wang and Sing (Thomson)	$MR = 1 + at + bt^2t = aln(MR) + b[ln(MR)]^2$
Diffusion approximation (Difusión)	$MR = a[e^{-(kt)}] + (1-a)[e^{(-kbt)}]$
Two terms	$MR = a\lfloor e^{(-kt^{n})}\rfloor + bt$
Midilli and Kucuk	$MR = a[e^{(-kt)}] + b[e^{(-gt)}] + c[e^{(-ht)}]$
Henderson and Pabis (Modified)	$MR = a[e^{(-kt)}] + (1-a)[e^{(-kat)}]$
Two exponential terms	$MR = e^{[-k(\frac{t}{L^2})^{n}]}$
Page (Modified, equation II)	

the fresh samples was determined by equipment from the brand Novasina, LabMaster-aw model at 25°C, with three repetitions for both tests.

Sweet chili samples dehydration: In order to determine the drying curves, 50 g samples of sweet chili were used, with known dimensions they were placed on the tray, verifying they completely covered the base and were put into the drying chamber of the convection oven, brand Technicook, model MINICONV, dimensions 580 mm width, 630 mm depth, 435 mm height, Laboratory tray GIPAVE from the University of Cordoba, Berastegui campus.

Treatment temperature conditions of 50, 60 and 70°C were applied, drying air speed of 2.7 ms^{-1}. A weight control of the samples is being held every 5 min throughout the process until constant weight values were obtained, using an analytical scale (Mettler PC4000 with 0.01 g accuracy). This procedure was applied to every treatment with three repetitions.

Drying curves construction and mathematical models of the drying kinetics: For the drying curve construction, the Geankoplis (1993) method was used for which a data conversion of the humidity on a humid base content (water kg/humid product kg) to dry base humidity content (water kg/dry solid kg) was made, using Eq. (1) (Zuluaga *et al*., 2010):

$$X_t = \frac{W - W_s}{W_s}\left(\frac{water\ kg}{dry\ solid\ kg}\right) \quad (1)$$

where,
X_t = Humidity content on dry base on time
W = Humid solid weight
W_s = Dry solid weight

After establishing the humidity content balance (X*), the value of free humidity content was calculated (X) on the food for each value of X_t, Eq. (2) (Zuluaga *et al*., 2010):

$$X = X_t - X^* \quad (2)$$

where,
X = Free humidity content
X_t = Dry base humidity content in time
X^* = Balance humidity content

Then, the speed R was calculated in time for each temperature, through Eq. (3) (Colina, 2010):

$$R = -\frac{L_s dx}{Adt} \quad (3)$$

where,
R = Drying speed
L_s = kg of used dry solid
A = Superficial area exposed to drying

Afterwards, a graph of the humidity content of the dry based product was made, opposite to time in order to determine the drying curves and the graph of the drying speed opposite to the free humidity of the product in order to determine the drying phases.

With the purpose of determining the mathematical modeling of the experimental data drying curves the adjustment to those 12 models were evaluated (Table 1) using as a dependent variable the humidity reason (MR), calculated through Eq. (4) (Michalewicz *et al*., 2011) and the nonlinear regression method for the estimation of the model constants:

$$MR = \frac{X - X_e}{X_o - X_e} \quad (4)$$

where,
X = The humidity content on a specific lapse of time
X_e = The balance humidity content
X_o = The initial humidity content, all expressed in water g/dry matter

The criteria used to evaluate the quality of the obtained adjustment of the proposed models over the experimental data were the adjusted R^2adjusted and the Sum of Squared Errors (SSE). Low SSE and high R^2values were used as criteria to indicate the high adjustment of the model (Espinosa, 2013).

The diffusion coefficient was calculated using a diffusion model from the second law of Fick for an infinite plate geometry and the uniform distribution of the initial humidity Eq. (5) obtaining the value from the slope of the In (MR) graph in function of time for each temperature (Michalewicz *et al*., 2011):

$$MR = \frac{X - X_e}{X_0 - X_e} = \frac{8}{\pi^2} e^{\left(\frac{-D_f \pi^2 t}{4L^2}\right)} \quad (5)$$

where,
D_f = The effective coefficient of water diffusivity (m^2 s^{-1})
t = Time in hours
L = The thickness factor of the finite plate (m)

To determine the activation energy, it was taken into account the fact that the drying temperature influence over water diffusion in food follows an Arrhenius-type tendency (see Eq. 6), obtaining the value from the slope of the Ln D_a graph in function of the temperature inverse ($\frac{1}{T}$) and the Arrhenius factor (D_a) of the ordinate in the origin (Vega *et al*., 2005):

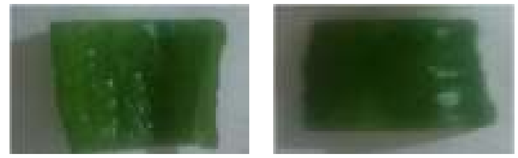
$$D_a = D_0 e^{\left(-\frac{E_a}{RT}\right)} \quad (6)$$

where,
E_a = The activation energy of the diffusion
R = The gas constant
T = The absolute temperature
D_0 = The diffusion for high humidity contents

For The experimental analysis, the nonlinear regression method was used, in order to estimate the model constant, selecting the model that fit best, using as choosing criteria the adjusted R^2 and the Sum of Squared Errors (SEE). The data was processed and evaluated through the Statgraphics Centurion XVI software. A completely random experimental design was applied, having as treatment the air drying temperature on three levels (50, 60 y 70°C) and three repetitions of each for a total of 9 experimental units. The results were Analyzed through a Variance Analysis (ANOVA) in order to determine if significant statistical differences existed at a 95% reliability rate. The significant differences were established using the Tukey test with a reliability rate of 95% in the statistical program Statgraphic Centurion XVI (16.2.04 version) and Microsoft Excel.

RESULTS AND DISCUSSION

Sample characterization and adequacy: The selected samples of sweet chili were green, presenting 9±0.2 °Brix, firmness (lbf) 12-16 and were geometrically fitted with the following dimensions: 0,1 cm de thick, 2.3 cm length and 2.3 cm width approximately (Fig. 1). The humidity content of the fresh product was 91.189±0.01% and the water activity of the fresh sample was 0.84±0.01.



(a) (b)

Fig. 1: Samples of sweet chili for drying

Drying speed curves: In the Fig. 2 are shown the drying speed curves of sweet chili (*Capsicum annuum* L.) at three temperatures (50, 60 and 70°C), evidencing through variance ANOVA analysis a highly significant influence of the temperature over sweet chili drying time, with a significant level of 5%. After the Tukey media comparison test it was observed significant differences among the three studied levels, because when the temperature is increased, the drying time lowers significantly, taking up less time to finalize the drying process at 70°C (230 min) than for 50°C (435 min) and 60°C (315 min), up until it reaches the same balanced humidity. Similar effects of the temperature over the process were obtained for red pepper (Vega *et al*., 2005), Chilean papaya (Vega and Lemus, 2006), guava (Hincapié *et al*., 2011) and Tabasco (Arrieta *et al*., 2015). Also, an initial drying phase is distinguished within the first 75 min at 50°C, 80 min at 60°C and 90 min at 70°C, in which the humidity loss on dry base of the sample has a lineal behavior of (R^2>90%), just like the drying speed for the same period of time, power assigned to the quick redistribution of humidity and the migration to the surface (Hincapié *et al*., 2011). After this phase the speed slows down faster until it reaches the humidity balance. It is characteristic because in it, most of the drying process happens, because humidity is spreaded with less speed through a solid.

Drying speed curves: In Fig. 3 we can appreciate the behavior of the drying speed of sweet chili (*Capsicum annuum* L.) through the three temperatures (50, 60 and 70°C), from which can be deduced (with the obtained ANOVA analysis) that the kinetics of drying of the sweet chili depend on the drying air temperature, being highly influential with a significance level of 5%. After going through with the Tukey tests the significant differences were observed among the three evaluated levels, due to the fact that when the air drying temperature is increased, the drying speed increases, appreciating initial average speeds at 70°C for 2.26 kg of water, $h^{-1}m^{-2}$, a significant higher value than the ones presented at 60°C with a speed of 1.78 kg of water $h^{-1}m^{-2}$ and this one at 50°C of 1.37 kg of water $h^{-1}m^{-2}$ of speed.

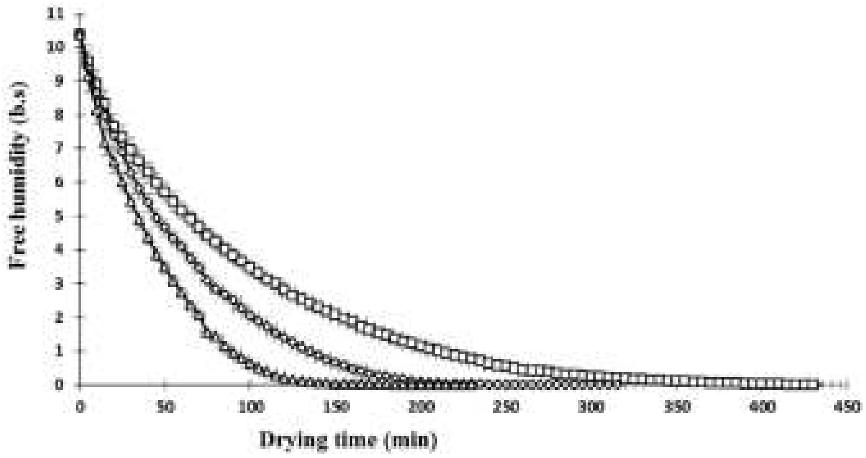


Fig. 2: Drying speed curves of the sweet chili at 50, 60 and 70°C temperatures. □50°C; ◇ 60°C; △70°

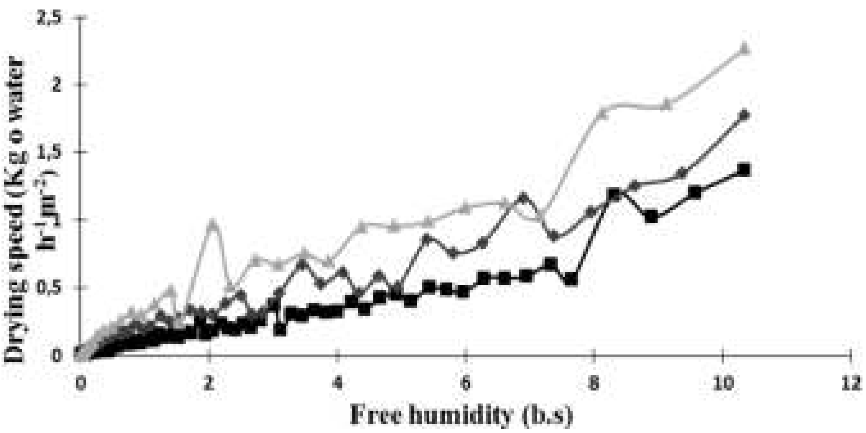


Fig. 3: Drying speed curves of sweet chili at 50, 60 and 70°C. ■ 50°C; ◆60°C; ▲ 70°C

Table 2: Midilli and Kucuk model constants for the temperatures of the paper

	Midilli and kucuk model parameters					
Treatment	k	a	b	N	R^2adjusted	SSE
50°C	0.6513	0.9586	3.412E-04	1.002	0.9976	0.012
60°C	0.933	0.960	6.841E-04	1.117	0.9972	0.011
70°C	1,34	0.953	9.203E-04	1.207	0.9961	0.012

In Fig. 3 the drying speed phases are illustrated, evidencing an absence of the constant speed span and the induction period, because the dried, at the moment of the sample being introduced, was at the required temperature. In addition, a fast-speed decreasing period is presented which makes the surface harden followed by a slower decreasing period in which the product surface is completely dry and the vaporization level starts to move, which is why the evaporated water goes through the solid in order to reach the air current so the samples start evidencing a more accentuated shrinking in this period (Jhonson, 2013). Similar effects of temperature over drying speed were reported on studies over drying peppers (Vega *et al*., 2005), Plantains (Sandoval-Torres *et al*., 2006), raspberry laminas (Jhonson, 2013) and Tabasco (Arrieta *et al*., 2015).

Mathematical modeling of the drying curves: The Midilli and Kucuk model is satisfactorily adjusted to the obtained experimental data for the construction of the sweet chili drying curves at 50, 60 and 70°C applied temperatures, with adjusted R^2 values superior to 99% and squared added values of the lowest error compared to the ones obtained for the remaining 11 evaluated models. In Table 2 the Midilli and Kucuk model parameter values are showing that the values of k and n are higher in treated chili at 70°C than the one treated at 60°C and 50°C.

Another drying products studies expose Midilli and Kucuk ad the model with the best fit regarding the dehydration behavior of yam (García-Mogollon *et al*., 2016). On parsley Lema *et al*. (2007) evaluated twelve mathematical models and found that the Logarithmic

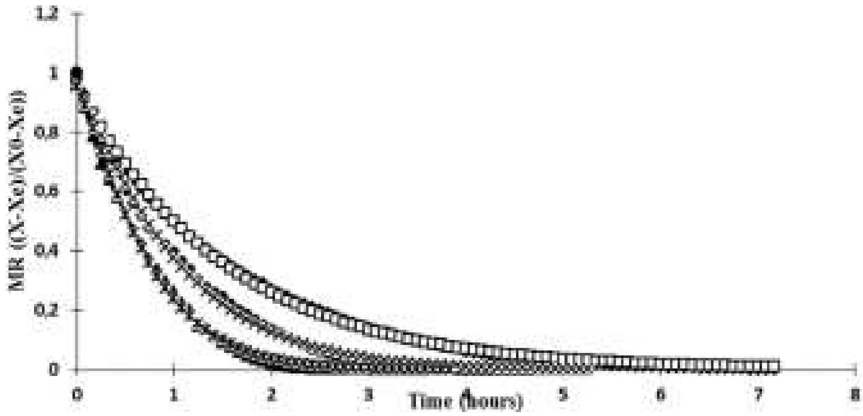


Fig. 4. Comparison of the MR for experimental data and adjusted models ▲ 50°C Exp; □ 50°C Mod; ● 60°C Exp; X 60°C Mod;◆ 70°C Exp

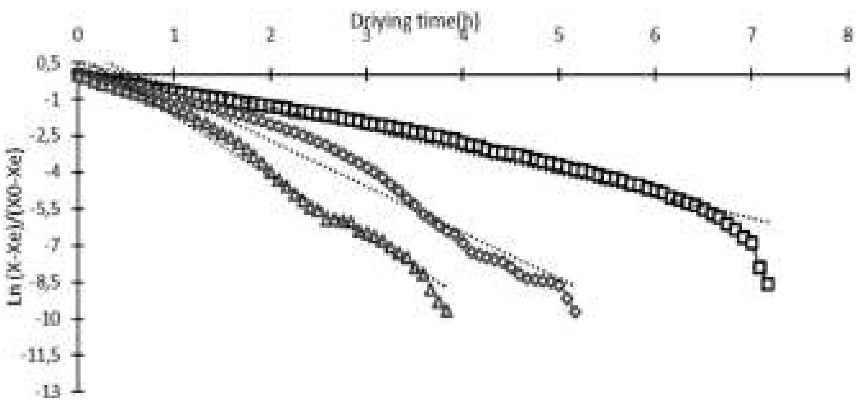


Fig. 5: Logarithmic correlation for the drying curves at 50, 60 and 70°C.° □ 50°C; ◇ 60°C; △ 70°C

model fits well with the experimental data, nevertheless the model that better fit was the Midilli and Kucuk while the Michalewicz *et al*. (2011) investigation in cajuil drying and Da Rocha *et al*. (2012) on thyme signal the Page model as the best fit for the experimental data.

Figure 4 compares the humidity reason (MR) experimentally obtained with the model that fit best, we can observe a very similar experiment-model tendency, confirming the well-adjustment of the model.

Diffusion coefficient and activation energy: To model the decreasing speed phase, the difusional model was used. The diffusion coefficient for each temperature was calculated from Fig. 5 where Ln (MR) is connected in relation of time.

The diffusion values presented significant differences ($p<0.05$) among the drying air temperatures (ANOVA), through the Tukey median comparison analysis it was discovered that diffusion levels at 50, 60 and 70°C present significant differences amongst each other.

In Table 3 we can observe that the diffusion values increased according to the increase of the drying air temperature which shows an intern resistance decrease

Table 3: Diffusion coefficient (Df) and activation energy (Ea)

Temperature°C	Effectivediffusionm ^{2}/s	Activation energy kJ/mol
50	3.665E-07	46.723
60	7.669E-07	
70	1.005E-06	

of the solid with the increasing of temperature. Similar results were obtained in the chilean papaya (Vega and Lemus, 2006), mango (Ocampo, 2006) and parsley (Lema *et al*., 2007).

Generally, the drying temperature influence over diffusion of the sweet chili water follows an Arrhenius-like tendency, using Fig. 6 in which Ln (Df) is in function of the temperature inverse (1/T), which permits the obtaining of a straight line, the slope representing the activation energy.

In Table 3 we can observe the activation energy which is found in the value range found in food material literature proposed by some authors: 28.39 kJ/mol for carrots (Doymaz, 2004); 39.7 kJ/mol for red pepper (Vega *et al*., 2005); 20 kJ/mol for potatoes and 149 kJ/mol for parsley (Lema *et al*., 2007). Said value represents the required energy to start the humidity diffusion of sweet chili, indicating the influence of the temperature in the process (Espinosa, 2013).

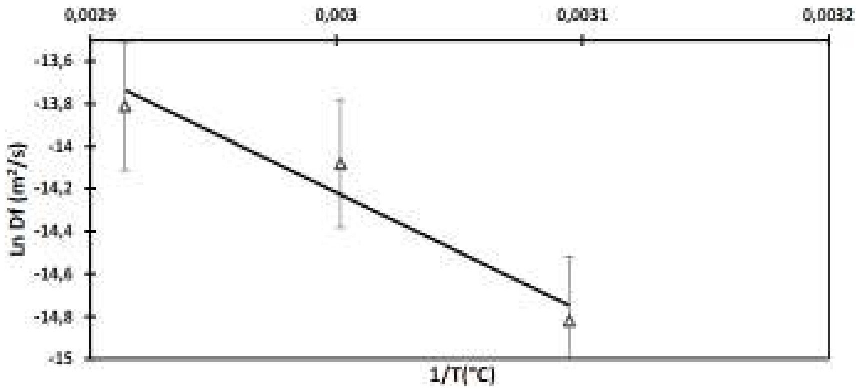


Fig. 6: Exponential correlation of diffusion (Df) at 50, 60 and 70°C

CONCLUSION

The drying air temperature was highly influential on the drying time, reflecting lower times for each increasing of it; on the other hand the drying speed raised when the temperature was increased as well. The Midilli and Kukuc model satisfactorily describes the sweet chili drying curve when treated at 50°C (R^2 adjusted by 0.9975), 60°C (R^2 adjusted by 0.9972) and 70°C (R^2 adjusted by 0.9960) with values of R^2>0.99 and SSE ≤ 10%.

REFERENCES

AOAC, 2003. Official Method of Analysis 950.46. Association of Official Analytical Chemists. Arlington, Virginia.

Arrieta, A.R.A., J.A.R. Angulo and T.M.R. Rocha, 2015. Secado de ají tabasco (*Capsicum frutescens*) mediante deshidratación por convección forzada. Rev. Prospect., 14(1): 89-95.

Asohofrucol, 2013. Programa de Transformación Productiva. Fondo Nacional de Fomento Hortofrutícola, Plan de Negocios de Ají, Bogotá, pp: 7-10, 30-31.

Colina, M., 2010. Deshidratación de Alimentos. Editorial Trillas, México, pp: 61-62-70.

Da Rocha, R.P., E.C. Melo, J.B. Corbín, P.A. Berbert, S.M.L. Donzeles and J.A. Tabar, 2012. Cinética del secado de tomillo. Rev. Bras. Eng. Agríc. Ambient., 16(6): 675-683.

Doymaz, I., 2004. Convective air drying characteristics of thin layer carrots. J. Food Eng., 61(3): 359-364.

Espinosa, A.M.T., 2013. Determinación de la influencia de la temperatura y velocidad del aire sobre las cineticas de secado sobre tres variedades de yuca procesadas en la planta instalada en la vereda los algarrobos. M.Sc. Tesis, Departamento en Ciencias Agroalimentarias con énfasis en Ingeniería, Universidad de Córdoba, Berástegui.

Estrada Velázquez, L.M., 2006. Tipo de secado y características en algunos alimentos. Monografía, Universidad Autónoma Agraria Antonio Narro, Coahuila, pp: 50.

García-Mogollon, C., M. Sierra-Bautista and L. Miranda-Ramos, 2016. Modelado de la cinética de secado en microondas de ñame. Inf. Tecnol., 27(1): 61-68.

Geankoplis, C.J., 1993. Transport Processes and Unit Operations. 3rd Edn., PTR Prentice Hall, Engelwood Cliffs, New Jersey.

González, A., A. Espinoza Estaba, A.E. Cañizares Chacín and J.R. Méndez Natera, 2008. Obtención de un polvo de ají dulce (*Capsicum chinense*) producido mediante deshidratación por aire forzado. Rev. Cien. UDO Agríc., 8(1): 118-126.

Hincapié, G.A., J.A. Barajas and Z. Arias, 2011. Evaluación del secado por convección de la guayaba (*Psidium guajava* L.) variedad manzana. Rev. Invest. Aplicadas, 5(2): 92-103.

Jhonson, D.A.Y., 2013. Elaboración de láminas de frambuesa (*Rubus idaeus*) con adición de diferentes semillas y sucralosa. Tesis Ingeniero de Alimentos, Universidad Austral de Chile, Valdivia.

Lema, A., M. Pontin, A. Sanmartino, M. Ziletti and M. Martinello, 2007. Características del proceso de secado en capa delgada del perejil. Rev. Avances Energ. Renov. Medio Amb., 11(8): 75-82.

Michalewicz, J.S., J.R. Henríquez and J.C. Charamba, 2011. Secado de Cajuil (*Anacardium occidentale* l.): Estudio experimental y modelado de la cinética de secado. Inf. Tecnol., 22(6): 63-74.

Ocampo, A., 2006. Modelo cinético del secado de la pulpa de mango. Rev. EIA. Esc. Ing. Antioq., 1(5): 119-128.

Sandoval-Torres, S., J. Rodríguez-Ramírez, L. Méndez-Lagunas and J. Sánchez-Ramírez, 2006. Rapidez de secado reducida: Una aplicación al secado convectivo de plátano Roatán. Rev. Mexicana Ingen. Quím., 5(1): 35-38.

Vega, A.A. and R.A. Lemus, 2006. Modelado de la cinética de secado de la papaya chilena (*Vasconcellea pubescens*). Inf. Tecnol., 17(3): 23-31.

Vega, A., A. Andrés and P. Fito, 2005. Modelado de la cinética de secado del pimiento rojo (*Capsicum annuum* L. cv Lamuyo). Inf. Tecnol., 16(6): 3-11.

Zuluaga, J.D., M. Cortés Rodríguez and E. Rodríguez-Sandoval, 2010. Evaluación de las características físicas de mango deshidratado aplicando secado por aire caliente y deshidratación osmótica. Rev. Fac. Ingen., 25(4): 127-135.