Biotecnia
Revista de Ciencias Biológicas y de la Salud
www.biotecnia.uson.mx
Universidad de Sonora
"El saber de mis hijos hará mi grandeza"

FLUIDIZED BED DRYING PROCESS OF MINIFLAKES BANANA (*Musa acuminata*)

PROCESO DE SECADO EN LECHO FLUIDIZADO DE MINIHOJUELAS DE PLATANO (*Musa acuminata*)

Calderón-Santoyo M[1], López-Hurtado JA[1], Luna-Solano G[2], Bautista-Rosales PU[1] and Ragazzo-Sánchez JA[1]*
[1]Instituto Tecnológico de Tepic. Laboratorio Integral de Investigación en Alimentos. Av. Tecnológico No. 2595, C.P. 63175. Tepic, Nayarit, México. Tel. (311) 213 15 43. | [2]Instituto Tecnologico de Orizaba. Division de Estudios de Posgrado e Investigacion, Av. Oriente 9 No. 852, CP. 94320. Orizaba, Veracruz, México.

ABSTRACT

The influence of pre-treatment and drying conditions on physical characteristics (moisture content, water activity, net colour difference, shrinking and effective diffusivity) of banana miniflakes during fluidized bed drying was investigated. Banana miniflakes in physiological state (diameters 1.0 - 2.0 cm) were pre-treated with citric acid solution (0-1 % w/w) before to be submitted to the drying process. Drying process (air temperature 50-70 **°C**) timed 90 min and was monitored every 5 min. A surface response model was used in order to analyse the effect of factors. Citric acid solution (1 % w/w) decrease colour difference since a minor difference of 2.72 was obtained. Banana miniflakes showed aw<0.2 after 60 min treatment, supposing a microbiological stable product. Miniflakes shrinking turned out to be independent of diameter, then, values from 20-25 % were achieved for the whole samples. It was found an inverse function between diffusivity coefficient (E^{-10}) and diameter sample. Drying of banana miniflakes was influenced by pre-treatment, drying temperature and miniflakes diameter.
Keywords: Banana miniflakes, fluidized drying, response surface.

RESUMEN

La influencia de diferentes pre-tratamientos y condiciones de secado sobre las características físicas (contenido de humedad, actividad de agua y la diferencia de color) de mini hojuelas de plátano cv Roatán (*M. acuminata*) durante el proceso de secado por lecho fluidizado fue investigada. Las minihojuelas de plátano en estado de madurez fisiológica (diámetros de 1, 1,5 y 2 cm) fueron pre-tratadas con solución de acido cítrico (0, 0,5, 1 % w/w). El proceso de deshidratación a temperaturas de 50, 60 y 70 °C, durante 90 min, se monitoreó cada 5 min. Se utilizó un modelo de superficie de respuesta para determinar el efecto de los factores evaluados. La solución de ácido cítrico de 1 % w/w presentó menor diferencia de color (2,72). Después de 60 min de tratamiento las minihojuelas mostraron tener a_w<0,2 suponiendo un producto microbiológicamente estable. La contracción o encogimiento, resultó ser independiente del diámetro, con una función inversa entre el coeficiente de difusión (E^{-8}) y el diámetro de la muestra. En general se observó que el secado de las minihojuelas de plátano fue influenciado por el pretratamiento, la temperatura de secado y el diámetro de las minihojuelas.
Palabras clave: minihojuelas de plátano, secado por fluidización, superficie de respuesta.

INTRODUCTION

Banana is considered one of the most important fruits worldwide because of its high content of vitamins (B, C and K) and minerals (iron, phosphorus and calcium). Da Mota *et al.* (2000) and Langkilde *et al*. (2002), pointed out the convenience of processing banana fruits in physiological state because of the fruits presented a more adequate texture to be dried. In Mexico, banana culture is highly extended but there is a lack of adequate strategies of commercialization and industrialization. Banana is sensitive to chemical and microbial deterioration during postharvest storage and handling; therefore, it has a limited shelf life in a fresh form, causing economic losses. Development of a shelf-stable product from fresh banana is an important consideration to reduce these losses. Rapid expansion of the fast-food industry shows the potential of quick-cooking dehydrated vegetable products to use as rehydrated products or as ingredients in vegetable and soup mixes (Ravindra and Chattopadhyay, 2000). Although the banana is known in the international markets, it is necessary to obtain a processed product with a longer shelf life and consumption diversity to increase its commercialization.

Drying is one of the oldest, most popular and most efficient natural methods for food preservation. In this context it is essential to determine the coefficients for the models used in this process in order to predict the behavior of the drying operation (Baini and Langrish, 2007). The basic aim of the drying process is the removal of water from the food products up to a level, at which microbial spoilage and deterioration are minimal (Cohen and Yang, 1995). In the cases of fruits, dehydration is generally carried out by convective drying. Many studies have been carried out for various types of vegetables like carrots, pepper, corn, tomatoes, mushrooms, garlic, onions, potato, spinach, pumpkin and banana (Krokida *et al*., 2003; Sukhchan *et al*., 2006; Dorota, 2006; Reyes *et al*., 2007; Demirel andTurhan, 2003). Using

Corresponding author: Ragazzo-Sánchez JA
E-Mail: arturoragazzo@hotmail.com
Recibido: 20 de septiembre de 2012
Aceptado: 1 de noviembre de 2012

convencional air-drying dried products with acceptable physicals and organoleptic characteristics can be obtained (Torregiani and Bertolo, 1998).

The major disadvantage of some drying process of foods is their low energy efficiency and long drying time required for the falling rate period. Among the convective dryers with particle-air contact, the fluidized bed drying offers the advantages of good mixing; high heat and mass transfer coefficients and hence increased drying rate. This drying process involves the fluidizing of particles in a flowing gas stream, typically heated air. Fluidized bed drying offers a tight control of process and product temperature necessary for processing heat sensitive plant and food products (Chua and Chou, 2005).

Response surface methodology (RSM) is a recompilation of mathematical and statistical techniques used to model and analyze problems where a variable is affected by some factors. The aim of this statistical tool is to optimize the variable, finding the optimal conditions for the operation of the system (Montgomery, 2005). The objective of this study was to determinate the optimal operation condition by RSM of banana c.v. Roatan (*M. acuminata*) miniflakes manufacturing by fluidized bed drying.

Nomenclature

ΔE	Net colour difference
ΔL	Luminosity difference
Δa	Green-red difference
Δb	Blue-yellow difference
X	Humidity (kg water/kg d.s.)
a_w	Water activity
t	Time (s)
Xe	Equilibrium humidity (kg water/kg d.s.)
Xo	Initial humidity (kg water/kg d.s.)
L	Distance (m)
Def	Effective diffusivity (m^2/h)
A	Constant
K	Drying constant (m^{-1})
Do	Initial diffusivity
R	Ideal gases constant (8.3144x10-3 kj mol/º K)
T	Temperature (ºK)
Ea	Activation energy (kJ/mol K)

MATERIALS AND METHODS

Materials

Banana variety Roatan (*M. acuminata*) in physiological state was obtained in a local market in Tepic, Nayarit, Mexico. Banana fruits were washed with tap water. Banana miniflakes with diameters of 1,0, 1,5 and 2,0 cm and thickness were obtained by using a cutting device designed for this purpose. Banana miniflakes were dipped into solutions containing citric acid (0, 0,5, 1 % w/w) prior to drying process during 15 minute. Then the miniflakes were dried into a fluidized bed dryer operated at different temperatures (50, 60, 70 ºC) during 90 min with an air rate of 7 m/s.

Drying Equipment

Fluidized bed and tray type pilot plant dryers were used to carry out the drying experiments. Fluidized bed dryer (FBD) with an inner diameter of 0,15 m (cross sectional area = 0,018 m^2) and a height of 0,85 m was used. It had several supporting features such as air flow meter, temperature controller, heaters and pressure manometers. The vertical tray dryer (VTD) used in this study, consisted of a steel drying chamber connected to an electric heater of 4,5 kW capacity. The heater increases the temperature of air to the desired drying temperature and can be electronically controlled within an error limit of ± 1 °C. The drying chamber contains ten perforated trays (0,50 m wide and 0,75 m long) through which the drying air flows vertically. The air velocity in both FBD and VTD dryers was measured with an anemometer at the outlet of the dryer.

Experimental Design

A 2^3 rotatable central composite design with three factors (independent variables) was performed for dehydration of banana miniflakes tests. The experiment was performed three times. The factors investigated were temperature (40-60 ºC), concentration of citric acid (0-1 % w/w) and miniflakes diameter (1,0 – 2,0 cm). Three levels of each variable (Table 1) were chosen for this study, including central values.

Response Variables

Moisture content, water activity, net colour difference, effective diffusivity and shrinking were the response variables evaluated. These variables were monitored every 5 min during the first hour and every 10 min after this period and until 90 min.

Moisture content was determined by a thermobalance (Sartorius MA 35) at 70 ºC. The results were expressed as percentage in dry basis (g water/g d.b).

Water activity was determined with an Aqualab Mod. CX2 (DECAGON Devices, Pullman, Washington) at 25 ºC.

Net colour difference (ΔE): was measured by a colorimeter Hunter Lab (Model MiniScan XE Plus). The equipment was calibrated with White and Black standards. The colour

Table 1. Codified independent variables used for response surface analysis.
Tabla 1. Variables independientes codificadas utilizadas en el análisis de superficie de respuesta

Independent Variables	Symbol Coded	Coded Variables		
		-1	0	+1
Temperature (ºC)	X_1	50	60	70
Citric acid (% w/w)	X_2	0	0,5	1
Miniflakes diameter (cm)	X_3	1	1,5	2

was determined by reflectance mode and expressed as L* (Luminosity), a (green-red) and b (blue-yellow) parameters. Net colour difference between the dried and fresh samples was calculated using the equation 1 proposed by Chen and Ramaswamy (2002).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

It was used a second degree polynomial model (equation 2) to describe the response variables:

$$Y_k = b_{k0} + \sum_{i=1}^{3} b_{ki} X_i + \sum_{i=1}^{3} b_{kii} X_i^2 + \sum_{i^1 j=1}^{3} b_{kij} X_i X_j \quad (2)$$

Where b_{k0}, b_{ki}, b_{kii}, b_{kij} represent regression coefficients (lineal, cross product and quadratic), and X_i's are the codified independent variables (X_1, X_2 and X_3)

Mathematical Considerations

The mathematical study was supported in terms that mass transfer during the drying process is performed from the fruit inner to the outer. Fruit is considered as a thin slide. The Fick's law of diffusion has been applied before to explain the drying process during the final stage were the drying velocity decrease. The diffusion coefficient D is estimated by the equation:

$$D = \frac{4L^2 m}{p^2} \quad (3)$$

The diffusivity dependence on the temperature was calculated with the aid of Arrhenius' equation as follows:

$$D = D_0 \exp\left(\frac{-Ea}{RT}\right) \quad (4)$$

Where, D = Diffusivity; Do = Initial diffusivity; R = Ideal gases constant (8,3144 x 10^{-3} kj mol/ºK), and T= Temperature (ºK). Ea was obtained from the slope resulted from the graphic 1/T vs ln(D).

RESULTS AND DISCUSSIONS

The miniflakes drying kinetics performed at 50, 60 y 70 °C are showed in Figure 1. A dependence of temperature to reach the equilibrium moisture was demonstrated, this profile has been demonstrated before (Villegas-Santiago, 2011).

The exponential regression used to fit the drying kinetics showed a $R^2 > 0,95$ for the whole treatments. The response surface analysis was conducted by StatGraphics software and the optimal values for the factors were found. This analysis indicated that 70 ºC was the optimal temperature to obtain miniflakes with a moisture content significantly lower as the content showed by the samples treated at 50 y 60 ºC. The surface response plot (Fig. 2) showed the effect of the drying temperature on the moisture content, this effect was more significant than the others because a minimal effect

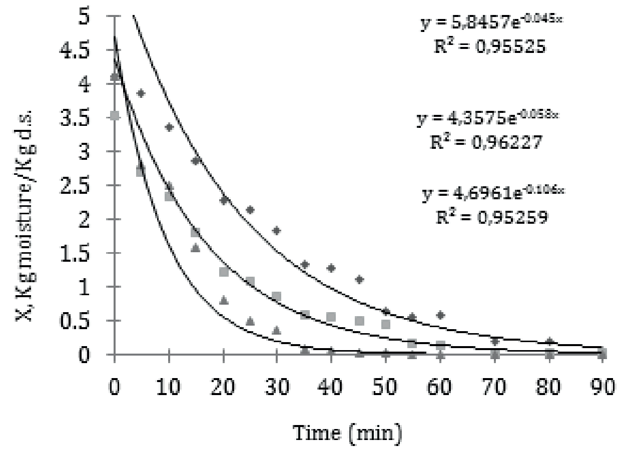

Figure 1. Drying kinetic performed for banana miniflakes diameter of 2 cm and antioxidant concentration of 0,5 % (w/w). (♦) 50, (■) 60 and (▲) 70 ºC.
Figura 1. Cinética de secado de mini-hojuelas de plátano de 2 cm de diámetro y 0,5 % (p/p) de antioxidante. (♦) 50, (■) 60 and (▲) 70 ºC.

was observed during variation of citric acid concentration and miniflakes diameter.

A food is considered as microbiologically stable when water activity (a_w) is lower than 0,5 (Beuchat, 1981). One of the objectives in this study was to optimize the values for the tested factors to obtain miniflakes with a low a_w in order to produce a microbiologically stable product. The surface response plot for a_w showed a clear effect of the temperature on this parameter. As observed in the moisture content profile, there was not a significant effect of the other factors analysed (Fig. 3). According to the surface response analysis,

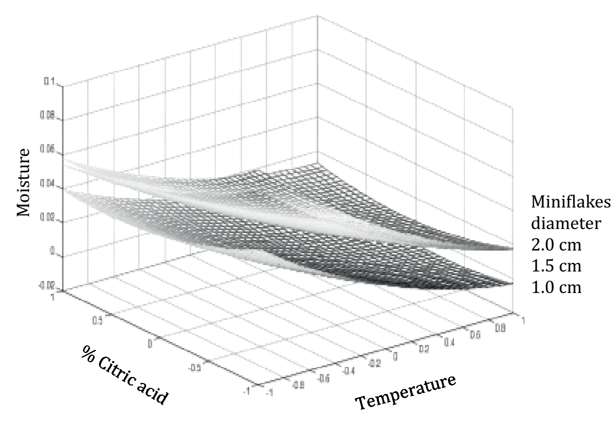

Figure 2. Surface response plot for moisture content as a function of temperature, % citric acid and miniflakes diameter.
Figura 2. Gráfico de superficie de respuesta del contenido de humedad en función de la temperatura, % ácido cítrico y diámetro de mini-hojuelas

the optimal value for the temperature was 70 ºC. This temperature enables the process to obtain a product with a_w lower than 0,5.

The food colour is highly important to have the preference from consumers (Dorota, 2006; Pérez *et al*., 2006; Chen and Ramaswamy, 2002). Thus, it is important to take care of the drying process in order to preserve the characteristics of the fresh product as possible. Two pathways realize the colour changes in oxidation sensible fruits: the enzymatic (PPO) and the chemical (Maillard reaction). The last one is mainly affected by the temperature. Treatments showing a greater net colour change were those in which 0,5 % citric acid was used (Fig. 4). Even if miniflakes in those treatments were treated with the antioxidant, this used concentration was not enough to avoid the oxygen action and to observe a preserving effect on the colour miniflakes.

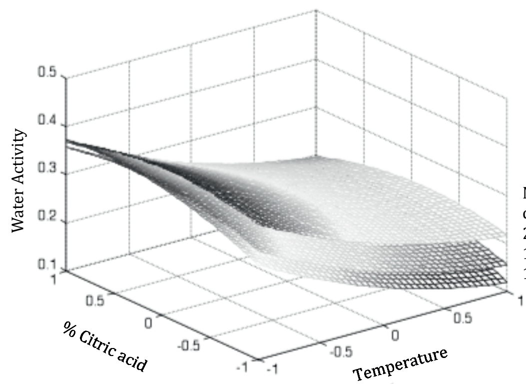

Figure 3. Surface response plot for water activity as a function of temperature, % citric acid and miniflakes diameter.
Figura 3. Gráfico de superficie de respuesta de la actividad de agua en función de la temperatura, % ácido cítrico y diámetro de mini-hojuelas.

The citric acid concentration that minimized the net colour difference was 1 % (Fig. 5). Some reports have demonstrated that citric acid is the best antioxidant among other compounds because of the inactivation of poliphenoloxidase, the enzyme responsible of fruits oxidation (Mancini *et al*., 2009; Limbo and Piergiovanni, 2006; Sammel and Claus, 2006; Villegas-Santiago, 2011). In this case, temperature did not have a significant effect on net colour difference, showing that Maillard reaction does not take place in the process.

Some methods have been reported for obtaining correlations between size reduction and moisture loss throughout the drying process (Nguyen and Price, 2007; Hatamipour and Mowla, 2005; Corzo *et al*., 2008). Figure 6 shows the procedure proposed by Hatamipour and Mowla (2005) to obtain the correlation between the diameter diminution and the moisture loss at the three temperatures tested. In this study, miniflakes shrinking rate was calculated using the correlations showed in the figure 6. In fact, this value corresponds to the slope of the lineal regression used to fit the diameters data plotted as a function of time. Surface response analyses indicate that miniflakes shrinking was only affected by temperature. Then 70 ºC was the temperature that had the greatest effect on size reduction.

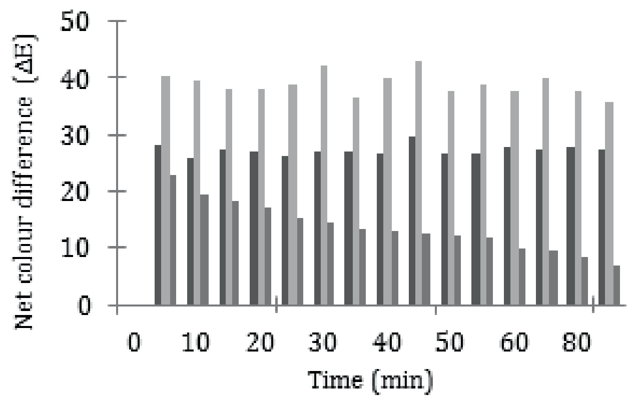

Figure 4. Citric acid concentration effect on net colour difference of miniflakes dried at 70 ºC. (■) 0 %, (■) 0,5 %, (■)1 %.
Figura 4. Efecto de la concentración de ácido cítrico sobre la diferencia neta de color de mini-hojuelas deshidratadas a 70 ºC. (■) 0 %, (■) 0.5 %, (■)1 %.

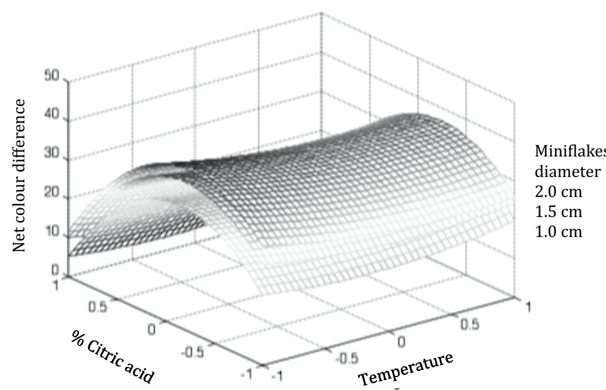

Figure 5. Surface response plot for net colour difference as a function of temperature, % citric acid and miniflakes diameter.
Figura 5. Gráfico de superficie de respuesta de la diferencia neta de color en función de la temperatura, % ácido cítrico y diámetro de mini-hojuelas.

The effective diffusivity coefficient could be affected by factors others than temperature. In this study a clear effect of citric acid addition was observed (Fig. 7). This could be due to the formation of weak bonds with water bonded before to banana components. This water could be considered as free water and be eliminated easier than bonded water in the product. The drying temperature also had influence on the effective diffusivity coefficient, showed a type Arrhenius behaviour. Applying the equation 4, a value of 34,5588036 kJ/mol ˚K for Ea was determined. The model coefficients obtained by regression for the second order polynomials of responses surface of Y_k to Y_5 are shown in table II.

The analysis of variance (ANOVA) performed with the NCSS 2004 software showed that there is a direct relation between temperature and the moisture content, water activity, net colour difference and the effective diffusivity coefficient. The antioxidant (citric acid) concentration affected the net colour difference as well as the effective diffusivity coefficient. Concerning the miniflakes final diameter, it was observed that the factor affecting the most was the antioxidant concentration.

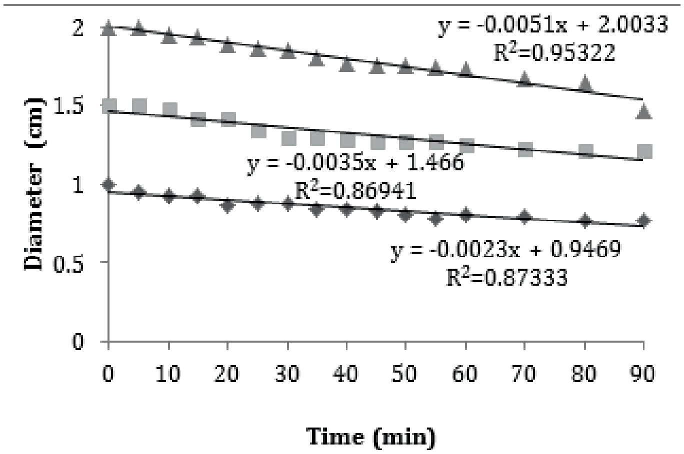

Figure 6. Miniflakes shrinking rate determination during dehydration process (♦ 50 ºC, ■ 60 ºC and ▲ 70 ºC).
Figura 6. Velocidad de deformación de mini-hojuelas durante el proceso de secado (♦50 ºC, ■ 60 ºC and ▲ 70 ºC).

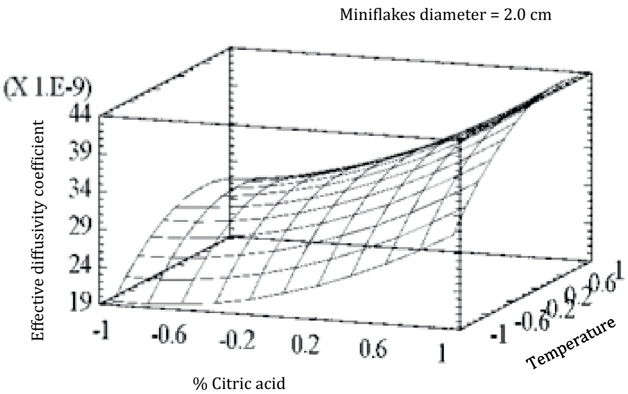

Figure 7. Surface response plot for effective diffusivity coefficient as a function of temperature, % citric acid and miniflakes diameter.
Figura 7. Gráfico de superficie de respuesta del coeficiente de difusividad efectiva en función de la temperatura, % ácido cítrico y diámetro de mini-hojuelas.

Table 2. Regression coefficients obtained for the response surface models
Tabla 2. Coeficientes de regresión obtenidos por el modelo de superficie de respuesta

Coefficient	Y1	Y2	Y3	Y4	Y5
b_{k0}	0,0238258	0,256759	33,804	1,215	3,12532E-8
b_{k1}	-0,0299762	-0,0870833	-0,839189	-0,0358333	7,15164E-9
b_{k2}	-0,00881226	0,0136667	-7,95237	-0,00111111	5,01052E-9
b_{k3}	0,00888257	0,023333	3,10585	0,431111	-4,328E-10
b_{k12}	0,0133696	0,027638	2,57441	0,0341667	3,40852E-9
b_{k13}	0.00860605	0,0035	0,148792	0,000833333	1,17103E-9
b_{k23}	-0,00656386	0,00345833	-1,66825	-0,01625	1,17283E-10
b_{k11}	0,00789693	-0,0299444	-19,2165	0,0	-4,39358E-9
b_{k22}	-0,00791278	-0,0221667	-1,59505	0,00833333	-9,95567E-10
b_{k33}	-0,0107351	0,0130556	-1,54185	-0,0783333	-2,55933E-10

CONCLUSIONS

The drying kinetics were efficiently adjusted by the exponential regression ($R^2 > 0{,}95$) indicating that data are correctly recovered. Optimal conditions calculated by response surface methodology turned out to be perfectly comparable to results obtained by statistical analysis. The optimized factors to obtain the best characteristics for banana miniflakes were temperature of 70 ºC, 1% citric acid concentration and size of 1 cm. The miniflakes drying kinetics for the whole assayed temperatures could be described in terms of the Fick's second law, using the first term. The values for the effective diffusivity coefficient are comparable with those reported for other fruits. Arrhenius behaviour was observed for the temperatures used.

References

Baini, T., y Langrish T.A.G. 2007. Choosing an appropriate drying model for intermittent and continuous drying of bananas. Journal of Food Engineering. 37: 330-343.

Beuchat, L.R. 1981. Microbial stability as affected by water activity. Cereal Foods World. 26(7): 345-349.

Chen, C.R., y Ramaswamy, H.S. 2002. Color and texture change kinetics in ripening bananas. Lebensmittel-Wissenschaft & Technologie. 35(5): 415-419.

Chua, K.J., y Chou, S.K. 2005. New hybrid drying technologies. En: Emerging technologies for food processing. Da-Wen Sun (ed.), pp 535–551. Elsevier Academic Press.

Cohen, J.S, y Yang, T.C.S. 1995. Progress in food dehydration. Trends in Food Science and Technology. 6: 20–25.

Corzo, O., Bracho, N., y Alvarez, C. 2008. Water effective diffusion coefficient of mango slices at different maturity stages during air drying. Journal of Food Engineering. 87(4): 479-484.

Da Mota, R., Lajolo, F.M., Ciacco, C., y Cordenunsi, B.R. 2000. Composition and functional properties of banana flour from different varieties. Starch/Starke. 52(2-3): 63-68.

Demirel, D., y Turhan, M. 2003. Air-drying behavior of dwarf cavendish and gros michel banana slices. Journal of Food Engineering. *59*: 1-11.

Dorota, K. 2006. The effect of enzymatic treatments on dried vegetable color. Drying Technology. 24(9): 1173–1178.

Hatamipour, M.S., y Mowla, D. 2005. Correlations for shrinkage, density and diffusivity for drying of maize and green peas in a fluidized bed with energy carrier. Journal of Food Engineering. 66: 463–468.

Krokida, M.K., Karathanos, V.T., Marouis, Z.B, y Marinos, K.D. 2003. Drying kinetics vegetables. Journal of Food Engineering. 59: 391–403.

Langkilde, A.M., Champ, M., y Andersson, H. 2002. Effects of high-resistant-starch banana flour (RS2) on *in vitro* fermentation and the small bowel excretion of energy, nutrients, and sterols: an ileostomy study. The American Journal of Clinical Nutrition. *75*: 104-111.

Limbo, S., y Piergiovanni, L. 2006. Shelf life of minimally processed potatoes: Part 1. Effects of high oxygen partial pressures in combination with ascorbic and citric acids on enzymatic Browning. Postharvest Biology and Technology. 39(3): 254-264.

Mancini, R.A., Hunt, M.C., Seyfert, M., Kropf, D.H., Hachmeister, K.A., Herald, T.J., y Johnson, D.E. 2007. Effects of ascorbic and citric acid on beef lumbar vertebrae marrow colour. Meat science. 76(3): 568-573.

Montgomery, D.C. 2005. Diseño y Analisis de Experimentos. Ed. Limusa Wiley. México.

Nguyen, M.H., y Price, W.E. 2007. Air-drying of banana: Influence of experimental parameters, slab thickness, banana maturity and harvesting season. Journal of Food Engineering. 79: 200– 207.

Pérez, R., Solis, G., Castillo, J.A., Salgado-Cervantes, M.A., y Luna-Solano, G. 2006. Drying of Mexican chayote wild types. The proceedings of the 15th International Drying Symposium, Budapest Hungary, 20–23 August, 3: 1437–1442.

Ravindra, M.R., y Chattopadhyay, P.K. 2000. Optimization of osmotic preconcentration and fluidized bed drying to produce dehydrated quick-cooking potato cubes. Journal of Food Engineering. 44: 5–11.

Reyes, A., Moyano, P., y Paz, J. 2007. Drying of potato slices in pulsed fluidized bed. Drying Technology. 25(4): 581–590.

Sammel, L.M., y Claus, J.R. 2006. Citric acid and sodium citrate effects on Pink color development of cooked ground turkey irradiated pre- and postcooking. Meat Science. 72(3): 567-573.

Sukhchan, S., Raina, C.V., Bawa, A.S., y Saxena, D.C. 2006. Effect of pretreatments on drying and rehydration kinetics and color of sweet potato slices. Drying Technology. 24 (11): 1487–1494.

Torregiani, D., y Bertolo, G. 1998. High-Quality fruit and vegetable products using combined processes. The proceedings of the 11th International Drying Symposium, Halkidiki Grece, 19–22 August, 1: 930–937.

Villegas-Santiago, J., Calderon-Santoyo, M., Ragazzo-Sánchez, J. A., Salgado- Cervantes, M. A., y Luna-Solano, G. 2011. Fluidized bed and tray drying of thinly sliced mango (*Mangifera indica*) pretreated with ascorbic and citric acid. International Journal of Food Science and Technology. 46: 1296–1302.