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Optimización

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OPTIMIZATION AND EXPERIMENTAL VALIDATION OF FLUIDIZED BED DRYING PROCESS OF MANGO MINIFLAKES

OPTIMIZACIÓN Y VALIDACIÓN EXPERIMENTAL DEL PROCESO DE SECADO POR LECHO FLUIDIZADO DE MINIHOJUELAS DE MANGO

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Abstract

The aim of this work was to optimize the drying process of mango miniflakes, and minimize energy resource (cost) under pre-fixed limits involving mango miniflakes moisture, water activity, color and production. The optimization of mango miniflakes drying was made by using genetic algorithms for minimum process cost and color difference between fresh and dried samples (moisture$\leq$0.10 g water g d.m.$^{-1}$). The optimum drying conditions were found at air temperature of 50 °C with 1.9 cm of sample diameter, and 0.083 % of citric acid concentration. On the optimized drying conditions, dried miniflakes presented values with moisture content of 0.025 g water g d.m.$^{-1}$, color difference of 4, production rate of 0.13 kg h^{-1} and total cost of 11.98 $ kg dried product^{-1}.

Keywords: mango, fluidized bed drying, optimization, energy.

Resumen

El objetivo de este trabajo fue optimizar el proceso de secado de minihojuelas de mango, y minimizar el consumo de energía (costo) bajo límites establecidos para la humedad, la actividad de agua, el color y la producción de minihojuelas de mango. La optimización del secado de minihojuelas de mango fue realizado utilizando algoritmos genéticos con el objetivo de minimizar el costo del proceso y la diferencia de color entre las muestras frescas y las deshidratadas (humedad $\leq$ 0.10 g de agua g de sólido seco^{-1}). Las condiciones óptimas de secado se obtuvieron a una temperatura del aire de secado de 50 ºC con un diámetro de muestra de 1.9 cm y concentración de ácido cítrico de 0.083 % w w^{-1}. Bajo las condiciones óptimas de secado, las minihojuelas de mango deshidratadas presentaron un contenido de humedad de 0.025 g de agua g de sólido seco^{-1}, una diferencia de color de 4, una tasa de producción de 0.13 kg h^{-1} y un costo total de 11.98 $ kg de producto obtenido^{-1}.

Palabras clave: mango, secado por lecho fluidizado, optimización, energía.

1 Introduction

Mango (*Mangifera indica*) represents the most important variety produced and exported from México. This fruit is rich in vitamin A and C. Mango is appreciated by consumers as fresh fruit but also as an ingredient in processed products such as ice creams, cereal, fruit salads or snacks (Sagarpa, 2011; Sudheer *et al*., 2012).

In addition, convective drying is the most frequent dehydration method used in food industry especially for vegetables, seed and fruits (Chua and Chou, 2005). Many studies have been carried out for various types of food like garlic, potato, banana, cassava, coffee grain, agave juice and vegetal pear (Sharma and Suresh, 2006; Pérez-Francisco *et al*., 2008; Blaise *et al*., 2009; Hernández-Díaz *et al*., 2013; Chávez-Rodríguez *et al*., 2016). Regarding studies on the mango, Villegas-Santiago *et al*. (2011) reported how drying process variables and some antioxidants might

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improve physical-chemical characteristic of dried mango. However, the major disadvantage of some drying process of foods is the long drying time required during the falling rate period.

Fluidization is the process by which solid particles attain a fluid-like state by being suspended in a flowing gas or liquid. This state is achieved when the drag force on the particles in the upward-flowing liquid or gas equals or slightly exceeds the weight of the particles. Fluidized bed drying offers many advantages, such as good mixing and high heat transfer and mass transfer coefficients, and hence a faster drying rate with consequently shorter drying time (Sangdao *et al*., 2011; Lozano-Acevedo *et al*., 2011; Dominguez-Niño *et al*., 2016). Then in the fluidized bed dryers, drying occurs rapidly, because it involves the homogeneous fluidizing of particles in a flowing gas stream, typically heated air (Chua and Chou, 2005; Sánchez-Ramírez *et al*., 2007; Vázquez-Chávez and Vizcarra-Mendoza, 2008; Stokie *et al*., 2015). Therefore, the fluidized bed drying is a feasible method to preserve mango.

On the other hand, drying is an energy intensive operation, and a greater understanding of the drying process is important if the drying efficiency is to be increased while maintaining product quality. The main objective of any drying process is to produce a dried product of desired quality at minimum cost and maximum throughput, and to optimize these factors consistently (Perez-Francisco *et al*., 2008). According to Montgomery, response surface methodology (RSM) is a collection of mathematical and statistical techniques that are useful for modeling and analysis in applications where a response of interest (or output) is influenced by several factors (Montgomery, 2005).

Although the drying process is widely used, few studies have focused on the analysis of energy consumption, for instance Hernández-Díaz *et al*. (2013) carried out the optimization of the drying process of coffee grains, in this study the authors used RSM in order to model the behavior of the response variables, and with the models obtained subsequently conducted the optimization of the process, obtaining a reduction of the energy consumption. Nevertheless, several papers have so far dealt with an objective function different of energy resource (Ponciano, 1997; Mudahar *et al*., 1990; Tripathy and Kumar, 2008). For instance, the drying of fresh and osmotically dehydrated garlic (Ponciano, 1997) and potato fluidized bed drying (Mudahar *et al*., 1990; Lozano-Acevedo *et al*., 2011) were optimized by maximizing the final product quality using the RSM. Moreover, by using RSM, Ponciano (1997) determined the minimal drying time required to obtain dried garlic with specified quality. These optimizations of engineering can also be carried out by genetic algorithms. Based on the generic principles of organisms, genetic algorithms (GA) are used to solve optimization problems. GA is the engineering application of the evolutionary process in which organisms adapt to the environment through crossover and mutation (Kim *et al*., 2007).

Thus, the objective of this study was to examine the optimal operation conditions of the drying process of mango miniflakes in order to minimize energy resources (cost) under pre-fixed limits involving mango miniflakes moisture, color and production.

2 Materials and methods

2.1 Materials

Mango (Manila var.) fruits were obtained from mangoes Agricultural Group located in the city of Actopan Veracruz, Mexico. Selecting was based on a similar ripening degree (12-15 °Brix) and fruits showing a skin color more green than yellow. The mangoes were washed, peeled and cut into miniflakes at diameters of 1, 1.5, 2 cm and 0.2 mm thickness. Mango miniflakes were submerged in antioxidant solutions (citric acid) for 20 minutes to prevent non-enzymatic browning during drying process (2 h).

A pilot plant dryer was used for dehydrating mango samples. Fluidized bed dryer (FBD) with an inner diameter of 0.15 m (cross sectional area = 0.01767 m^2) and a height of 0.90 m was used, having several supporting features such as air flow meter, temperature controller, heaters and pressure manometers. The air flow was controlled in the range of 1 and 1.5 ms^{-1} to well fluidized the bed of samples. A schematic diagram of the experimental set-up with dimensions is shows in Fig. 1.

The size of its gas distribution chamber is approximately 0.20 m in length and 0.15 m in diameter. The temperature during the drying process was measured with thermocouples placed inside the inlet section of the drying chamber.

2.2 Optimization parameter

Moisture content of the fresh and dried product was determined with an infra-red moisture balance (MB35 HALOGEN, OHAUS) at 65 °C of samples containing approximately 1 g mango miniflakes.

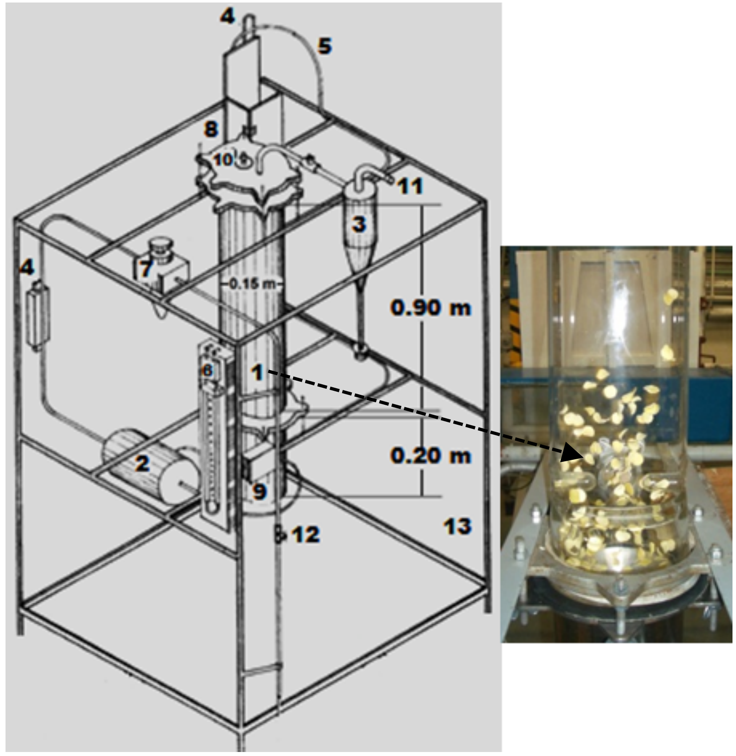

Fig. 1. Schematic diagram of the experimental setup. (1) Fluidized bed chamber. (2) Electric resistances. (3) Cyclone. (4) Anemometer. (5) Thermocouples. (6) Differential manometer. (7) Control valve of pressure. (8) Temperature controller. (9) Gas distribution chamber. (10) Feed hopper. (11) Exhaust gas. (12) Air intake. (13) Metallic support.

Water activity (a_w) of the mango miniflakes taken during drying process was determined at 25±1 °C using Aqualab water activity meter, series 3 TE, DECAGON, Washington.

The color of mango was measured by a colorimeter HunterLab (model MiniScan XE plus). The color was determined by reflectance mode and expressed by L^* (Luminosity), a (green-red) and b (blue-yellow) parameters. After each run of drying, samples of approximately 1 g were taken for color measurements. Color difference (ΔE) between the dried and fresh samples was calculated using following equation:

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

where, $\Delta L = L$ of dried sample $-L$ of fresh sample, $\Delta a = a$ of dried sample $-a$ fresh sample and $\Delta b = b$ of dried sample - fresh sample.

The energy resources required to obtain a dried mango at given moisture and color difference may be defined in terms of cost function per unit of product defined in the following equations:

$$C_T = C_E + C_S \tag{2}$$

$$P = G_{\beta 0}(1 + X_\beta) \tag{3}$$

where, C_T is the total cost (\$ kg^{-1}), C_E is the cost of energy consumed (\$ kg^{-1}) during drying process and C_S is the cost of raw materials (\$ kg^{-1}). The costs were stated (are states) in terms of units (these units are based in México local money: 1 unit=0.17 US\$ in the first half of 2015 year). The costs used were: mango=5 \$ kg^{-1}, citric acid=2800 \$ kg^{-1} and energy=0.9 \$ kW^{-1}h^{-1}. Equation (3) defines the mango production (kgh^{-1}), where, $G_{\beta 0}$ is initial charge of mango miniflakes (kgh^{-1}) and X_β is the water content (kg water (kg dry matter)$^{-1}$) at given time.

2.3 Experimental design and optimization

The experimental design was based on a range of the process parameters which were determined in the preliminary investigations to include the optimum (Villegas-Santiago *et al.*, 2011). Process optimization was conducted using genetic algorithms (GA) to minimize energy resources and color difference between fresh and dried samples. A Box-Behnken design was adopted. In this design, three levels were required for each factor, one central points, thus making the total number of experiment equal to 15 instead of 27 with full factorial design (Mongomery, 2005). Experiments were randomized to minimize the effects of unexplained variability in the observed responses as a result of external factors. The responses were: final moisture content (Y_1), water activity (Y_2), color difference (Y_3), energy consumption (Y_4), production (Y_5) as well as total cost (Y_6) of the dried product. Six mathematical functions $(1,2,3,4,5,6)$ were assumed to exist for Y_k as shown in equation 4.

$$Y_k = f_k(X_1, X_2, X_3) \tag{4}$$

where X_1 is the drying temperature (°C), X_2 is the concentration of citric acid (%, w w^{-1}) and X_3 is the sample diameter (cm). A second-degree polynomial equation of the form of equation 5 was used to approximate the function f_k using the response surface methodology (RSM) of Minitab Release 16.

$$Y_k = b_{k0} + \sum_{i=1}^{3} b_{ki}X_i + \sum_{i=1}^{3} b_{kii}X_i^2 + \sum_{i \neq j=1}^{3} b_{kij}X_iX_j \tag{5}$$

Where Y_k is the response variable and b_{k0}, b_{ki}, b_{kii}, b_{kij} are the regression coefficients for interception, linear, quadratic, and cross product terms, respectively. $X_{i's}$ are the coded independent variables, linearly related X_1, X_2 and X_3. Table 1 shows the independent variables (X_i) with their levels used to determine the optimum drying parameters for mango miniflakes including the coding symbol and codes.

2.4 *Sensory evaluation*

In addition to the optimization of the drying process, a sensory evaluation of dried miniflakes was performed. Thirty students of Instituto Tecnológico of Orizaba, México were selected as panelists of the sensory evaluation. Dried mango miniflakes were analyzed for color, flavor, taste, texture or mouth feel, and overall preference on the nine points hedonic scale. The sensory scored included: like extremely=9, like very much=8, like moderately=7, like slightly=6, neither like nor dislike=5, dislike slightly=4, dislike moderately=3, dislike very much=2, dislike extremely=1. The results were assessed by analysis of variance (ANOVA) using Minitab^{TM} program version 16 (Minitab Inc., USA). Duncan was applied for mean comparison at p=0.05.

3 Results and discussion

3.1 *Response surface analysis and optimization conditions*

Experimental results (Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6) are listed in Table 2 against the coded values from Table 1. An analysis of variance revealed that drying temperature and samples diameter significantly (95 % confidence level) affected color of mango miniflakes while no effect was observed for citric acid. Similar results were obtained by Vázquez-Chávez and Vizcarra-Mendoza (2008), they concluded that the drying temperature had the highest effect on the wheat quality. Preferred colors of a dried product are those closest to the original color of fresh sample. Color is an important factor and is part of the attribute that determines product acceptability (Dorota, 2006; Reis *et al*., 2009). The highest values of color difference occurred at 55 °C and samples diameter of 1.5 cm. These variables caused color darkening on samples of mango. The discoloration during drying may be related to the non-enzymatic browning (Tan *et al*., 2001; Dorota, 2006).

Air temperature significantly (95% confidence level) affected a_w of mango miniflakes. There was no significant difference at 95% confidence level among the treatments in moisture or mango production. Moisture and a_w were ranged from 0.006 to 0.0608 g H_2O g d.m.$^{-1}$ and from 0.334 to 0.675 respectively (Table 2), therefore dried product can be considered free of microorganism growth. The temperature, citric acid and sample diameter affected energy consumption and cost of dried mango miniflakes. In Table 2 can be observed that highest mango cost (20.316 \$ kg d.p.$^{-1}$) corresponded to highest energy consumption (2.494 kW h).

Table 1. The factors used in the optimization study

Independent variables	Independent coded	Coded variables		
		-1	0	+1
Temperature (°C)	X_1	50	55	60
Citric acid conc. (% w w^{-1})	X_2	0	0.5	1
Sample diameter (cm)	X_3	1	1.5	2

Table 2: The experimental data for the response surface analysis

Exp.	Coded		Responses						
	X_1	X_2 X_3	Y_1 (g H_2O g d.m.$^{-1}$)	Y_2 (N.D.)	Y_3) (ΔE	Y_4 (kW h)	Y_5 (kg d.p. h^{-1})	Y_6 (\$ kg d.p.$^{-1}$)	
1	-1	-1	-1	0.0203	0.594	6.53	1.362	0.1312	12.925
2	-1	+1	-1	0.0144	0.564	4.37	2.196	0.1304	18.411
3	+1	-1	-1	0.0064	0.429	2.51	2.351	0.1294	18.985
4	+1	+1	-1	0.0064	0.334	4.55	2.494	0.1294	20.316
5	-1	-1	+1	0.0186	0.562	4.34	1.228	0.1310	12.142
6	-1	+1	+1	0.0608	0.675	5.19	1.228	0.1364	12.137
7	+1	-1	+1	0.0122	0.521	3.83	2.354	0.1302	18.890
8	+1	+1	+1	0.0060	0.400	4.25	2.351	0.1293	19.475
9	0	-1	0	0.0112	0.522	8.54	1.929	0.1300	16.395
10	0	+1	0	0.0230	0.566	7.35	1.848	0.1315	16.200
11	0	0	0	0.0152	0.498	3.70	2.075	0.1305	17.425
12	-1	0	0	0.0202	0.570	4.00	1.337	0.1312	12.997
13	+1	0	0	0.0093	0.448	3.94	2.318	0.1298	18.976
14	0	0	+1	0.0215	0.570	2.85	2.014	0.1313	16.949
15	0	0	-1	0.0141	0.536	6.94	1.796	0.1304	15.792

Table 3: Regression coefficients (based on coded data) of the polynomial equations representing the relationship of the response and the factors

Coefficient	Y_1 k=1	Y_2 k=1	Y_3 k=1	Y_4 k=1	Y_5 k=1	Y_6 k=1
b_{k0}	0.0156	0.5334	5.4681	1.907	0.1306	16.4101
b_{k1}	-0.0094	-0.0834	-0.536	0.4518	-0.0012	2.8082
b_{k2}	0.0042	-0.0089	-0.0045	0.0893	0.0005	0.7207
b_{k3}	0.0058	0.0271	-0.444	-0.1024	0.0007	-0.6839
b_{k12}	-0.0053	-0.0374	0.4725	-0.0865	-0.0007	-0.446
b_{k13}	-0.0049	0.0099	0.3	0.1203	-0.0006	0.7654
b_{k23}	0.0052	0.0146	0.1738	-0.1226	0.0007	-0.78
b_{k11}	-0.0009	-0.0336	-1.9389	-0.0367	-0.0001	-0.1694
b_{k22}	0.0014	0.0014	2.0386	0.0244	0.0002	0.1416
b_{k33}	0.0021	0.0107	-1.0089	0.0406	0.0003	0.2147

The model coefficients obtained by regression for the second order polynomials of response surface of Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6 are shown in Table 3. The analysis of variance (ANOVA) for all coded models indicated that the models were statistically significant ($p \leq 0.05$). The interactions of temperature X_1 and citric acid concentration X_2, temperature X_1 and sampler diameter X_3 as well as citric acid concentration X_2 and sample diameter X_3 were significant at $p \leq 0.05$, on dried mango color, energy consumption and cost whereas these interactions to other three responses were insignificant. The results were represented with response surface models. The response surface plots for the moisture content, production and total cost are shown in the Figures 2, 3 and 4 respectively.

Analysis of variance indicated that temperature showed statistically significant effect on the moisture content and production. According with results, production increased with the lowest air temperature because of at these conditions dried product had the highest final moisture. Production of dried miniflakes is increasing at smaller temperatures. This is expected because at smaller temperatures, greater final moisture (Fig. 2), and therefore in agreement with Eq. (3), the production is increasing.

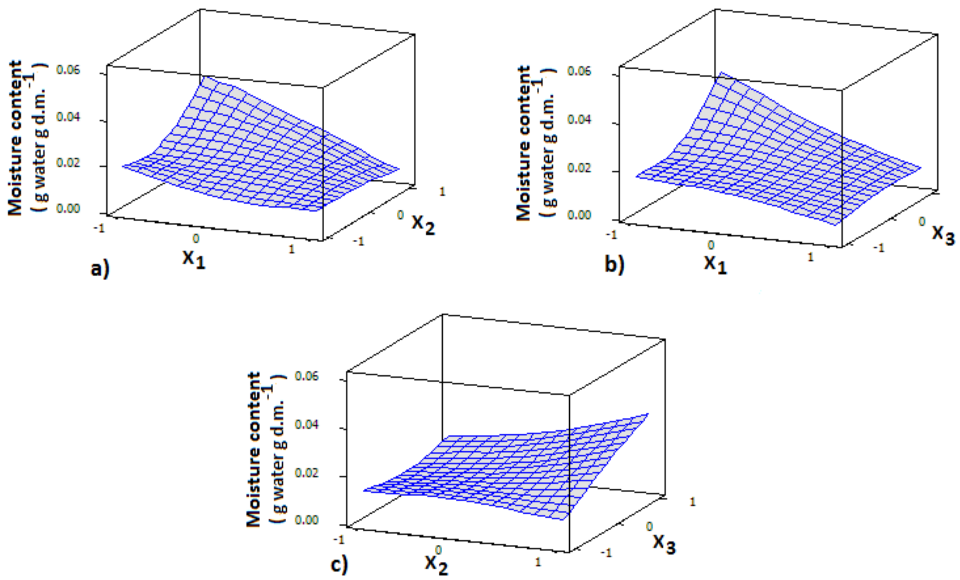

Fig. 2. 3D plot of moisture content as a function of: a) temperature and citric acid, b) temperature and sample diameter, c) citric acid and sample diameter.

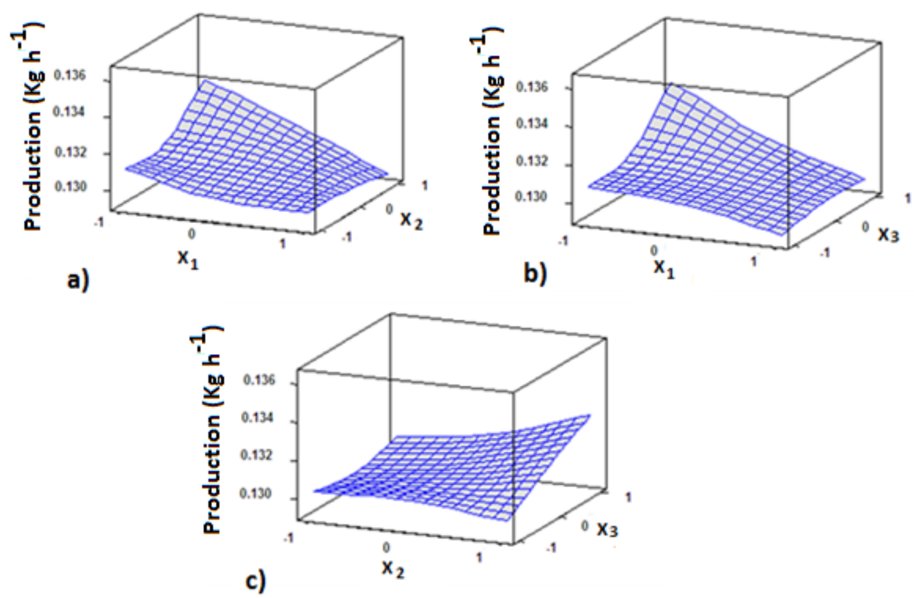

Fig. 3. 3D plot of production as a function of: a) temperature and citric acid, b) temperature and sample diameter, c) citric acid and sample diameter.

The region with highest values of mango production (Y_5) corresponded to temperature of 50 °C, citric acid concentration 1 %, and sample diameter 2 cm (Fig. 3). The region with lowest values of total cost of mango miniflakes corresponded to temperatures between 55 and 60 °C and citric acid concentration between 0.5 and 1 % (Fig. 4).

It was evident that an increase of temperature produces a significantly increase in the cost and color difference. Considering these effects, a two-step optimal design method (minimize Y_3 and Y_6) for the drying was proposed. It includes the GA for determining the optimal design for the drying.

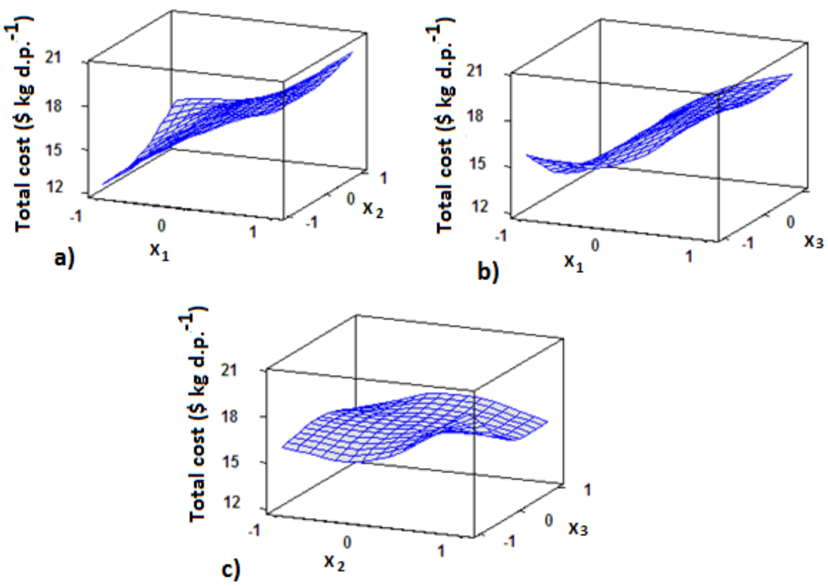

Fig. 4. 3D plot of total cost as a function of: a) temperature and citric acid, b) temperature and sample diameter, c) citric acid and sample diameter.

A drying process analysis method was used for this investigation, which required a relatively small volume of computation. In this instance, it was used the software RISKOptimizer of Palisade company and Microsoft Office Excel 2010. This research used responses couple (Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6) simulation with one point model for temperature (X_1), citric acid concentration (X_2) and sample diameter (X_3), which were obtained from the predictive equations developed with coefficients shown in Table 3. This point model was analyzed with the values corresponding to the lowest cost and color difference and the highest production being chosen as the optimum condition.

The optimum conditions or point model of drying process were 50 °C drying temperature, 1.9 cm of sample diameter, and 0.083 % of citric acid concentration. On the optimized drying conditions, dried mango miniflakes presented values of moisture content with 0.025 g water g d.m.$^{-1}$, a_w of 0.57, color difference of 4, production rate of 0.13 kg h^{-1} and total cost of 11.98 $ kg d.p.$^{-1}$. The visual color of dried mango miniflakes at optimal drying was compared with other drying conditions. Fig. 5 shows that the color of dried mango miniflakes obtained at optima conditions of drying process was closer than in other conditions. The adequacy of the GA at predicted optimum conditions was tested by performing independent experiments corresponding to the optimums conditions. The experimental results were: moisture content with 0.031 g water g d.m.$^{-1}$, a_w of 0.58, color difference of 12, production rate of 0.139 kg h^{-1} and total cost of 11.42 $ kg d.p.$^{-1}$. Some experimental values were close to predicted values. The largest difference between experimental and predicted variables was found in moisture content and color difference of mango miniflakes. The corresponding relative errors were 19 and 33.3 % respectively. The differences may be attributed to several assumptions made in el drying process as: relative humidity of the inlet ambient air and fresh mango color were same among the days of drying experimentation and optimal validation.

3.2 *Sensory evaluation*

The results of the sensory evaluation of dried miniflakes obtained from various drying temperature compared to those from optimum conditions are shown in Table 4. The best sensory score (8.85 in color) was obtained for mango miniflakes dehydrated using optimum conditions. In general, the highest score of overall acceptance was acquired when mango miniflakes were dried at 50 and 55 °C. At these temperatures, dried miniflakes also gained good scores for the acceptance of color and flavor. A decrease in the sensorial properties (color, flavor, taste and texture) was observed when the drying temperature reached 60 °C.

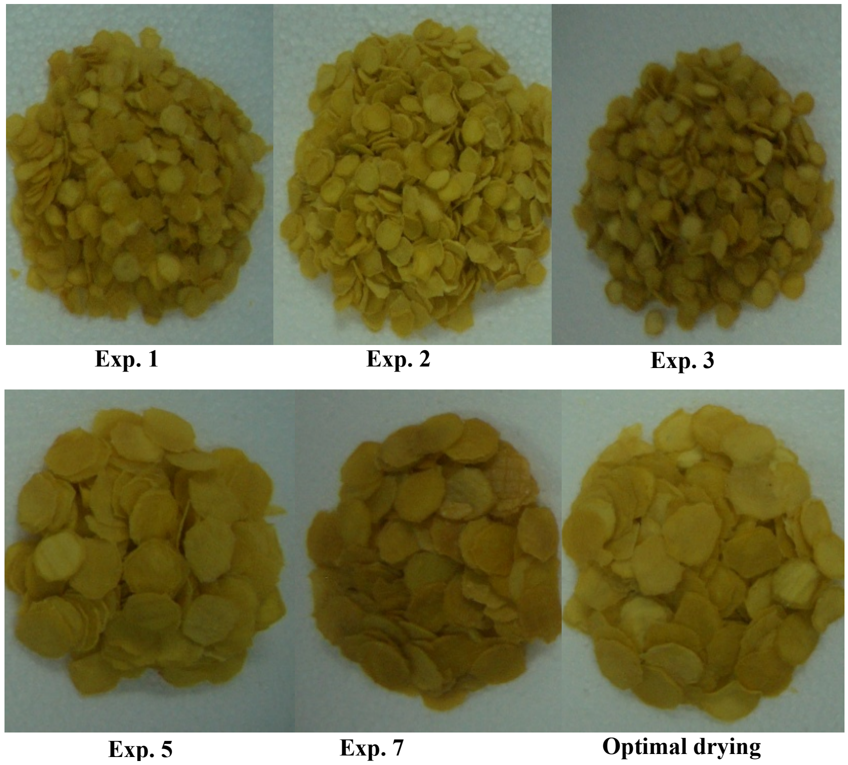

Fig. 5. Visual color images of mango miniflakes obtained at different conditions of fluidized bed drying.

Table 4: Sensory attributes scores of dried mango miniflakes with the optimum diameter of 1.9 cm

Drying temperature (°C)	Color*	Flavor*	Taste*	Texture*	Overall acceptance*
50 (optimum)	8.85±1.29^a	8.00±1.84^a	7.80±1.96^a	7.80±2.19^a	8.30±1.84^a
55	8.65±1.39^a	8.62±1.32^a	7.70±1.63^a	7.70±1.81^a	8.15±1.53^a
60	6.65±1.63^b	7.30±1.56^b	6.15±2.23^b	5.95±1.82^b	6.30±1.78^b

*Column values that are followed by the same letter are not significantly different at the 0.05 probability level with the Duncan's test.

Conclusions

Response surface methodology and genetic algorithms were used to optimize the drying conditions using moisture content, color differences, energy consumption, production and total cost as the response parameters. The second order polynomial models for all the response variables were found to be statistically significant. By GA an optimum drying temperature of 50 °C was obtained for 1.9 cm mango miniflakes diameter and 0.083 % citric acid with predicted values close to experimental values. This resulted in the highest score of the sensorial acceptance especially in color and flavor of the product.

Nomenclature

C_T	total cost, \$ kg^{-1}
C_E	cost of energy consumed, \$ kg^{-1}
C_S	cost of ra_w materials, \$ kg^{-1}
FBD	fluidized bed dryer
GA	algorithms genetic
P	production of dried vegetal pear, kgh^{-1}
$G_{\beta 0}$	initial feeding of vegetal pear, kgh^{-1}
X_β	water content of sample at given time, kg water (kg dry matter)$^{-1}$
X_1	drying temperature, °C)
X_2	concentration of citric acid, % w/w
X_3	sample diameter, cm
Y_1	moisture content, g H_2O (g dry matter)$^{-1}$
Y_2	water activity

Y_3	color difference (ΔE)
Y_4	energy consumption, kW
Y_5	production, kg dry product h^{-1}
Y_6	total cost, \$(kg dry product)$^{-1}$
ΔL, Δa, Δb	variations of the color measures between the fresh and dried samples

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References

Blaise, K.K., Ferdinand, W.F., Gbaha, P. and Toure, S. (2009). Mathematical modeling of the thin layer solar drying of banana, mango and cassava. *Energy-International Journal 34*, 1594-1602.

Chávez-Rodríguez, A., Farias-Cervantes, V.S., Luna-Solano, G., Chávez-Rodríguez, A.M., Ortíz-Basulto, R.I. and Andrade-González, I. (2016). Quality attributes and particles deposition of spray dried fructans of blue agave juice. *Revista Mexicana de Ingeniería Química 15*, 493-502.

Chua, K. J. and Chou, S. K. (2005). New hybrid drying technologies. In: *Emerging Technologies for Food Processing*, (D.W. Sun, ed), Pp. 535-551. Elsevier Academic Press

Domínguez-Niño, A., Buendía-Gonzalez, A.N., Cantu-Lozano, D., Andrade-Gonzalez, I. and Luna-Solano, G. (2016). Effect of fluidized bed drying on physicochemical and microbiological properties of Mexican fresh cheese. *Revista Mexicana de Ingeniería Química 15*, 869-881.

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

Hernández-Díaz, W.N., Hernández-Campos, F.J., Vargas-Galarza, Z., Rodríguez-Jimenes, G.C. and García-Alvarado, M.A. (2013). Coffee grain rotary drying optimization. *Revista Mexicana de Ingeniería Química 12*, 315-325.

Kim, T., Song, D., Kato, S. and Murakami, S. (2007). Two-step optimal design method using genetic algorithms and CFD-coupled simulation for indoor thermal environments. *Applied Thermal Engineering 27*, 3-11.

Lozano-Acevedo, A., Jimenez-Fernandez, M., Ragazzo-Sánchez, A., Urrea-Garcia, G.R. and Luna-Solano, G. (2011). Fluidized bed drying process of thinly sliced potato (*Solanum tuberosum*). *American Journal of Potato Research 88*, 360-366.

Montgomery, D.C. (2005). *Diseño y Análisis de Experimentos*. Editorial Limusa Wiley, México.

Mudahar, S. G., Toledo, T. R. and Jen, J. J. (1990). A response surface methodology approach to optimize potato dehydration process. *Journal of Food Processing and Preservation 28*, 93-106.

Pérez-Francisco, J.M., Cerecero-Enríquez, R., Andrade-González, I., Ragazzo-Sánchez, J.A. and Luna-Solano, G. (2008). Optimization of vegetal pear drying using response surface methodology. *Drying Technology 26*,1401-1405.

Ponciano, S.M. (1997). Optimization of the drying process: An application to the drying of garlic. *Drying Technology 15*,117-136.

Reis, R. C., Ramos, A. M., Regazzi, A. J., Minim, V. P. R. and Stringueta, P. C. (2009). Storage of dried mango: physicochemical, microbiological, color and sensory analysis. *CyTA - Journal of Food 5*, 214-225.

SAGARPA. (2011). Claridades agropecuarias. *Revista Mexicana 175*, 16-19.

Sánchez-Ramírez, J., Anaya-Sosa, I., Vizcarra-Mendoza, M.G., Gutiérrez-López, G. y Santiago-Pineda, T. (2007). Estudio de la hidrodinámica del café tostado (*Coffea arabica L.*) en lecho fluidizado. *Revista Mexicana de Ingeniería Química 6*, 185-192.

Sangdao, C., Songsermpong, S. and Krairiks, M. (2011). A continuous fluidized bed microwave paddy drying system using applicators with perpendicular slots on a concentric cylindrical cavit. *Drying Technology 29*, 35-46.

Sharma, G.P. and Suresh, P. (2006). Specific energy consumption in microwave drying of garlic cloves. *Energy - International Journal 31*, 1921-1926.

Stokie, D., Wai, W.M. and Bhattacharya, S. (2015). Attrition of Victorian brown coal during drying in a fluidized bed. *Drying Technology 3*, 793-801.

Sudheer, K.Y., Yarakumar, S. and Reddy, O.V.S. (2012). Evaluation of antioxidant and sensory properties of mango (*Mangifera indica* L.) wine. *CyTA - Journal of Food 10*, 12-20.

Tan, M., Chua, K.J., Mujundar, A.S. and Chou, S.K. (2001). Effect of osmotic pre-treatment and infrared radiation on drying rate and color changes during drying of potato and pineapple. *Drying Technology 19*, 2193-2207.

Tripathy, P.P. and Kumar, S. (2008). Modeling of heat transfer and energy analysis of potato slices and cylinders during solar drying. *Applied Thermal Engineering 29*, 884-891.

Vázquez-Chávez, L. y Vizcarra-Mendoza, M. (2008). Secado por lecho fluidizado del trigo y su calidad. *Revista Mexicana de Ingeniería Química 7*, 131-137.

Villegas-Santiago, J., Calderon-Santoyo, M., Ragazzo-Sánchez, I., Salgado-Cervantes, M.A. and 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.