VITAE, REVISTA DE LA FACULTAD DE QUÍMICA FARMACÉUTICA
ISSN 0121-4004 Volumen 12 número 2, año 2005.
Universidad de Antioquia, Medellín - Colombia. págs. 5-12

MÉTODOS COMBINADOS DE SECADO PARA EL ESCARCHADO DE MANGO (*Mangifera indica) var. Kent*

COMBINING DRYING METHODS FOR CANDY MANGO (*Mangifera indica) var. Kent*

GIRALDO G. Germán A. [1*], DUQUE C. Alba L.[1] y GARCÍA W. Claudia L.[1]

Recibido: agosto 2 de 2005 Aceptado: septiembre 13 de 2005

RESUMEN

En este trabajo la deshidratación osmótica (DO) y el secado con aire caliente se combinan para producir mango cristalizado conservando las propiedades organolépticas de la fruta fresca. El mango se procesa en cilindros de 1.5cm de diámetro por 2cm de altura. Estos se deshidratan osmóticamente durante 72 horas y luego se secan con aire a 35ºC hasta alcanzar concentraciones de 68 grados Brix (ºBx) y 72ºBx. El tratamiento se inicia con un pretratamiento osmótico (PO), utilizando soluciones de sacarosa a 25, 35, 45, 55 y 65ºBx, aplicando un pulso de vacío (50 mbar) durante 10 minutos, después del cual las muestras se mantienen durante 20 minutos más a presión atmosférica. A continuación, las muestras se sumergen en solución de 65ºBx y se mantienen a presión atmosférica, hasta alcanzar 72 horas de tratamiento total. De la misma manera, se trata otra muestra usando una concentración de sacarosa de 45ºBx durante todo el proceso. Se caracterizan las muestras secas analizando masa, volumen, humedad y sólidos solubles. Las pérdidas de masa y volumen son más bajas para las muestras que se tratan con 25, 45 y 65ºBx durante el pretratamiento osmótico. También se observa que a 25ºBx las muestras ganan una cantidad más alta de sólidos solubles al compararlas con el resto de las muestras mientras que la difusividad de agua durante el proceso de secado es mayor para las muestras tratadas en soluciones menos concentradas durante el pretratamiento osmótico.
Palabras clave: mango, frutas cristalizadas, secado, sólidos solubles

ABSTRACT

In this work, osmotic dehydration (OD) and air drying (AD) are combined in order to produce crystallized mango keeping the organoleptic properties of the fresh fruit. Mango fruits are cut into cylinders of 1.5cm diameter and 2cm height; they are osmotically dehydrated during 72 hours and then dried with air at 35ºC to reach 68 and 72 Brix degrees (ºBx). The treatment begins with an osmotic pre-treatment (OP), with different sucrose solutions at 25, 35, 45, 55 and 65ºBx and applying a vacuum pulse (50mbar) during 10 minutes, after which the samples are left 20 minutes more to atmospheric pressure. Next, the samples are submerged into a solution of 65ºBx and are left to atmospheric pressure until reaching 72 hours of total treatment. In the same way, other sample is treated with a 45ºBx sucrose concentration solution during the whole process. The dry samples are characterized by analyzing the amounts of mass, volume, moisture and soluble solids. Mass and volume losses are lower for the samples treated with 25, 45 and 65ºBx solutions during the osmotic pre-treatment. It is also observed that the 25ºBx sample gains a significantly higher amount of soluble solids compared to the rest of the samples, while water diffusivity during the drying process is higher for the samples treated in less concentrated solutions.
Keywords: mango, crystallized fruits, drying, soluble solids

1 Programa de Química. Universidad del Quindío. Calle 12 Norte Cra 15, Armenia, Colombia.

* Autor a quien se debe dirigir la correspondencia: ggiraldo@uniquindio.edu.co

INTRODUCTION

Dehydrated tropical fruits are used nowadays to produce candy fruits or as a garnish in pastry making. However their use as a raw material to elaborate products such as breakfast snacks, jams, dairy products with fruits, jellies, ice-creams, sauces and desserts, is not a common practice. In Latino America some works have been carried out using combined methods of preservation for mango, pineapple and peach, providing good results for products with intermediate moisture content which means a useful life up to 4 months of storage at room temperature (1).

The osmotic pre-treatment (OP), is a process that helps to diminish the detrimental changes that can take place during the processing or storage of plant tissues. OP has been previously used in the dehydration of fruits to produce candy pineapple with non-thermal treatments (2). Samples were vacuum impregnated in sucrose solutions at concentrations of 25, 35, 45, 55 and 65 Brix degrees (°Bx). Samples were then equilibrated immersed in a 65°Bx sucrose solution, the samples with the better quality, yield and organoleptic properties were the samples impregnated in a 25°Bx sucrose solution, dehydrated for 24 hours in a 55°Bx solution and finally equilibrated in a 65°Bx solution for 48 hours. Likewise, some authors propose that in osmotic dehydration processes, sucrose acts lowering the water activity in the sample (3); in this sense, sugar concentration has a greater effect than the temperature in the preservation of the product for longer periods of time.

There are several works about dehydration of mango fruit, one of them (4) shows the advantage of increasing solutions concentration for further dehydration in processes where a vacuum pulse is applied. It has been previously demonstrated that an osmotic dehydration treatment reduces the drying time of mango samples up to 75 % when compared to fresh samples (5,6).

Dried fresh mango slices (var. *Manila*) have been treated with air at various temperatures 50, 60 and 70°C and two different air velocities 0.5 and 1.75m/s (7). From their experimentation, the authors concluded that the external convection is the main mechanism responsible for the heat transfer while the internal water diffusion is the mechanism responsible for the overall transfer. In another work, the authors frosted mango in cubes of 2cm, scalded the samples for 10 min and transferred them to a sucrose:glucose (9:1) solution at 30°Bx with pH 4. Mango samples were hold for 48 hours until osmotic equilibrium was attained, and then the initial solution was replaced for higher concentration solutions. After 19 days, the concentration solution was 76.5°Bx and the fruit reached 71.6 °Bx (8).

Other investigation (9) scalded and dehydrated mango in a sugar solution of 60°Bx for 6 hours. After the osmotic dehydration treatment the samples were dried for 21 hours in a stove with air circulation, the results being so promising so that they considered this combined drying methods as a technological alternative for the conservation of mango fruit.

The aim of this work was the optimisation of the candy process in mango fruit using osmotic dehydration treatments for long periods of time combined with hot air-drying. The variables were the sugar solution concentration during the vacuum pulse and the final moisture content after the drying process.

MATERIALS AND METHODS

Raw material

The mango (*Mangifera indica var. Kent*) was purchased in a local market and selected according to a similar ripeness degree. Each fruit was peeled and cut into parallel pieces to the bone obtaining cylinders of 1.5cm height and 2cm diameter, fresh fruit was characterised measuring the moisture and soluble solids content as well as the water activity.

Osmotic pre-treatment (OP)

The osmotic pre-treatment was carried out in two steps; in the first one, a vacuum pulse was applied to the samples immersed in different osmotic solutions and in the second step the samples were placed in a concentrated solution and held there to attain the osmotic equilibrium. The cylinders were immersed in sucrose solution (25, 35, 45, 55 and 65°Bx), the sample: solution ratio was 1:20. A vacuum pulse of 50 mbar was applied for 10 minutes, after which the atmospheric pressure was restored for 20 minutes. In the second step, the samples were transferred to a 65°Bx solution. All samples were osmotic dehydrated for a total time of 72 hours, which is the estimated time to reach the equilibrium

according to the water activity (a_w) measurements of the mango samples and final sucrose solution. Another experiment was carried out in which the mango fruits were processed in a 45ºBx solution (10). The moisture and soluble solids content of the mango samples were analysed at the end of the osmotic treatment. Volume and mass changes were also determined.

Drying period

The osmotic dehydrated cylinders were dried with air at 35°C until the soluble solids concentration in the liquid phase (z_s) was 0.68 or 0.72. From the initial values of the moisture content and soluble solids content the loss of mass during the process drying was calculated in order to achieve the required concentrations. At the end of the drying process, the mechanical properties of the samples were evaluated as well as the moisture and soluble solids content, mass and volume changes.

Analysis

The volumes of the samples were measured with a picnometer using the respective isotonic solution. The mass was determined by gravimetry in an analytic scale with four significative numbers. The moisture content was determined drying the samples in a vacuum oven at 60°C until constant weight was reached (11). Water activity (a_w) was determined with a dew point hygrometer (Decagon, model Aqualab CX3) and the soluble solids content of the samples previously homogenized was determined with a refractometer (model 89553 3T). Mechanical assays were performed using a texture analyser Stable Micro Systems TA.XT2. Samples were positioned vertically on the slotted platform; the cylinders were cut/compressed parallel to the main axis of them.

RESULTS AND DISCUSSION

The mango fruits were processed keeping in mind the system of combined drying methods, osmotic pre-treatment and air-drying. The two processed lots reached mass fractions of soluble solids in the liquid phase (z_s) of 0.68 and 0.72. It was used like methodological principle the observations made by (2,3,8,12).

PRODUCT CHARACTERIZATION

Physicochemical properties of the fresh fruit

The moisture content of the fresh mango fruit was 0.83 ± 0.03, the water activity 0.983 ± 0.005 and the soluble solids content 0.14 ± 0.03; similar to that previously determined in other lost. (10).

Variation in mass, volume of the liquid phase, moisture and soluble solids content during the periods of candy process

The candy process took place in two periods: A first period which consisted in a pre-treatment of osmotic dehydration and a drying period. Mass, volume, moisture and soluble solids content were registered for all the samples in each period. From these data the next values were calculated: mass changes, ΔM (equation 1); volume changes, ΔV (equation 2); variations in liquid phase volume of the samples, ΔV_{FL} (equation 3); water loss, ΔM_w (equation 4) and soluble solids gain, ΔM_s (equation 5).

$$\Delta M = \frac{M_t - M_0}{M_0} \quad (1)$$

$$\Delta V = \frac{V_t - V_0}{V_0} \quad (2)$$

$$\Delta V_{FL} = \frac{\dfrac{m_t\left((x_w)_t + (x_{ss})_t\right)}{(\rho_{FL})_t} - \dfrac{m_0\left((x_w)_0 + (x_{ss})_0\right)}{(\rho_{FL})_0}}{\dfrac{m_0}{\rho_0}} \quad (3)$$

$$\Delta M_w = \frac{\left(\left(M_t (x_w)_t\right) - \left(M_0 (x_w)_t\right)\right)}{M_0} \quad (4)$$

$$\Delta M_s = \frac{\left(\left(M_t (x_{ss})_t\right) - \left(M_0 (x_{ss})_t\right)\right)}{M_0} \quad (5)$$

Where:

M_0 = initial sample mass (Kg).
M_t = sample mass at time t (Kg).
V_0 = initial volume sample (m^3).
V_t = sample volume at time t (m^3).
$(x_{ss})_0$ = Mass fraction of soluble solids at time 0 (ºBx).
$(x_{ss})_t$ = Mass fraction of soluble solids at time t (ºBx).
$(x_w)_0$ = Mass fraction of water at time 0 (Kg/Kg).
$(x_w)_t$ = Mass fraction of water at time t (Kg/Kg).

Table 1 shows the moisture content, Brix degrees, soluble solids content and mass changes of the samples once osmotic treatment was finished. As it was expected, the soluble solid content in the fruit after 72 hours of osmotic treatment was very similar to the soluble solid content of the respective solution. From previous works 72 hours of process was considered the proper time length to reach the equilibrium.

Table 1. Moisture $(x_w)_{PO}$, Soluble solids $(x_{ss})_{PO}$, Brix degrees $(^oBx)_{PO}$ and variation of mass (ΔM_{PO}) at the end of the osmotic dehydration of the different treatments of mango cylinders

Pre-treatment	Treatment	$(x_w)_{PO}$	$(x_{ss})_{PO}$	$(^oBx)_{PO}$	ΔM_{PO}
25°Bx	65°Bx	0.35	0.59	63.0	-0.390±0.204
35°Bx	65°Bx	0.35	0.62	64.2	-0.423±0.126
45°Bx	45°Bx	0.57	0.38	39.7	-0.211±0.070
45°Bx	65°Bx	0.32	0.58	64.8	-0.449±0.089
55°Bx	65°Bx	0.35	0.60	63.1	-0.511±0.031
65°Bx	65°Bx	0.33	0.60	64.6	-0.506±0.057

At the end of the pre-treatment, mass changes were greater with solutions of higher concentration, which is in coherence with the observations of other authors (10,13). This is the result of increasing soluble solids gain instead of water loss as concentration/viscosity of the solution increases. The treatment 45-45 treatment (pre-treatment at 45°Bx and treatment at 45°Bx) resulted in lower mass changes as well as soluble solids content and in a higher moisture level during the equilibrium period due to the low concentration of the osmotic solution.

Table 2 shows the moisture content, Brix degrees, soluble solids content and mass changes of the samples during the drying process until two different levels, 68 and 72°Bx, were reached. The values obtained for the Brix degrees were very close to the preset values except for the 45-45 treatment, these samples offered resistance to the drying, probably due to the compositional changes occurred during the osmotic treatment in which solutes gain was very high.

Table 2. Moisture $(x_w)_f$, soluble solids $(x_{ss})_f$, Brix degrees $(^oBx)_f$ and variation of mass ΔM_f at the end of the stage of drying of the different treatments of mango cylinders

68 °Bx (DHA)

Pre-treatment	Treatment	$(x_w)_f$	$(x_{ss})_f$	$(^oBx)_f$	ΔM_f
25°Bx	65°Bx	0.306±0.014	0.630±0.012	67.3±1.3	-0.320±0.019
35°Bx	65°Bx	0.309±0.004	0.661±0.004	68.1±0.4	-0.566±0.006
45°Bx	45°Bx	0.313±0.051	0.600±0.045	65.8±5.4	-0.473±0.192
45°Bx	65°Bx	0.294±0.012	0.601±0.010	67.1±1.3	-0.613±0.010
55°Bx	65°Bx	0.312±0.008	0.634±0.008	67.0±0.8	-0.614±0.011
65°Bx	65°Bx	0.314±0.010	0.619±0.009	66.3±1.0	-0.637±0.014

72 °Bx (DHA and MW)

Pre-treatment	Treatment	$(x_w)_f$	$(x_{ss})_f$	$(^oBx)_f$	ΔM_f
25°Bx	65°Bx	0.251±0.011	0.673±0.010	72.8±1.1	-0.465±0.184
35°Bx	65°Bx	0.269±0.004	0.700±0.004	72.2±0.4	-0.485±0.112
45°Bx	45°Bx	0.297±0.039	0.614±0.034	67.5±4.1	-0.510±0.067
45°Bx	65°Bx	0.243±0.011	0.644±0.009	72.6±1.2	-0.503±0.080
55°Bx	65°Bx	0.268±0.016	0.675±0.015	71.6±1.7	-0.566±0.032
65°Bx	65°Bx	0.256±0.012	0.672±0.011	72.4±1.2	-0.555±0.054

Figure 1 shows the mass changes during the OP and during the drying process for the two concentration levels. In the osmotic stage, the treatments 25-65 and 35-65 showed a great variability in mass losses. During the drying stage, the samples equilibrated with 45 °Bx solution lost more mass due to its lower initial concentration value. For the remaining treatments the differences were not statistically significant. The best yields in the candy process were established according to the total mass losses, in this sense the treatments 25-65 and 45-65 resulted in lower mass losses for the same final level of soluble solids concentration. It has been observed that the impregnation with diluted solutions also restrains the mass losses during pineapple candy process (2). On the other hand, it was previously reported that treatments with sucrose at 45°Bx increases solutes gain (10) which will have a relevant effect in the process efficiency.

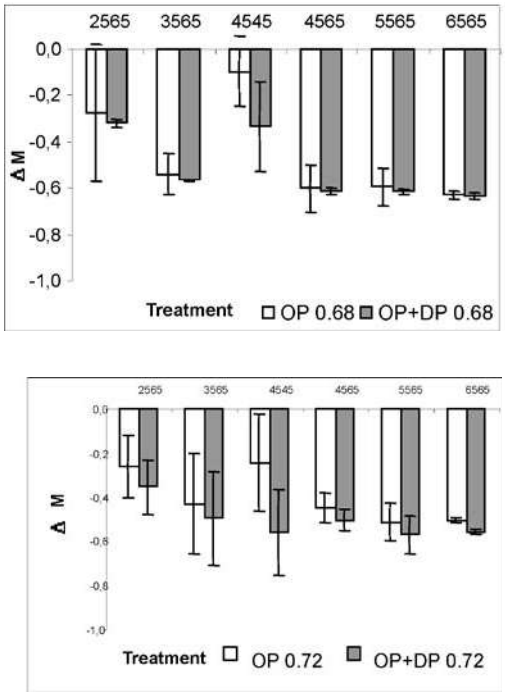

Figure 1. Mass variations in the stages of osmotic dehydration and drying of mango cylinders.

Volume sample changes at the end of the candy process are shown in figure 2. There were no significant differences between samples caused by any of the analysed factors: different osmotic treatments or final drying level. The response of different samples to the same treatment presented a great variability in volume changes.

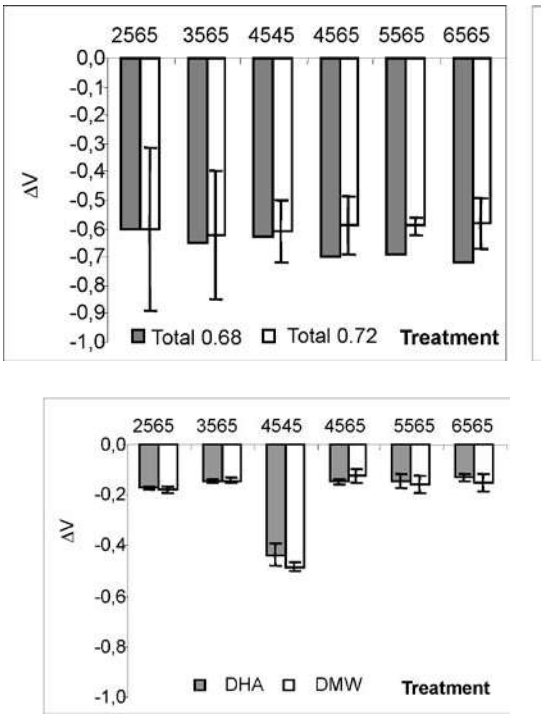

Figure 2. Volume variations in the stages of osmotic dehydration and drying of mango cylinders.

The moisture loss and solids gain in the dehydration processes, which were calculated from equations 4 and 5, and are shown in Figure 3. During the osmotic treatment, moisture losses were higher as the solution concentration was higher. It could be said that the vacuum impregnation period had an effect on the samples treated with higher concentration solutions although the effect of the equilibrium period on the dehydration was more relevant, due to the osmotic and diffusion effect caused by the viscosity and concentration solution (10,13). The air drying process resulted in minimal additional water losses as the mass fractions of the soluble solids content in the liquid phase of the samples (z_s) were very close to the preset values after the osmotic treatment. The 45-45 treatment was the exception as it reached the equilibrium in the osmotic solution at a lower concentration (z_s=0.45), this lower concentration increased the ratio of soluble solids gain to water loss, helping to preserve the sample shape and volume. Solution concentration and viscosity had a direct effect on solutes gain, since 25-65 and 45-45 treatments resulted in higher solids concentrations without damaging the cellular tissues.

The drying stage decreased the differences among the final moisture content of the cylinders,

this is one of the reasons why the drying process was used as a way to provide the samples the required stability to increase the life of the candy mango storage at room temperature (Figure 3)

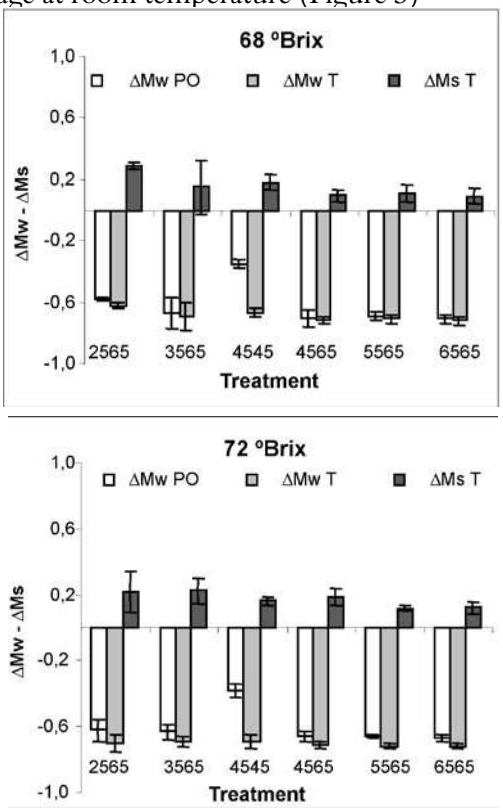

Figure 3. Losses and gains of water in the processes of the drying of mango cylinders

Volume variations

The total volume loss is plotted versus volume loss of the liquid phase at the end of the candy process for all different treatments. The candy process with a final level z_s=0.68, showed a volume loss of the liquid phase smaller than the total volume loss, this effect could be caused probably by the solubilization of the sucrose. The forces generated as a consequence of the water loss results in the shrinkage of the tissue and the loss of porous. The opposite situation appeared when samples were dried up to z_s=0.72, in this case the total volume loss was smaller than the liquid phase volume loss (with the exception of 45-45 treatment), the smaller total volume loss implies an increase in porosity which could be caused by the formation of sucrose crystals during storage as a consequence of the lower moisture level (figure 4).

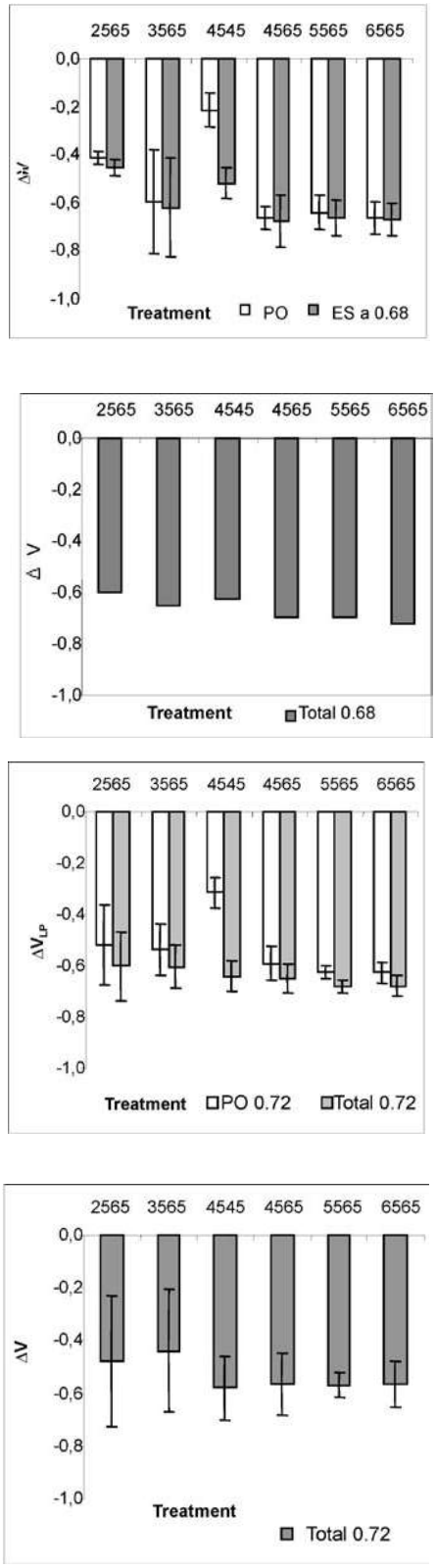

Figure 4. Variation in the volume of the liquid phase and total volume of mango cylinders dried off by combined method.

Drying curves

Figure 5 shows the drying curves for the different treatments. As it was expected samples processed according with the 45-45 treatment presented higher drying times due to the higher amount of water in the samples at the end of the osmotic treatment and the distribution of the water inside the sample.

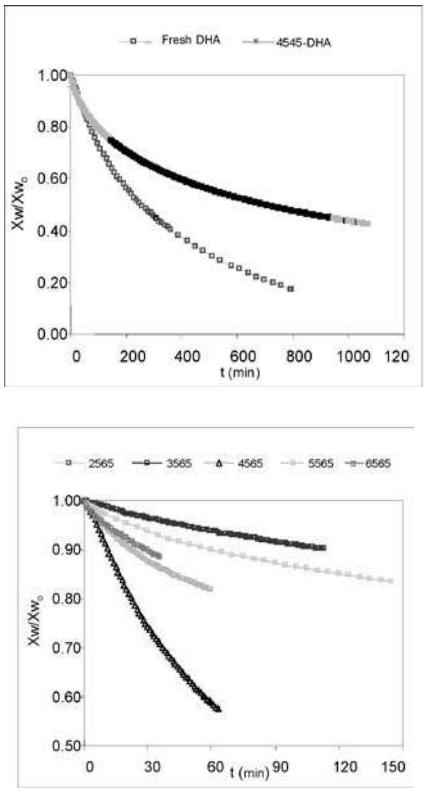

Figure 5. Drying curves of mango cylinders with hot air.

The diffusivity of the water was calculated from equation 6 (14). In figure 6 it is observed that the diffusivity was highest for the 25-65 and 45-45 treatments due to the better distribution of the water inside the solid matrix as a response to the concentration/viscosity balance.

$$\frac{X_{bs(r,\ t)} - X_{bs.e}}{X_{bs.0} - X_{bs.e}} = 4\left[\sum_{n=0}^{\infty} \frac{1}{(\lambda_n L)^2} e^{\left(\frac{De}{L^2}\lambda_n^2 t\right)}\right] \quad (6)$$

donde:

De = Effective diffusivity (m^2/s)

L = half height of the cylinder (m)

t = time (s)

$X_{bs.\ (r,t)}$ = Water content (Kg water/Kg soluble solids)

$X_{bs.0}$ = Initial water content (Kg water/Kg soluble solids)

$X_{bs.e}$ = Water content at equilibrium (Kg water/ Kg soluble solids)

λn = Characteristic value for the repetitions (m^{-1}).

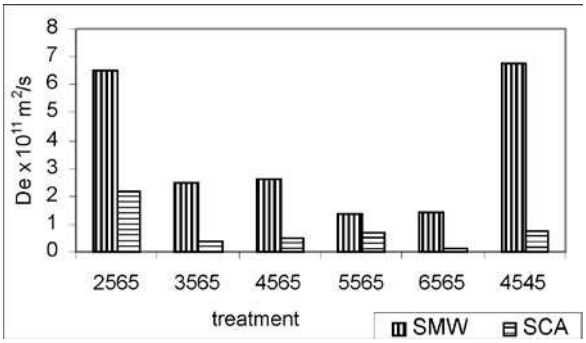

Figure 6. Effective Diffusion of the moisture of the mango cylinders, during the drying with current of hot air.

Mechanical properties: Compression assay

The mechanical properties of the processed candy mango were evaluated according to the response of the samples to a compression/shearing assay. Three different treatments were evaluated: Samples dried up to z_s=0.68, a second set of samples dried up to Zs=0.72 and for the third treatment an additional storage stage was included after drying the samples up to z_s=0.72. Storage conditions were RH content of 0.72 at room temperature.

The Figure 7 shows the compression force versus the distance during the mechanical assay of mango cylinders processed combining osmotic dehydration and air drying. Each curve represent the average curve for each candy process.

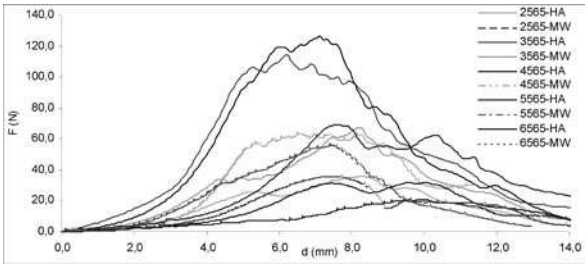

Figure 7. Cutting forces from the mango cylinders at different concentrations of solutions osmotic and different drying processes.

There were no significant differences in the response of the samples dried up to z_s=0.68 and up to z_s=0.72, this can be due to the small differences

in the soluble solids concentration at the end of the process and to the short availability of time to crystallize the sugar. On the other hand, when comparing samples dried up to z_s=0.72 without storage with the stored ones, it can be observed that the storage increased the hardness of the samples probably due to the sugar crystallization. The different osmotic treatment caused different sample textures; from soft samples (45-45) to very hard samples (45-65 with storage).

Differences between osmotic treatments for the same candy process are shown in Figure 8. In most of the cases the stored samples dried up to 72°Bx exhibited higher compression forces, probably due to the case hardening effect during the air drying process and to the sugar crystallization during the storage stage. 25-65 and 45-45 treatments didn't show differences among the three candy processes, showing a low compression force. From these results, these two treatments can be considered as the recommended ones for the candy process, especially given that these samples showed a low variability in their response to the compression assay.

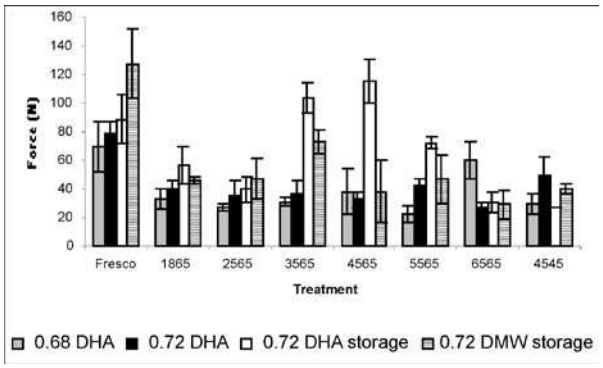

Figure 8. Cutting forces from the mango cylinders to the different concentrations of solutions osmotic and different drying processes.

BIBLIOGRAPHICAL REFERENCES

1. Aguilera JM. & Chirife J. (1994). Combined Methods for the Preservation of Foods in Latin America and the CYTED-D Project. *Journal of Food Engineering*, 22: 433-444.
2. Barat JM, Talens P., Barrera C. & Chiralt A. (2002). No-thermal pineapple candying optimisation. *Journal Food Science*.
3. Panagiotou N., Karathanos V. & Maroulis Z.(1998). Mass transfer modelling of the osmotic dehydration of some fruits. *International Journal of Food Science and Technology*, 33, 267-284.
4. Mujica-Paz H., Valdez-Fragoso A, Martínez-Pantoja Y & Welti_Canes J. (2000) Response surface methodology applied to vacuum osmotic dehydration of mango slices. In J. Welty-Chanes, G.V. Barbosa-Cánovas, & J.M. Aguilera *Proceedings of the Eighth International*
5. Castañón X., Ibarz A., Welti-Chanel J., Palou E. & lopez-Malo A. (2000) Water activity on air drying behaviour and quality of mango. In J. Welty-Chanes, G.V. Barbosa-Cánovas, & J.M. Aguilera *Proceedings of the Eighth International Congress on Engineering and Food -ICEF 8-* (pp.1066-1070). Lancaster: Technomic Publishing Co., Inc.
6. Welti J., Palou E., Lopez-Malo A., & Balseira A. (1995). Osmotic Concentration – Drying of Mango Slices. Drying Technology 13 (1-2) 405-416.
7. Pavón-Meléndez, Hernández, Salgado, García, (2002). Dimensionless analysis of the simultaneous heat and mass transfer in food drying. *Journal of Food Engineering* 51(4)347-453).
8. Ribeiro MS & Anuncio De Sabaa A. (2000). Mango (*Mangifera indica L.*) saturación del cv. Rosa con azúcares. Ciencia e Tecnología de Alimentos; 19 (1) 118-122.
9. Maldonado S. & Sammán N(2000). Dehydration of tropical fruits produced in noa region, Argentina: Mango (*Mangifera indica*) stage 1. In J. Welty-Chanes, G.V. Barbosa-Cánovas, & J.M. Aguilera *Proceedings of the Eighth International Congress on Engineering and Food -ICEF 8-* (pp.1204-1208). Lancaster: Technomic Publishing Co., Inc.
10. Giraldo G., Talens P., Fito P. & Chiralt A. (2003) Influence of sucrose solution concentration on kinetics and yield of mango osmotic dehydration. *Journal of Food Engineering* (58) 33-43.
11. A.O.A.C. (1980). Association of official Analytical Chemist Official Methods of Analysis. Washington. D.C.
13. Lewicki, P. & Lenart A.(1995). Osmotic dehydration of fruits and vegetables. In: Handbook of Industrial Drying (ed. By A. S. Mujumdar). Pp 691-713. New York: Marcel Dekker.
12. Lewicki, P. (1998). Some remarks on rehydration of dried foods. *Journal of Food Engineering*. 36: 81-87.
14. Bon J., Benedito J., Sanjuán N., Cárcel J. y Clemente G.(2000). Cálculo y ajuste de propiedades de transferencia de materia en productos con geometría cilíndrica. VII Taller de Herramientas de Cálculo - Chile. Editor *versión electrónica:* José J. Benedito Fort, www.upv.es, Pub. Universidad Politécnica de Valencia. España