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Optical and mechanical properties of cocona chips as affected by the drying process

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Abstract

The effect of the application of a pre-osmotic treatment to obtain hot air dried cocona (*Solanum sessiliofurum Dunal*) chips was studied. The drying kinetics and the optical and mechanical properties of cocona chips obtained by the combined method of osmotic dehydration and hot air drying (OD+HAD) and by only hot air drying (HAD) were compared. Samples were dried by hot air at 60ºC. For the combined method, they were pre-dried to a moisture content of 75 g_{water}/100g, immersed in a 55 ºBrix sucrose solution at 25ºC for 48 minutes. The pre-osmodehydration applied did not influence the subsequent hot air drying kinetics, resulting in a final product with 0.055 ± 0.005 $g_{water}/g_{cocona.}$ The optical properties of OD+HAD chips were more favourable, exhibiting a smaller color change with respect to the fresh fruit (±15 units) than the HAD samples (±23 units). On the other hand, the OD+HAD chips presented more fracture peaks than HAD ones, this related with a structure with a higher degree of crispness, a very desirable property for a chip product.

Keywords: osmotic dehydration, hot air drying, drying kinetics, translucency, colour, Kramer compression-extrusion test.

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1. Introduction

Solanum sessiliflorum Dunal, known as cocona or topiro, is an exotic fruit which is native to tropical America and distributed around the Amazon basin of Brazil, Colombia, Peru, Ecuador and Venezuela (Pereira da Silva et al., 2011). The interest in the trade and consumption of tropical fruits has increased significantly in recent years due to their sensory properties and a growing recognition of their therapeutic and nutritional value (Bicas et al., 2011). Recent studies into the nutritional and functional properties, in different ecotypes of cocona, have emphasized its attractive characteristics (Yuyama et al., 2007; Murillo et al., 2010; Contreras-Calderón et al., 2011). However, due to its high degree of acidity and astringency this exotic fruit is not consumed fresh and its use is limited to the elaboration of traditional, home-made products, such as juices, jams or candies. The cocona is little known because its production is small scale, which is due to its great variability, poor dissemination, logistical problems and gaps in basic research and technology. For these reasons, it seems essential to evaluate how the quality properties of cocona are affected by the different processing methods.

Dehydration is a technique that is widely applied in the preservation of fruit and vegetables. This technology has been used since ancient times to stabilize and increase the shelf-life of food products. It relies on reducing the water activity (a_w) in the food, slowing down degradation processes, especially those caused by chemical and microbiological agents. Dehydration causes an appreciable change in the geometric properties with a consequent reduction in the weight and volume of the product, which facilitates transport and storage. At the same time, it causes a number of changes related to the nutritional, sensory, optical and textural properties that can sometimes become undesirable (Fito et al., 2001, Bennett et al., 2011). For dehydrated fruit pieces, the optical and textural properties greatly influence the quality and, thus, consumer-acceptance. Both color changes that occur due to enzymatic browning phenomena and structural changes in

the fruit tissues caused by water loss during drying depend on the method used and the conditions in which the process takes place (Torreggiani and Bertolo, 2001).

The dehydration technique most commonly used on food products is hot air drying (Krokida et al., 2003). Using this technique, a simultaneous mass and heat transfer occurs (Nguyen and Price, 2006). Hot air drying (HAD) produces stable dehydrated products, but unfortunately their final quality is drastically reduced when compared to the fresh fruit due to the high temperatures and times involved in the process (Ratti, 2001). To avoid this problem, different combined drying methods may be considered. In this sense, the application of osmotic dehydration (OD) prior to using HAD to obtain dried fruit has been investigated (Alvarez et al., 1995, Rodriguez et al., 2003; Garcia et al., 2007; Rozek et al., 2010). These authors have observed an improvement in the quality of the dried products as well as a reduction in the process drying time. During OD, the cellular tissue is immersed in a concentrated sugar or salt solution to promote the loss of water (Fito and Chiralt, 2003). In addition to mass transfer, structural changes occur as a result of the deformation and breakage of the cellular element. This causes changes in the macroscopic properties of the sample, such as in the optical and mechanical properties, which are related to the appearance (Chiralt and Talens, 2005). However, unlike other drying processes, in the case of osmotic dehydration the damage to the flavor and color of the fruit caused by enzymatic browning phenomena is minimal (Uddin et al., 2004). Nevertheless, as prolonged immersion times are required to achieve adequate levels of osmotic dehydration, it is a good candidate for combining with hot air drying.

The aim of this work was to study the effect of osmotic dehydration combined with hot air drying on the mechanical and optical properties of cocona chips for the purposes of being able to offer a new product to consumers. A kinetic study of the drying process was assessed.

2. Materials and methods

2.1. Sample preparation and osmotic solution preparation

The cocona studied was obtained from the Center for Biological Research and Agroforestry Production (CIPAF) of the Technological University of Chocó (Colombia). The water content, ºBrix and water activity of the fruit was measured as described below. The fruit pieces were peeled and cut perpendicularly to the fruit axis into 5mm thick half slices. Food grade commercial sucrose was used to prepare the osmotic solution (OS) by mixing 55 g of sucrose with approximately 45 g of distilled water to obtain a homogeneous 55° Brix solution.

2.2. Drying procedures

Dried slices of cocona, called chips in this study, were obtained by hot air drying (HAD chips) and by a combined osmotic-hot air drying procedure (OD+HAD chips). In order to optimize both processes, previous kinetic studies were conducted. In this sense, the effective diffusivity of water (D_e) was determined for each process. The simplified solution of Fick's Second Law (Eq. 1), valid for an infinite plane sheet and long drying times, was used to this end. A non-linear regression method was applied to fit the data.

$$Y = \frac{(xw^t - xw^\infty)}{(xw^0 - xw^\infty)} = \frac{8}{\pi^2}\exp^{\frac{De\pi^2 t}{4l^2}} \quad (1)$$

where: Y is the reduced driving force, x_w is the water content (g/g_{cocona}) with superscripts: 0 (initial condition), t (at time t) or e (at equilibrium condition); De is the effective water diffusivity (m^2/s); l is the slab half-thickness (m); and t is the time (s).

2.2.1 Osmotic dehydration kinetics.

The halves of cocona slices were placed in the 55 ºBrix OS, maintaining a 1:10 fruit:OS ratio. The system was kept at 25 °C and continuously stirred. Changes in the total mass weight, mass fraction of water, mass fraction of soluble solids and water activity of the samples at 0, 5, 10, 15, 20, 25, 30, 40, 60, 120, 180, 240, 300 and 360 min were analyzed, as described below.

The obtained results were used to select the osmotic dehydration time necessary to obtain samples with 0.75 g water/g sample. These pre-osmodehydrated samples were air dried, as described below.

2.2.2 Hot air drying kinetics.

Both fresh samples and those pre-osmodehydrated to x_w 0.75 were dried at 60 ºC to obtain chip samples. Air drying experiments were carried out in a perforated tray dryer (Back to Basics FD-600) with a constant air flow rate of 1.6 ms^{-1}. The samples were air dried for 0, 30, 60, 120, 180, 240 and 300 min, where constant weight was achieved. The change in the total mass of the samples was registered at each time, together with the water content (see section 2.3.1). Furthermore, the characteristic dimensions of the cocona slice were measured to determine the percentage of shrinkage (see section 2.3.2).

2.3. Analysis

2.3.1. Water content, ºBrix and water activity

The mass fraction of water (x_w) was obtained in triplicate by vacuum drying the samples in a vacuum oven (Vaciotem, J.P. Selecta) at 60 ºC ± 1 ºC under a pressure of < 100 mm Hg until constant weight (AOAC method 934.06, 2000). The mass fraction of soluble solids in the liquid phase (Z_s) was obtained at 20°C by measuring the °Brix (Refracto 30 PX, Mettler Toledo at 20ºC) of the previously homogenized samples (Ultraturrax T25, Janke & Kunkel). The mass fraction of soluble solids (x_s) in the sample was calculated by Eq. (2).

$$x_s = \frac{^{o}Brix.\ x_w}{(100 - {}^{o}Brix)} \quad (2)$$

The water activity (a_w) was measured by using a water activity meter (Aqualab CX-2, Decagon Devices). Changes in the total water and soluble solids mass were calculated by means of Eqs. (3) to (5) (Igual et al., 2010).

$$\Delta M = \frac{M^t - M^0}{M^0} \quad (3)$$

$$\Delta M_w = \frac{M^t X w^t - M^0 X w^0}{M^0} \quad (4)$$

$$\Delta M_s = \frac{M^t X s^t - M^0 X s^0}{M^0} \quad (5)$$

Where ΔM is the total mass variation of samples (g/g fresh sample); ΔM_w and ΔM_s: the relative mass variation of the water and soluble solids, respectively; M: the mass of the sample (g), X_w and X_s: the mass fraction of the water and soluble solids in the sample, respectively (g/g product); t: the time of dehydration; 0: the fresh sample.

2.3.2. Percentage of shrinkage

The characteristic dimensions of the cocona slice (diameter and thickness) were measured by means of a caliper. The percentage of shrinkage was determined from the variation in the thickness, the area (considering the surface of the half-slice of cocona as a semi-circle) and the volume (volumetric semi-circular base body at a height equal to the thickness of the sample) of the slice.

2.4. Optical and mechanical properties.

Measurements were taken of the optical and mechanical properties of fresh samples, those osmodehydrated to x_w 0.75 and pre-treated (OD+HAD) or non-pretreated (HAD) chips.

The same 12 halves of cocona slices were identified and their optical properties were measured before and after the drying process. Translucency and CIE*L*a*b* color coordinates were determined from the surface reflectance spectra obtained between 400 and 700 nm, when measuring on white and black backgrounds, considering standard light source D65 and standard observer 10º (Minolta spectrophotometer CM-3600d, Japan). Measurements were taken on the inner and outer part of the cocona slice in duplicate and triplicate, respectively. The translucency of the samples was determined by applying the Kubelka-Munk theory for multiple scattering to the reflection spectra (Hutchings, 1999; Talens et al., 2001). This theory assumes that the light flux that passes through the sample is related to the ratio of absorbed to scattered light. The calculated reflectance of an infinitely thick layer of the material was used to obtain the coordinates CIE*L*a*b, the hue (h^*_{ab}) and the chroma (C^*_{ab}) color attributes. The total color difference (ΔE) of dehydrated samples was calculated with respect to the fresh sample.

The mechanical behavior of the samples was registered at 20ºC by means of an extrusion-compression test (Kramer cell) using a Stable Micro Systems, TA.XT2 plus Texture Analyzer (Haslemere, England). The test speed was 0.50 mm/s. Eight replicates were performed per treatment. The parameter analyzed in each case was the maximum force registered during the test per unit mass of sample (F_{max}/g).

2.5. Statistical analysis

Analyses of variance (ANOVA) were carried out to evaluate inter-treatment differences. When the p value was lower than 0.05, it was assumed to be significant differences

between samples. In order to evaluate the effect of the osmotic dehydration pretreatment on the air drying kinetics, the models fitted to obtain the effective diffusivity of water for OD+HAD and HAD data were statistically compared with that obtained when fitting all the data together. To this end, the values of statistic E (Eq. 6) were compared with tabulated F-Snedecor as a function of the values of DFDR and FDRi, at 95% significance level.

$$\mathrm{E} = \frac{\frac{RSS_g - \sum_{i=1}^{n} RSS_i}{DFDR}}{\frac{\sum_{i=1}^{n} RSS_i}{\sum_{i=1}^{n} FDR_i}} \qquad (6)$$

Where

RSS_g: Residual square sum of the function fitted to a group of series;

RSS_i: Residual square sum of the function fitted to an individual series;

DFDR: Difference between freedom degrees of the residuals of the function fitted to a group of series and the sum of freedom degrees of the residuals of the individual fittings of the series involved in the groups;

FDR_i: Freedom degrees of the residuals of the function fitted to an individual series.

3. Results and Discussion

3.1 Osmotic dehydration kinetics.

Fig. 1 shows the OD kinetics, studied in terms of water loss and the gain in soluble solids in the fruit. At the start of the osmotic process, a rapid increase in both soluble solids gain and water loss was observed, followed by a reduction in these flows near the end of the process. Both profiles changed over time from an initial average value of x_w = 0.930 ± 0.004 (g_{water}/g_{sample}) and x_s = 0.059 ± 0.001 ($g_{solutes}/g_{sample}$), to values of x_w = 0.480 ± 0.003

(g_{water}/g_{sample}) and x_s = 0.51 ± 0.28 ($g_{solutes}/g_{sample}$) after 360 minutes of dehydration, when the product reached thermodynamic equilibrium with the OS and there was no more perceived solute or water transfer, reaching the maximum dehydration level (Falade et al., 2007). The rise in x_s and the consequent decrease in x_w, is because OD promotes the diffusion of water from the outer layer of the product to the OS, while external solute simultaneously enters throughout the semi-permeable cell membranes of the plant tissue, due to the difference between the concentration gradients (Chiralt and Talens, 2005).

OD leads to an increase in the soluble solid content, helping to increase the level of sweetness in the fruit and reducing the excess acidity that limits its fresh consumption, which is of particular significance in the case of this product. The a_w and z_s profiles also varied during OD dehydration, as shown in Fig. 1b. The cocona presented an initial value of a_w = 0.992 ± 0.003, which decreased gradually to reach a final value of 0.934 ± 0.003 after 360 minutes of dehydration. The relationship between a_w as a function of z_s was well fitted to the Norrish equation (Fig. 1b). In this equation, a K value of 6.47 was used, corresponding to the sucrose used for the OD process (Martínez-Navarrete et al., 2000). This relationship allows the a_w of osmotically dehydrated cocona to be predicted easily, by means of a simple measurement of the °Brix.

The results in terms of total weight variation, water loss and soluble solids gain, is presented in Fig. 2. The material balance shows that most of the points are distributed on the diagonal, with an adjustment of the experimental ΔM vs. (ΔMw + ΔMs) results giving a determination coefficient (R^2) = 0.996. This behaviour reflects the very few experimental errors, the observed minor variation from a perfect linear relationship being due to some loss of seeds from the fruit to the OS.

The total mass loss increased as a result of mass transfer phenomena which occur mainly in the first 60 minutes, after which ΔM decreased slowly until a total loss of approximately 53% of the initial mass after 360 minutes of the study.

The obtained D_e (Eq. 1) during the osmotic process was $2.9*10^{-10}m^2/s$, with a standard error of $0.4*10^{-10}$. This value was similar to that reported for studies on tomato (Telis et al., 2004), apple and pineapple (Ochoa and Ayala, 2005). From these results, 48 minutes was selected as the osmotic dehydration time necessary to pre-treat the samples before air drying, after which a product with a water content of 0.75 ± 0.02 g_{water}/g_{cocona} and soluble solid content of 0.248 ± 0.003 $g_{solublesolids}/g_{cocona}$ will be obtained. According to the results of the dehydration kinetics study carried out, dipping the fruit in the OS for longer will lead to slower water loss and solute gain. This could result in increased structural damage.

3.2. Hot Air Drying kinetics

Fig. 3 represents the change in the water content, the drying curves and the drying rate of the slices, both pre-osmodehydrated or not, during hot air drying. Due to the osmotic treatment, OD+HAD samples begin the drying process with a lower water content (x_w = 0.75 ± 0.02 g_{water}/g_{cocona}) than the fresh samples (x_w = 0.92 ± 0.20 g_{water}/g_{cocona}). As can be seen in Fig. 3a, both samples showed a rapid decrease in the water content during the first 120 minutes of drying. After this time, the water content of OD+HAD samples remained stable, while HAD samples continued the drying process. Similar results were reported by Mandala et al. (2005) studying apple samples pre-treated with sucrose during HAD.

According to the obtained drying curves (Fig. 3b), the rate of water transfer from within the product to the outside decreases, exhibiting two falling rate periods for both treatments (Fig. 3c). In the first period, the evaporation of water takes place near the surface of the half-slices of the cocona. When the drying continues, the surface dries completely while the interior remains moist and the drying rate decreases to reach a plateau with a more or less constant value. Once the water from the interior rises to the surface, the drying rate decreases slowly from a critical water content, which leads to the second drying period (Thuwapanichayanan et al., 2011). It appears that the initial drying period of the pre-

treated slices is shorter compared with the drying rate of the non-pretreated samples (Fig. 3c). This may be due to the concentration of sugars that occurs in the intracellular spaces during OD along with the moisture reduction, which decreases the driving force for the mass transport near the interface during HAD. The drying processes were considered to have finished when a constant weight for the samples was reached. This was after 3 or 4 h for OD+HAD and HAD samples, respectively. At this moment, OD+HAD slices reached a final moisture content of 0.055 ± 0.005 g_{water}/g_{cocona}, while HAD reached 0.0160 ± 0.0013 g_{water}/g_{cocona}.

In both cases, the effective diffusivity of water was also modeled with the solution of Fick's second law (Eq. 1). The D_e values obtained were $1.8*10^{-9} m^2/s$ (standard error of $0.5*10^{-9}$) and $1.2*10^{-9}$ m^2/s (standard error of $0.5*10^{-9}$) for OD+HAD and HAD slices, respectively. Using the Snedecor test, the statistical analysis showed there was no significant difference ($p>0.05$), suggesting that although the short osmotic dehydration process applied previously does not influence the drying kinetics, it could induce some structural damage to the cell wall membranes of the fruit. This behavior has also been observed by authors such as Alvarez et al. (1995), who found that the immersion of strawberries in a glucose solution did not have any effect on the value of HAD D_e, because of two counterbalancing phenomena that occur during OD. The first one is solute absorption which increases the resistance to water transport, and the second is the significant reduction in the resistance of the cell walls. The shorter OD+HAD drying time is due to the lower water content of these samples when placed in the dryer.

As regards the shrinkage of the samples, Fig. 4 details the shrink curves taking into account the area, thickness and volume of OD+HAD and HAD samples. HAD application caused a reduction in the sample volume due to the protoplast water loss, leading to an appreciable change in the product properties. According to the results obtained, when both

processes are applied for the length of time necessary for the sample to reach 0.055 ± 0.005 g_{water}/g_{cocona}, the reduction in the total volume of the sample caused by the OD+HAD process was 84.04 % ± 0.05, while the application of only HAD reduced the volume by 87.960% ± 0.014. Similar results have been reported by Garcia et al. (2007) when studying the dehydration of pumpkins; they suggest that osmotic treatment causes less compaction of the sample due to the volume occupied by sucrose impregnated into the tissue.

3.3 Changes in the optical properties.

Fig. 5 shows the reflection spectra (a) and distribution curves of the ratio K/S (b) for the external part of the fresh and dried samples. Similar results were obtained for the internal part. Despite dehydration treatments caused a slight decrease in reflectance and a slight increase in the values of K/S, the values of K/S were low for all the samples. As the Kubelka-Munk theory describes, the ability of the materials to transmit light depends on their light scattering (S) and absorbing (K) properties. Low K/S values imply that a high light is scattered by the samples indicating that the cocona samples have closed structures and, therefore, certain opacity.

Table 1 presents the mean values of the different color coordinates and attributes evaluated in the fresh product, in the pre-OD sample and in both chip products (OD+HAD and HAD). Generally speaking, no significant differences ($p>0.05$) were observed between the internal and external part of the slices and, when observed, they were very small. For this reason, the more uniform color of the external part (lower standard deviation) is considered in the following discussion. As can be seen, the application of both OD and HAD to cocona slices caused a significant ($p<0.05$) decrease in the clarity (L*) of the samples and an increase in the a* coordinate, whereas b* increased with OD and decreased with HAD. In this way, the hue angle decreased in every case, becoming less

yellow , and the chroma or color purity increased with OD and decreased with HAD. The changes observed in the color of the samples are associated with the extent to which different browning phenomena overlap, which affects the optical properties of the measured surface (Acevedo et al., 2006). OD involves a loss of water in the product and a gas-liquid exchange due to the action of hydrodynamic mechanisms which lead to a more homogeneous refractive index in the tissue (Chiralt and Talens, 2005). This promotes the greater light absorption which would explain the decrease in the clarity observed in the samples. This treatment does not seem to affect the pigments responsible for the color. By contrast, the application of HAD involves a surface concentration of pigments associated with the intense loss of water, which gives rise to an increase in the refractive index of the liquid portion of the sample and, therefore, an increase in opacity. On the other hand, this treatment seems to favor the development of browning reactions as the hue and chroma were observed to decrease. Table 1 also shows the color differences of the different treatments when compared to fresh fruit (ΔE). As expected from the changes commented on above, a smaller color change was measured when cocona chips were obtained with a previous OD step, which seems to play a very important role in minimizing the impact of the drying process on the quality of the final product.

3.4. Changes in the mechanical properties.

Fig. 6 shows the average curves obtained after the compression-extrusion test of fresh, OD, OD+HAD and HAD samples. As can be observed, the drying treatments led to a significant increase ($p<0.05$) in the force necessary for the extrusion of the samples, mainly due to the loss of product water and the increase in the proportion of dry matter. The fresh sample showed a value of 20 ± 4 N/g. This value increased to 38 ± 3 N/g with OD. In this case, the sugar uptake during osmotic pre-treatment leads to a firmer structure, less elastic and less porous, which leads to increased mechanical parameters (Zou et al.,

2013). After the hot air drying of pre-treated samples (OD+HAD), the F_{max}/g increased significantly ($p<0.05$), reaching mean values of 113 ± 8 N/g, lower than that exhibited by the HAD sample (340 ± 70 N/g). On the other hand, before F_{max} is achieved, more fracture peaks can be observed in Fig. 6 for the OD+HAD sample than for the HAD one. This is associated with a crisper structure in the first case, which is a very desirable property for a chip product. The structure of HAD samples becomes overly hard.

4. Conclusion

A combined osmotic-air drying process may be proposed to obtain cocona chips. The pre-osmotic treatment caused an increase in the content of soluble solids, suitable as a means of increasing the sweetness of the fruit and reducing the excess acidity that limits the consumption of fresh cocona. The short osmotic dehydration process applied does not influence the hot air drying kinetics. Furthermore, a smaller color change was observed in the pre-treated fruit samples than in the non-pretreated ones, the structure of the former also being crisper, a property desirable in this kind of product.

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Table 1

Table 1.

	Sample							
	Fresh		**OD**		**OD+HAD**		**HAD**	
Optical properties	**Internal**	**External**	**Internal**	**External**	**Internal**	**External**	**Internal**	**External**
L*	62 (3)^{aA}	61(1.3)^{aA}	55 (4)^{bA}	59(2)^{abB}	48 (2)^{bcA}	51.0(1.9)^{bB}	42 (2)^{cA}	43(2)^{cA}
a*	1 (1)^{aA}	-0.6(0.3)^{aA}	0.2 (1.3)^{bA}	0.9(0.7)^{bA}	6 (1)^{cA}	5.4(1.3)^{cA}	5.1 (0.3)^{cA}	4.1 (0.5)^{dA}
b*	26 (2)^{aA}	22(2)^{aB}	24 (4)^{bA}	26(2)^{abA}	22 (3)^{cA}	23.4(0.7)^{aA}	15.7 (1.6)^{cA}	14 (2)^{bA}
h^*_{ab}	88 (2)^{aA}	90.6(0.7)^{aB}	94 (3)^{bA}	85.5(1.0)^{bA}	75 (3)^{cA}	77(3)^{cA}	70.6 (1.4)^{dA}	67 (3)^{dA}
C^*_{ab}	26 (2)^{abA}	23.6(1.3)^{abB}	24 (4)^{aA}	26.1(2)^{bcA}	23 (3)^{bA}	24.0(0.9)^{aA}	16.7 (1.6)^{cA}	15 (2)^{cA}
ΔE	---------	--------	9 (1)^{aA}	6.1(1.0)^{aB}	15 (3)^{bA}	13.6(0.8)^{bA}	23 (2)^{cA}	28 (2)^{cB}
Mechanical properties								
$F_{máx}$/g	20 (4)^{a}		43 (12)^{a}		140 (16)^{b}		341 (70)^{c}	

The same capital letter superscripts within the same row for the internal or external part of the slice indicate homogeneous groups among treatments ($p \geq 0.05$); the same lower case superscripts within the same row for each sample indicate homogeneous groups between the internal and external part ($p \leq 0.05$). OD: partially osmodehydrated sample; OD+HAD: combined osmotic-hot air drying; HAD: hot air drying

Figure 1

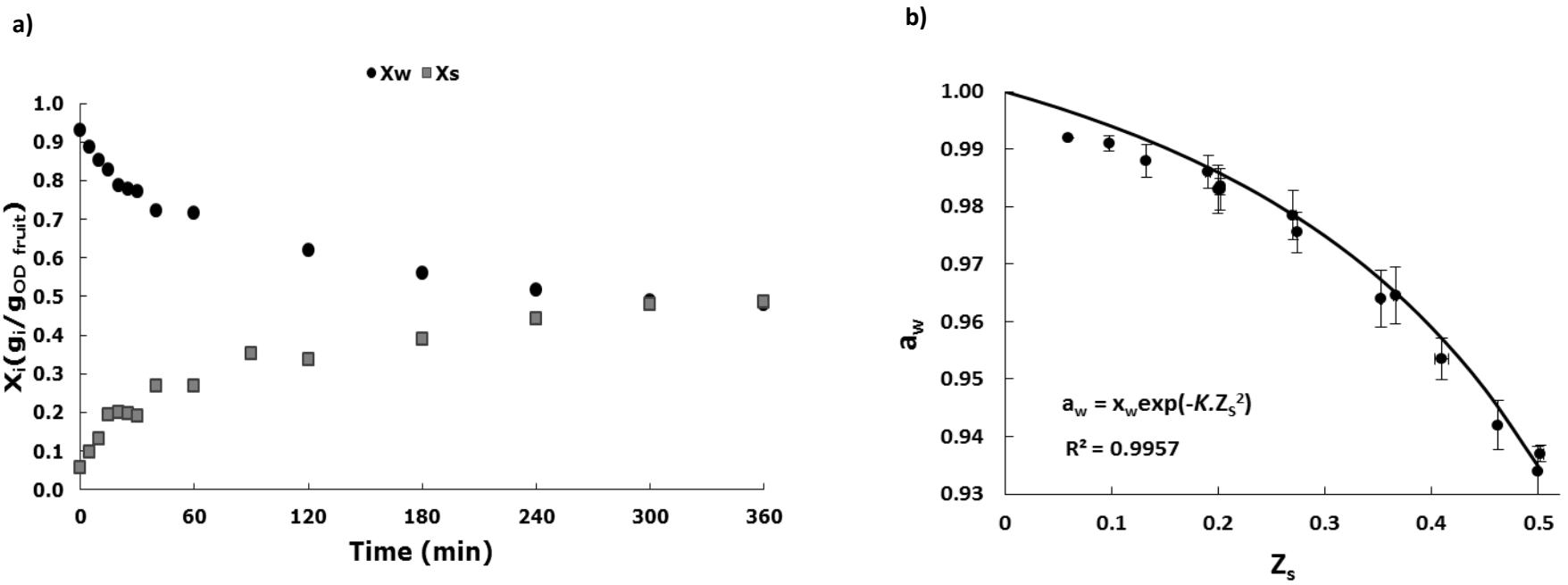


Figure 1.

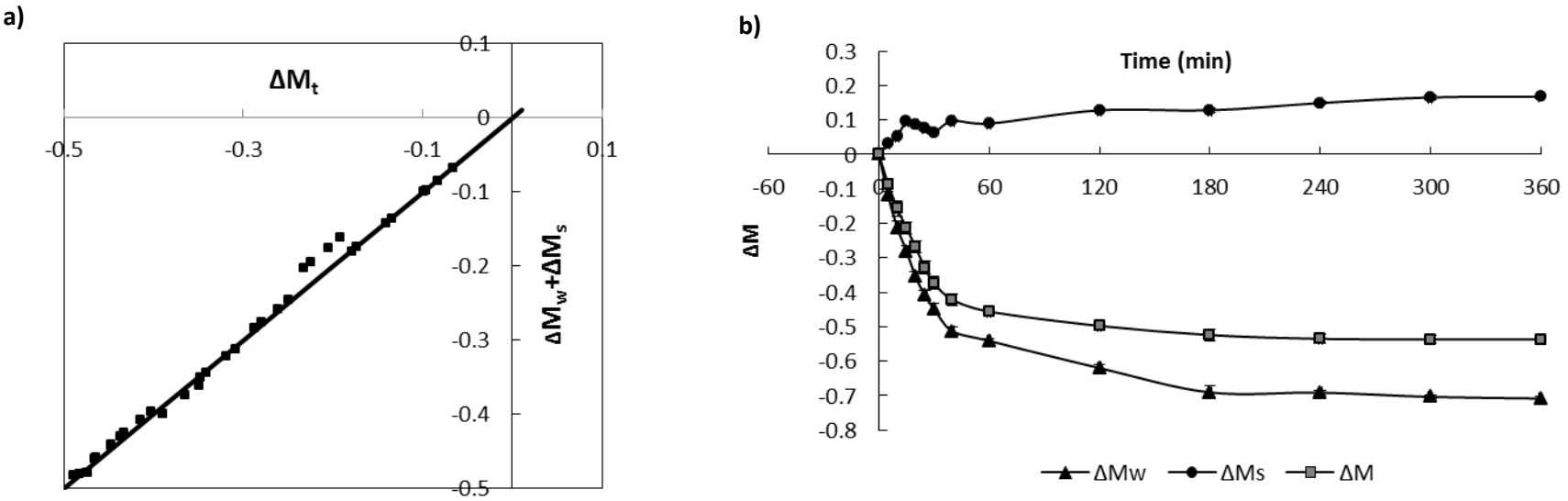

a)
ΔMt
ΔMw+ΔMs
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
-0.3
-0.1
0.1
b)
Time (min)
ΔM
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-60
0
60
120
180
240
300
360
ΔMw
ΔMs
ΔM

Figure 2

Figure 3

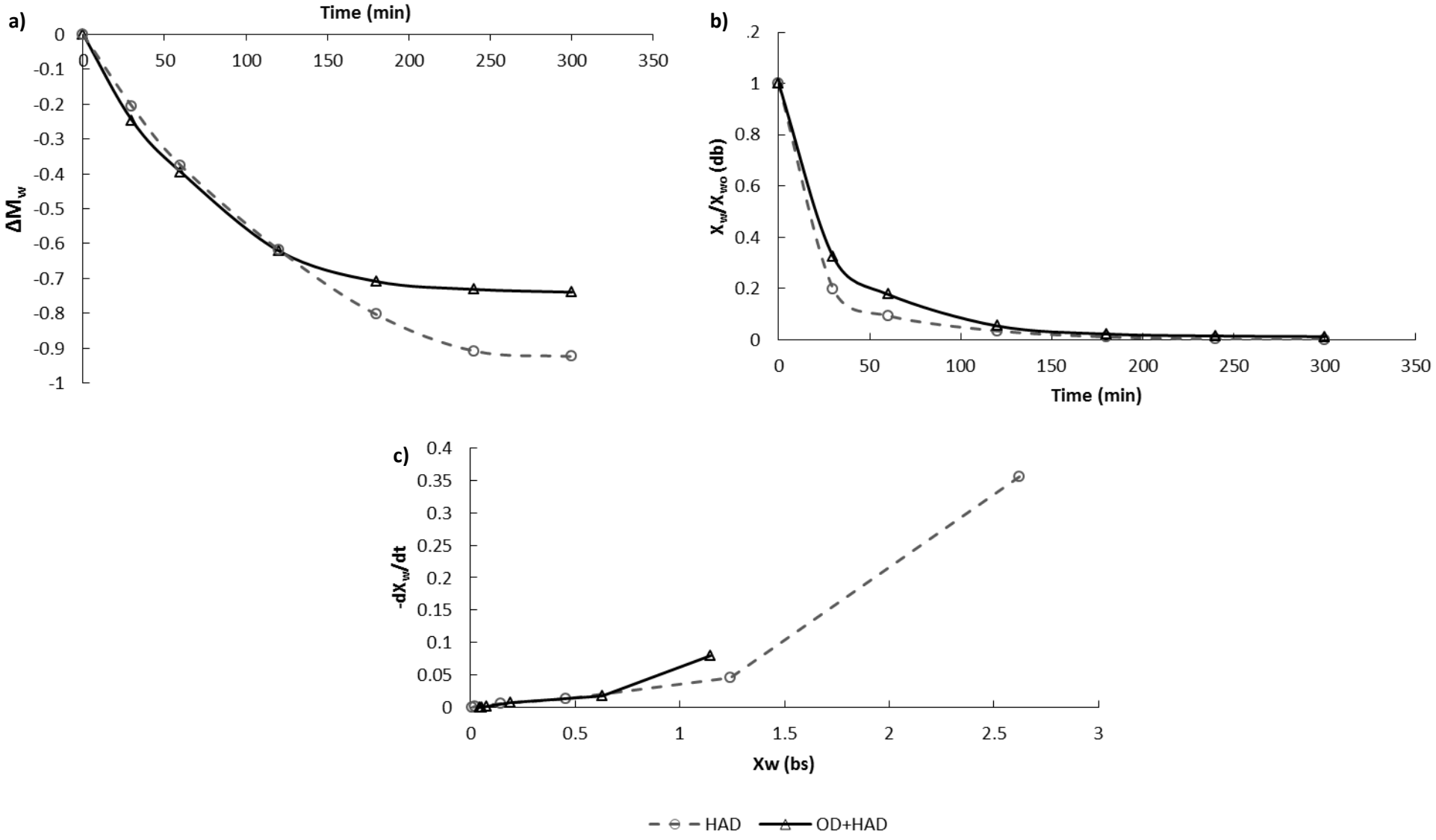
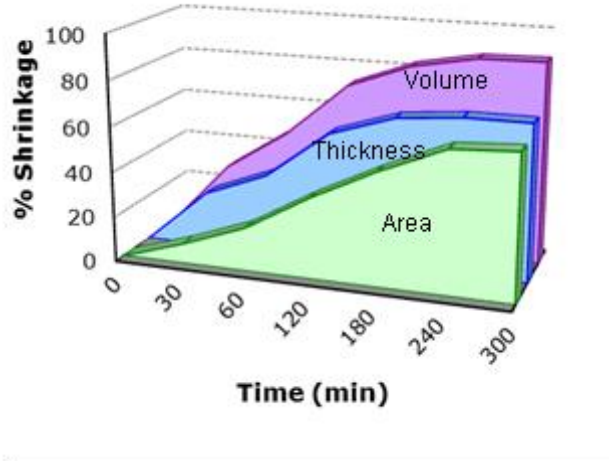


Figure 3

a)


% Shrinkage
100
80
60
40
20
0
Volume
Thickness
Area
0
30
60
120
180
240
300
Time (min)

b)

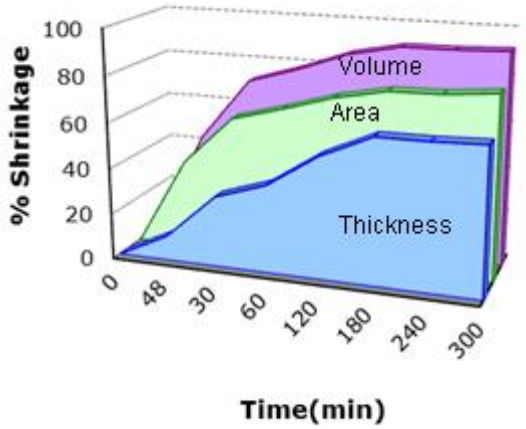

% Shrinkage
100
80
60
40
20
0
Volume
Area
Thickness
0
48
30
60
120
180
240
300
Time(min)

Figure 4

Figure 5

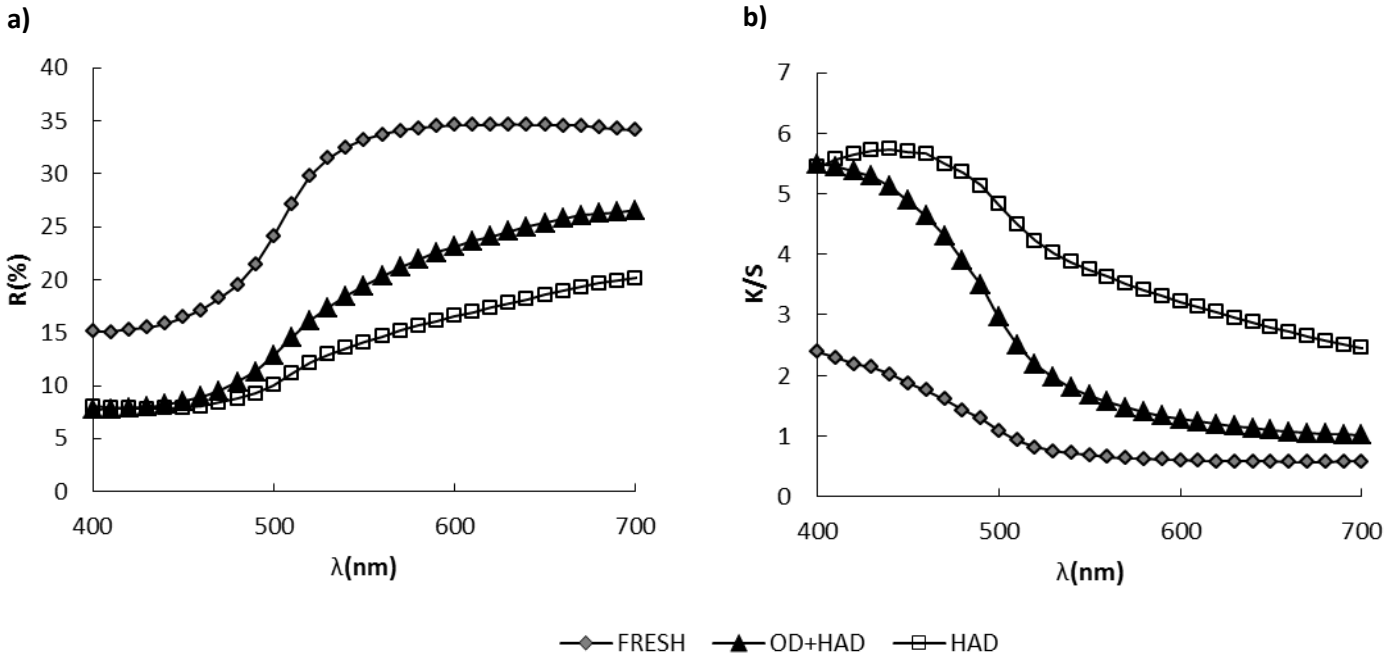


Figure 5

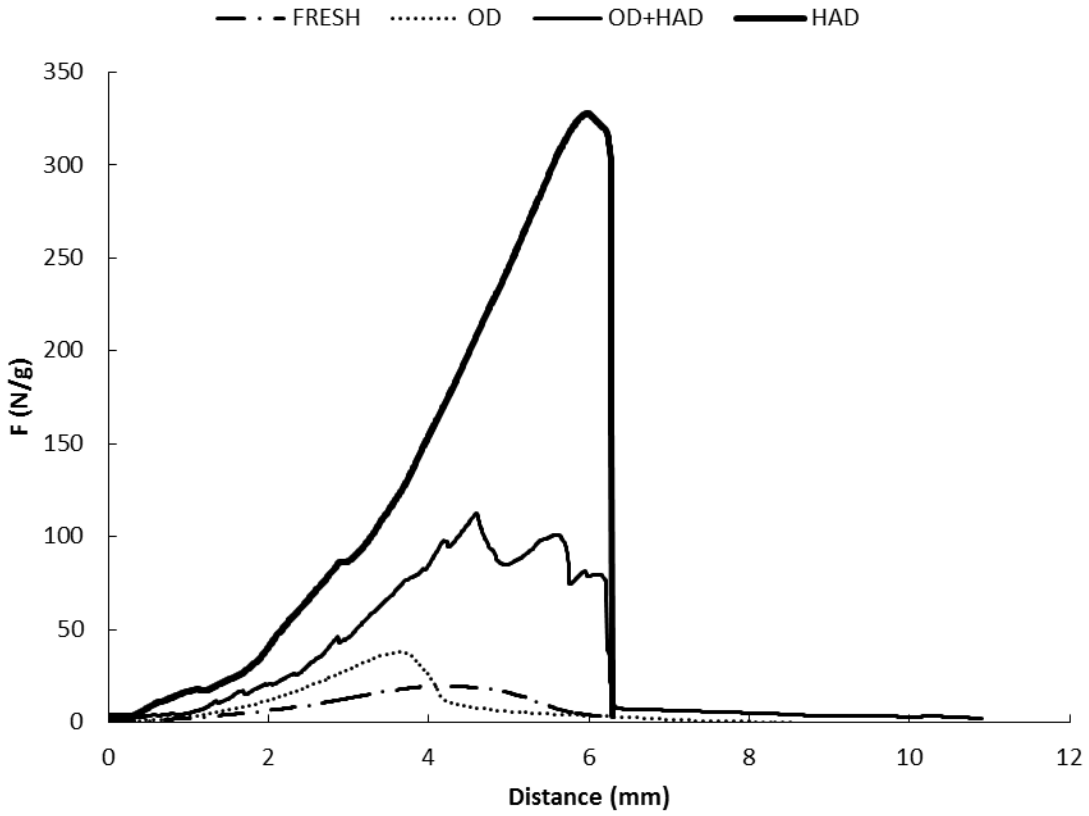

FRESH
OD
OD+HAD
HAD
350
300
250
200
150
100
50
0
F (N/g)
0
2
4
6
8
10
12
Distance (mm)

Figure 6

TABLE CAPTIONS

Table 1. Mean values and standard deviation (in brackets) of color coordinates (L*, a*, b*), hue angle (h^*_{ab}), chroma (C^*_{ab}), color difference of the treated samples compared to fresh fruit (ΔE) and maximum force of compression-extrusion of the sample, related to the mass weight (F_{max}/g).

FIGURE CAPTIONS

Figure 1. (a) Experimental mass fraction of water (x_w) and soluble solutes (x_s) evolution during osmotic dehydration. (b) Relationship between the water activity (a_w) and the soluble solutes concentration in the liquid phase (Z_s); experimental data (points) and fitted model (line).

Figure 2. (a) Mass balance: water loss (ΔM_w) and soluble solutes gain (ΔM_s) plotted against loss of mass (ΔM_t). (b) Evolution of total mass (ΔM), mass variation of water (ΔM_w) and mass variation of soluble solutes (ΔM_s) during osmotic dehydration.

Figure 3. (a) Change of water mass (ΔM_w) during hot air drying, (b) Drying curves and (c) Drying rate curves, of osmotically pre-treated (OD+HAD) or not (HAD) cocona slices.

Figure 4. Shrinkage of the area, thickness and volume of samples (a) hot air dried and (b) combined osmotic-hot air dried.

Figure 5. (a) Reflectance spectra (R%), and (b) spectral distribution of Kubelka-Munk's index (K-S ratio), of fresh cocona, hot air dried cocona (HAD) and combined osmotic-hot air dried cocona (OD+HAD) for the external part.

Figure 6. Curve force (N/g) vs. distance (mm) of fresh cocona, partially osmodehydrated cocona (OD), combined osmotic-hot air dried cocona (OD+HAD) and hot air dried cocona (HAD).