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A. Rodriguez[a], M.A. García[a] & L.A. Campañone[ab]

[a] CIDCA (Centro de Investigación y Desarrollo en Criotecnología de Alimentos, UNLP-CONICET) La Plata, Argentina

[b] MODIAL, Facultad de Ingeniería, Universidad Nacional de La Plata, Argentina

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Experimental Study of the Application of Edible Coatings in Pumpkin Sticks Submitted to Osmotic Dehydration

A. Rodriguez[1], M.A. García[1], L.A.Campañone[1,2,*]
[1]CIDCA (Centro de Investigación y Desarrollo en Criotecnología de Alimentos, UNLP–CONICET) La Plata, Argentina, [2]MODIAL, Facultad de Ingeniería, Universidad Nacional de La Plata, Argentina

Corresponding author. E-mail: lacampa@ing.unlp.edu.ar

Abstract

Osmotic dehydration (OD) process permits to improve the organoleptic characteristics of the products; nevertheless, depending of the product, the incorporation of great amounts of solute can be not desirable for consumers. The application of hydrogel coatings would contribute to overcome this inconvenient acting as a barrier to solute entering. An Alginate-Calcium Chloride barrier system (A-CC) was tested with or without pretreatment of Ca^{2+} as a firmness agent applied to pumpkin sticks. Products were dehydrated in sucrose and glucose solutions (40 and 60 % w/w). Different parameters were estimated along the process such as soluble solids uptake, water content, weight reduction; besides, texture and microstructural changes were studied. The A-CC configuration complies with the barrier function to solids uptake from the dehydrating solution in case of 60% of sucrose, allowing water exit from the vegetal matrix. The pretreatment with Ca^{2+} contributed to the retention of the product firmness. Integrity, adhesiveness and thickness of the A-CC system during the OD process were evaluated by ESEM. In this case, the coating thickness reduction was according to the product weight reduction, indicating that the coated product was dehydrated as an integrated system.

KEYWORDS: Osmotic dehydration, Pumpkin, Hydrogels coating, Texture, Microstructure.

NOMENCLATURE

Fe	Force value of treated samples (N)
Fo	Force value of fresh samples (N)
m	Sample mass (kg)
NF	Normalized force
SS	Soluble solids (ºBrix)
t	Time (s)
WC	Water content for each osmotic dehydration time (%)
WL	Water Loss (%)
WR	Weight reduction (%)
WR_{OD}	Weight reduction of the dehydrated product (%)

Subscripts

dw	Dried
f	Final
i	Initial

t Total

INTRODUCTION

Pumpkin belongs to the *Cucurbitaceae* family from Moschata gender and is a high consumption product, low cost and easy to store and process. It is a source of nutrients such as potassium, provitamin A, carotenoids, mainly carotene A and B, vitamins B2, C and E and it contains a high content of dietary fiber [1–3]. However, its high water content makes the product sensitive to microbial deterioration, even under refrigeration conditions [4].

Dehydration is one of the main unitary operations for conservation in food processing. Osmotic dehydration (OD) technique has been applied to obtain new intermediate moisture products, opening alternatives in the current market. Besides, it has received considerable attention because requires low energy and permits to obtain very high quality products [5–6]. Numerous technological advances occurred in recent years related to the use of OD technique as a pretreatment of other drying operations such as microwave drying, hot air, freezing, and others [7–11].

In osmotic dehydration a cellular tissue is immersed in a concentrated solution of sugars or salts in order to promote water loss in the cells due to the difference in water chemical potential established between the external solution and the internal liquid phase of the cells. Nevertheless, due to the open structure of the tissue in the intercellular spaces and cut external cells, diffusion of external solutes and hydrodynamic gain of external solutes

also occur. In addition, structural changes such as cell alteration due to deformation and break of cellular elements associated to dehydration and gas–liquid exchanges can also take place. Moreover, all these phenomena provoke changes in the macroscopic properties of the samples, such as optical and mechanical properties, related to the product appearance and texture, respectively [8, 11, 12–13].

Likewise, in the recent years the application of appropriate coatings on the surface of raw material prior to dehydration has been proposed to minimize these structural changes [14–19].

Edible coatings could be considered as thin layers of edible material formed on a food surface. In general, they extend minimally processed fruits and vegetables shelf life by reducing moisture and solute migration, gas exchange, respiration and oxidative reaction rates, suppress physiological disorders, delay changes in textural properties, and improve mechanical integrity or food handling characteristics. Excellent reviews and books on edible coatings and packaging materials have been published in the last years [20–21].

Likewise, edible coatings could be used to control the intake of osmotic solutes without affecting the rate of water loss [22]. According to Wong et al. [23], the advantages of the use of these films in the osmotic process are: the reduction of food solutes losses, greater dehydration of the product compared to the uncoated samples, allows the use of osmotic agents with low molecular weight reducing the solute amount entering the food, reduces microbial contamination, provides greater integrity to the food and a better acceptance of

the product. These authors also stated that edible coatings should comply with five basic properties: good sensory properties, easy and fast formation, high water diffusivity and low solute diffusivity, likewise the formed hydrogels must remain intact on the wet surface without being dissolved in the osmotic solution [23].

Several authors reported the use of different polysaccharide based coatings to minimally processed vegetables submitted to OD process [24–29]. Azam and coworkers [22] stressed that nature and concentration of the coating material as well as drying conditions have a pronounced effect on the dehydration efficiency of osmotically dehydrated foods. Besides, edible coating also provides a barrier to oxygen and assists in retaining aroma and flavor [30]. Most previous work on osmotic dehydration has been carried out using polysaccharide-based edible coatings, [29, 31] or gluten protein based ones [22]. In the present work an alginate coating from pumpkin sticks were applied. The hydrogel formation requires the sample immersion in the alginate solution and then in a divalent cation (Ca^{+2}) solution, due to the gelation mechanism of alginate, known as egg-box gelation mechanism. Besides, since it is well known that during OD soften samples are obtained a first step of firmness agent treatment was evaluated, immersion in Ca^{+2} solutions are the most widely used pretreatments for firmness maintaining of vegetables.

However, to the best of our knowledge, a pretreatment with Calcium on pumpkin sticks prior to coating application, as well as the analysis of different dehydrating agent concentrations have been little studied.

According to the above, the objective of the present work was to study experimentally the use of edible coatings in pumpkin sticks (with or without adding Ca^{2+} as firmness agent) submitted to osmotic dehydration. The capability of the formulated barrier systems to prevent or reduce the incorporation of solutes during the immersion process was evaluated and textural and microstructural characteristics were studied after the applied treatments.

MATERIALS AND METHODS

Materials

Commercial pumpkins (*cv. Curcubita Moschata*), were acquired at a local shop in La Plata city-Argentina and stored at 4°C prior to the experimental runs (initial water content of 91 ± 2.4 % (wet basis) and soluble solids of 8.93 ± 2.4 Brix). Pumpkins were selected and washed with running water to remove surface dirt. Then, they were manually peeled and cut, using a stainless steel knife. Only the proximal portion of the fruit was employed to obtain stick samples (1 x 1 x 1 cm).

Preparation And Application Of Hydrogel Coating

The hydrogels were prepared from a sodium alginate solution (1% w/w) (Natriumalginat, USA) and calcium chloride (10% w/w) (Anedra, Argentina). The used concentrations were obtained through preliminary tests. The aqueous solutions of alginate was prepared by stirring at a constant temperature (50º C), until the hydrocolloid was completely solubilized and then cooled to room temperature. Pumpkin sticks without hydrogel

coating were considered as control samples. The application of the coatings was carried out on the pumpkin sticks with or without pretreatment with Ca^{+2}:

Barrier system without pretreatment with Ca^{+2} (A-CC): the pumpkin sticks were immersed in sodium alginate solution during 5 minutes, after this time they were dipped in calcium chloride solution, during 5 minutes. Then, samples were removed from the solution and left to dry during 15 minutes over a plastic mesh. The immersion time of the products in each solution was selected from preliminary tests, and it was according to the time needed to achieve the adhesion of the coating and assure its integrity during the osmotic treatment.

Barrier system with pretreatment with Ca^{+2} (CC-A-CC): the sticks were introduced into the calcium chloride solution during 5 minutes; and after that the procedure was the same as the previous case.

Osmotic Dehydration

Dehydrating agents such as commercial sucrose (Ledesma, Jujuy, Argentina); and glucose (Anhydride Dextrose; USA) were used for the osmotic dehydration. Two concentrations of aqueous dehydrating solutions were prepared: 40 % and 60 % (w/w).

The sample/solution relation was 1:20 (w/w). The osmotic dehydration tests were carried out in a thermostatic bath, (FERCA, model TT 400, Argentina) at 20 ºC with constant

linear stirring (100 rpm). The samples were extracted at different selected times (0, 30, 60, 120 and 180 min).

Once the samples were extracted, they were washed with distilled water and put on an absorbent paper to remove the solution excess, then the samples were weighed to determine the weight reduction in relation to the initial mass of the product. During the process, the soluble solids gain, weight reduction and water content were determined as a function of OD time. The osmotic drying experiments were carried out in duplicate.

Weight Reduction (WR)

Weight reduction was determined through the weight difference of the samples before and after the osmotic treatment using an analytic scale (Adventurer Okaus No AR2140; Ohaus USA), for each tested time (sensibility 0.0001g). The weight reduction was calculated from the following equation:

$$WR_{OD}(\%) = \frac{(m_i - m_t)}{m_i} \times 100 \quad (1)$$

Determination Of Soluble Solids Content (SS)

The determination of the soluble solids content (ºBrix) of the samples and that of the osmotic solutions was carried out using a digital refractometer (Hanna Instrumental HI 96801, Romania).

Determination Of Water Content (WC)

The moisture content was determined in a vacuum oven at 70 ºC (Gallenkamp, UK) according to the A.O.A.C. (2002) method until reaching a constant weight [32]. The mass fraction of water was calculated from the analyzed moisture in the fresh product and that for each dehydration time, according to the equation:

$$WC\ (\%) = \frac{m_t - m_{dw}}{m_t} \times 100 \qquad (2)$$

Texture And Microstructure Analysis

Texture tests were carried out using a texturometer Universal Testing Machine, model TATX2i, Stable Micro Systems (Surrey, UK). Rupture tests were performed with a SMSP/3 probe of 3 mm diameter. The running parameters were: pre-test and post-test velocity: 5 mm/s and rupture distance: 15.0 mm. Force curves (N) were recorded as a function of deformation (mm) by the software Texture Expert Exceed installed on a PC connected to the equipment. Maximum force was calculated from these curves. This parameter represents the firmness of the samples and permitted to evaluate the effect of the pre-treatment and the osmotic dehydration. The presented results correspond to the average of at least 10 measurements. For comparison purposes, and to minimize the variability of the vegetal product, the force parameter was normalized according to the following relation:

$$NF = \frac{Fe}{Fo} \qquad (3)$$

Furthermore, fresh and processed samples were analyzed using an Environmental Scanning Electron Microscopy (Philips XL 30 ESEM, USA) under a pressure of 1.3 torr and a temperature of 15ºC. Pumpkin sticks of fresh samples, coated samples with A-CC

previous and after 180 minutes of the OD with sucrose solution 60% were evaluated, and micrographs of surfaces and cross-sections were taken.

Statistical Analysis

The results obtained from the different assays were analyzed using the SYSTAT 12 software (Systat, USA). A variance analysis was carried out (ANOVA) followed by a means comparison test (Tukey Test). The significance level was defined with $p<0.05$.

RESULTS AND DISCUSSION

Soluble Solids Gain, Water Content And Weight Reduction

Tables 1, 2 and 3 show the obtained results of soluble solids (SS), water content (WC) and weight reduction (WR) under different osmotic treatments for samples with and without pretreatment with Ca^{2+} as well as the control ones. A greater kinetic of solids gain, weight loss increase and water content reduction were observed within the first 30 minutes of process, as a consequence of the concentration gradient between the dehydrating solutions and the samples. As the processing time progressed, mass transfer rates slow down due to the driving forces decrease. On the other hand, no significant differences ($p>0.05$) between 120 and 180 min were found in control samples submitted to OD; which allow to reduce processing times; this behaviour has been reported by other authors [33].

In OD with sucrose and glucose 60%, the soluble solids uptake of the samples with hydrogel A-CC was significantly ($p<0.05$) lower than the control ones. It could be

explained by the solid accumulation at coating surface, together with the use of coating, both effects could constitute a barrier to soluble gain [27].

Solids uptake in samples pretreated with Ca^{+2} (CC-A-CC), were significantly ($p>0.05$) higher than those of the sticks with A-CC coatings and did not differ ($p>0.05$) from the control ones. These results indicate that A-CC systems were more efficient to minimize the solids entry from the dehydrating surrounding to the samples at 60%.

In OD samples with glucose 40% and sucrose 40%, none of the tested systems were efficient with respect to solids uptake because obtained values were similar to control ones and even higher.

Regarding the effect of the solutions concentration, control samples and coated samples with CC-A-CC system presented a higher solid gain treated with more concentrated solutions (60%). A similar trend was observed by Azam et al. [22] working on osmotic dehydrated mango cubes with a wheat gluten based coating and submitted to different concentrations (45, 55 and 65º Brix) of sucrose solutions.

In Table 2, the water content behavior of the samples is presented as a function of process time. Samples with the A-CC barrier system treated with sucrose 60% presented values of WC similar to those obtained with the control samples, which indicates that the hydrogel permits the transfer of water molecules through it due to its hydrophilic nature. This is the behavior expected from a semipermeable coating, which allows the water exit

from the vegetal tissue and yet be a barrier to the solutes entry from the dehydrating solution [34–35]. Dehghannya et al. [31] observed the same trend using carboxy-methyl cellulose coating in apple slices. The coating allows water release from the fruit during osmotic dehydration regardless the glucose syrup concentration tested.

In turn, samples treated with Ca^{+2} (CC-A-CC) presented a lower WC with respect to the coated pumpkins with the A-CC system. The values of WR (Table 3) are consistent and support the WC and SS values. The lower value of WR (%) was obtained in coated samples of CC-A-CC, regardless the immersion time. In order to evaluate the individual contribution of the food and the coating to the global value obtained, an independent test was carried out. For each one of the processing times, coated sticks with CC-A-CC were dehydrated and the water content of the complete sample was measured. After this, the hydrogel (CC-A-CC coating) of the treated product was separated from the vegetable tissue. Water content of the vegetable matrix and the hydrogel were determined in order to evaluate the individual contribution to the global value (WC). In Figure 1, kinetics of water content of coated samples is shown as well as each one of the parts. It can be observed that the hydrogel behavior controls the global kinetics. These results are in concordance with the lack of adhesion observed in CC-A-CC systems. The pretreatment with Ca^{+2} prevents the interaction between the alginate and the vegetal matrix. In the case of A-CC, where the coating is integrated to the pumpkin matrix, the coated product is dehydrated as an integrated system.

The system without Ca^{+2} pretreatment presented better results as a barrier system. Nevertheless, the system was efficient only when samples were treated with high concentration solutions (60%).

Mathematical Modeling Of Osmotic Dehydration Process

According to the experimental evolution of osmotic dehydration, it can be observed an exponential behavior of water loss and solid gain as function of processing time. In the model formulation, the following relation for water loss and soluble solid content can be established:

$$y = a * \exp^{(k*t)} \quad (4)$$

Where *a* and *k* are constants, *y* is SS or WC and *t* is the processing time (min).

Besides, the drying rate parameter can be obtained by the derivation of Eq (4):

$$DR = -C * \exp^{(-k*t)} \quad (5)$$

where *C* corresponds to the product of *k* and a and *DR* is defined as drying rate. Table 4 shows the estimated parameters obtained by non linear regression of the data using the Systat 12 software, for WC parameter. The values at initial stages corresponds to the higher values of *DR*; the *C* constant represents the *DR* at t=0. The higher values were obtained for the osmodehydrated samples in glucose solutions, regardless the coating application or solution concentration.

Texture Analysis

Firmness parameters obtained under different conditions are shown in Figure 2 (a-d). As it is well known, during osmotic dehydration, firmness of vegetable tissues decreases mainly due to water loss [36–37].

ANOVA showed that both the coatings and the time have a very significant effect on the firmness of the samples ($p<0.05$), also a significant interaction among both was found.

When samples were coated with the hydrogel CC-A-CC it was observed that the force value remains constant at the end of the process (Figure 2). Furthermore, coated samples pretreated with Ca^{2+} presented a similar behavior during the OD process. The adding of Ca^{+2} to minimally processed vegetables is a commonly used practice in order to improve their firmness [38-39]. The stress suffered by the tissues during the peeling and cutting operations could increase the permeability of the membranes, thus increasing the cell exchange of fluids with the consequent flooding of intercellular spaces [40]. This cell damage leads to enzyme and substrate decompartmentalization causing an increase in enzymatic activity and fluids loss. Different types of calcium salts have been studied to preserve the structure and texture of the cut fresh fruit. The treatment with calcium chloride ($CaCl_2$) has been tested in minimally processed fruits, in concentrations ranging between 0.1% and 5% [41-43].

The analysis of obtained values of firmness for A-CC coated samples is complex. In this case, several contributions have to be considered: the coating barrier efficiency, the cell wall damage caused by the solid uptake as well as the water retention. Figure 2a shows

that samples retain their turgency after 180 minutes of immersion in sucrose 60%, which could be attributed to the barrier effect of the coating. At this operating condition, the coating controls the solid uptake (Table 1). Khin et al. [14] working on coated apples submitted to OD, using similar osmotic solution concentration of dextrose and sucrose reported that the coating helped to prevent cell wall over-softening. Figure 2c shows the results obtained in samples submitted to sucrose 40%. It could be observed that firmness decreases during the measured processing times. Since the samples submitted to both 60% and 40% sucrose did not differ in their final water content values (Table 2), the dominant effect on this textural parameter was the tissue damage caused by the sucrose uptake. Moreover, solid gain was higher in samples submitted to sucrose 40% (Table 1). This phenomenon is well reported in the literature [13, 44–46]; Lenart and Potrowski [47] studied the maximum compressive force of apples coated with low methyled pectin. They observed a significant reduction of this parameter in coated samples submitted to osmotic dehydration with 61.5% sucrose solution at 30 ^{o}C.

At 40% dehydrating agent concentration, the samples immersed in sucrose were softer than those in glucose (Figure 2c and d). These results could be attributed to the well known effect of molecular weight of the solute on firmness due to cell collapse [48].

The dehydrating process causes changes on the structure and properties of the vegetal material. These changes consist of physical alterations, chemical reactions, and biochemical processes. Physical alterations include shrinking, porosity change, reduction of the water absorption capacity and damages on the microscopic structure [49]. The

environmental electronic microscopy is a non invasive technique, widely used to evaluate these structural changes.

In the present work, the structure of processed pumpkins was analyzed using ESEM. This microscopic technique allows evaluating the coating adhesion to pumpkin surface, the coating-vegetable interface characteristics which conditioned the barrier efficiency of the proposed systems as well as the coating thickness measurements.

Cross-sections of the samples are shown in Figure 3. This technique could be applied only in coated samples with A-CC; the system CC-A-CC could not be evaluated due to representative samples including the product and the entire film could not be obtained, considering that their thickness exceeded 1000 microns. Figure 3a shows the microstructure of pumpkins without coating. Figure 3b exhibits the coated surface before OD process, the good integrity of the coating could be observed, since no cracks or pores were detected.

Figure 3c-d shows a cross-section of the coated A-CC pumpkins sticks before OD presenting the adhesion of the coating to the vegetal tissue. This technique permitted to estimate the coating thickness, which ranged between 159 μm and 337 μm.

As can be seen, the thickness is highly variable due to the used immersion technique; the formation of uniform hydrogel layer over the vegetable surface is difficult [49].

In Figure 3e, a cross-section of a pumpkin stick is observed coated with the A-CC system, after 180 minutes of the osmotic dehydration process in solution of sucrose 60%. It is observed that the dehydrating process did not affect the integrity of the coating, although it was dehydrated due to the hydrophilic nature of the hydrogel. Consequently the thickness of the film was reduced to values of 110 μm to 135 μm which correspond to a reduction of 50% of the initial mean value. Although this thickness reduction, the coating remained bounded on the vegetable tissue. This result is relevant since other authors working on apples cubes coated with maltodextrin at 60% sucrose solution, informed the dissolution of the coating during the first 10 min of OD process [14].

CONCLUSIONS

During osmotic processing under different conditions applied over sticks of pumpkins, the greater velocity in the change of solid gain, weight loss, water content and texture were observed during the first 30 minutes of process.

These results are attributed to the fact that for this processing time the pressure difference is larger; then, the driving force decreases until the chemical potential of the sample and the solution are finally equal reaching equilibrium. In this work, equilibrium was reached at 120 minutes considering that no significant differences were found between 120 and 180 minutes, being possible to shorten the times of process.

Regarding the different tested systems, the configuration A-CC is the one that gets better results, compared to the CC-A-CC and the control sample, for all studied parameters. The

coating without pretreatment with Ca^{2+} fulfill its barrier function to solids entry from the dehydrating solution, in case of sucrose and glucose 60%, but allows water exit from the vegetal matrix. The coating with pretreatment of Ca^{+2} does not present good adhesiveness and its handling is difficult; therefore its use is not suggested for future investigations. ESEM technique permitted to evaluate the adhesiveness and thickness of the system A-CC during OD. Thickness reduction coincides with weight loss, in the case of A-CC, where the coating is integrated to the matrix and the coated product is dehydrated as an integrated system. On the other hand, the CC-A-CC system works independently from the vegetal tissue, where the dehydration of the coating controls the global kinetics of the weight loss.

Finally, it can be concluded that the sodium alginate-calcium chloride coating acts as a barrier to solids entry (sucrose and glucose 60%), without stopping the water transfer, during the osmotic dehydration.

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REFERENCES

1. Dutta, A.; Raychaudhuri, U.; Chakraborty, R. Rheological characteristic and thermal degradation kinetics of beta – carotene. Journal of Food Engineering **2006**, 76 (4), 538-546.

2. De Escalada Pla, M.F.; Ponce, N.M.; Stortz, C.A.; Gerschenson, L.N.; Rojas, A.M. Composition and functional properties of enriched fiber products obtained from pumpkin (Cucurbita Moschata Duchesne exPoiret). LWT- Food Science and Technology **2007**, 40 (7), 1176-1185.

3. Bambicha, R.; Agnelli, M.E.; Mascheroni, R.H. Optimization of osmotic dehydration process of pumpkin in ternary solutions. Avances en Ciencias e Ingeniería, **2012**, 3 (2), 121-136.

4. Doymaz, I. The kinetics of forced convective air-drying of pumpkin slices. Journal of Food Engineering **2007**, 79 (1), 243–248.

5. Panagiotou, N.M; Karathanos, V.T.; Maroulis Z.B. Effect of osmotic agent on osmotic dehydration of fruits. Drying Technology **1999**, 17 (1-2), 175-189.

6. Kowalska, H.; Lenart, A. Mass exchange during osmotic pretreatment of vegetables. Journal of Food Engineering **2001**, 49 (2-3), 137-140.

7. Raoult-Wack, A. L.; Lafont, F.; Ríos, G.; Guilbert, S. Osmotic dehydration: Study of mass transfer in terms of engineering properties. In: Mujumdar A.S. and Roques M. (Ed.). Drying ’89. Hemisphere Publishin Corp.: New York, **1989**; 487-495.

8. Torreggiani, D. Technological aspects of osmotic dehydration in foods. In Food preservation by moisture control fundamentals and applications, ISOPOW PRACTICUM II. Barbosa-Cánovas G.V. and Welti Ch. Eds; Lancaster PA: USA, **1995**.

9. Lazarides, H.N.; Fito, P.; Chiralt, A.; Gekas, V.; Lenart A. Advances in osmotic dehydration. Processing foods: quality optimization and process assessment. Oliveira F.A.R., Oliveira J.C. Eds.; CRC Press: USA, **1999**.

10. Fito, P.; Chiralt, A.; Betoret, N.; Gras, M.; Cháfer, M.; Martínez-Monzó, J.; Andrés, A.; Vidal D. Vacuum impregnation and osmotic dehydration in matrix engineering. Application in functional fresh food development. Journal of Food Engineering **2001**, 49 (2-3), 175-183.

11. Torregiani, D.; Bertolo, G. Osmotic pre-treatments in fruit processing: chemical, physical and structural effects. Journal of Food Engineering **2001**, 49 (2-3), 247-253.

12. Chiralt, A.; Martinez-Navarrete, N.; Martinez-Monzó, J.; Talens, P.; Moraga, G. Changes in mechanical properties throughout osmotic processes: Cryoprotectant Effect. Journal of Food Engineering **2001**, 49 (2-3), 129-135.

13. Talens, P.; Martínez-Navarrete, N.; Fito, P.; Chiralt, A. Changes in optical and mechanical properties during osmodehydrofreezing of kiwifruit. Innovative Food Science & Emerging Technologies **2002**, 3(2), 191-199.

14. Khin, M.M.; Zhou, W.; Yeo S.Y. Mass transfer in the osmotic dehydration of coated apple cubes by using maltodextrin as the coating material and their textural properties. Journal of Food Engineering **2007**, 81 (3), 514–522.

15. Vargas, M.; Chiralt, A.; Albors, A.; González-Martínez, C. Effect of chitosan-based edible coatings applied by vacuum impregnation on quality preservation of fresh-cut carrot. Postharvest Biology and Technology **2009**, 51 (2), 263–271.

16. Jalaeea, F.; Fazeli, A.; Fatemianc, H.; Tavakolipour, H. Mass transfer coefficient and the characteristics of coated apples in osmotic dehydrating. Food and Bioproducts Processing **2001**, 89 (4), 367–374.

17. Zhou, R.; Li, Y.; Yan, L.; Xie, J. Effect of edible coatings on enzymes, cell-membrane integrity, and cell-wall constituents in relation to brittleness and firmness of Huanghua pears (Pyrus pyrifolia Nakai, cv. Huanghua) during storage. Food Chemistry **2011**, 124 (2), 569–575.

18. Mavroudis, N.E.; Gidley, M.J. and Sjöholm I. Osmotic processing: Effects of osmotic medium composition on the kinetics and texture of apple tissue. Food Research International **2012**, 48 (2), 839–847.

19. Rahimi, J.; Singh, A.; Adewale, P.O.; Adedeji, A.A.; Ngadi, M.O.; Raghavan V. Effect of Carboxylmethyl Cellulose Coating and Osmotic Dehydration on Freeze Drying Kinetics of Apple Slices**.** Foods **2013**, 2, 170-182.

20. Embuscado, M.E.; Huber, K.C. Edible films and coatings for food applications. Springer: New York, **2009**.

21. Jimenez, A.; Fabra, M.J.; Talens, P.; Chiralt, A. Edible and Biodegradable Starch Films: A Review. Food and Bioprocess Technology **2012**, 5(6), 2058-2076.

22. Azam, M.; Haq, M.A.; Hasnain, A. Osmotic Dehydration of Mango Cubes: Effect of Novel Gluten-Based Coating. Drying Technology **2013**, 31 (1), 120–127.

23. Wong, D.W.S.; Camirand, W.M.; Pavlath A.E. Development of edible coatings for minimally processed fruits and vegetables. In Edible Coatings and films to improve Food Quality, Krochta J.M., Balwin E.A., Nisperos-Carriedo N. Eds; Lancaster; PA., Techomic Publ. Co: USA, **1994**; 65-82.

24. Matuska, M.; Lenart, A.; Lazarides, H.N. On the use of edible coatings to monitor osmotic dehydration kinetics for minimal solids uptake. Journal of Food Engineering **2006**, 72 (1), 85–91.

25. Khin, M.M.; Zhou, W.; Perera, C.O. A study of the mass transfer in osmotic dehydration of coated potato cubes. Journal of Food Engineering **2006**, 77 (1), 84–95.

26. Lazarides, H.N.; Mitrakas, G.E.; Matsos K.I. Edible coating and counter-current product/solution contacting: A novel approach to monitoring solids uptake during osmotic dehydration of a model food system. Journal of Food Engineering **2007**, 82 (2), 171–177.

27. García, M.; Díaz, R.; Martínez, Y.; Casariego A. Effects of chitosan coating on mass transfer during osmotic dehydration of papaya. Food Research International **2010**, 43 (6), 1656–1660.

28. Talens, P.; Pérez-Masía, R.; Fabra, R.J.; Vargas, M.; Chiralt A. Application of edible coatings to partially dehydrated pineapple for use in fruit–cereal products. Journal of Food Engineering **2012**, 112 (1-2), 86–93.

29. Ferrari, C.C.; Sarantópoulos, C.I.G.L.; Carmello-Guerreiro, S.M.; Hubinger, M. D. Effect of Osmotic Dehydration and Pectin Edible Coatings on Quality and Shelf Life of Fresh-Cut Melon. Food and Bioprocess Technology **2013**, 6 (1), 80-91.

30. Camirand, W.; Krochta, J.M.; Pavlath, A.E.; Wong, D.; Cole, M.E. Properties of some edible carbohydrate polymer coatings for potential use in osmotic dehydration. Carbohydrate Polymers **1992**, 17(1), 39–49.

31. Dehghannya, J.; Emam-Djomeh, Z.; Sotudeh-Gharebagh, R.; Ngadi, M. Osmotic dehydration of apple slices with carboxy-methyl cellulose coating. Drying Technology **2006**, 24 (1), 45–50.

32. A.O.A.C. Official Methods of Analysis of the Association of Official Analytical Chemists, 17th ed., William Horwitz Ed.; Gaithersburg, **2002**.

33. Kowalska, H.; Lenart, A.; Leszczyk, D. The effect of blanching and freezing on osmotic dehydration of pumpkin. Journal of Food Engineering **2008**, 86 (1), 30-38.

34. Nieto, A.B.; Salavatori, D.M.; Castro, M.A.; Alzamora, S.M. Structural changes in apple tissue during glucose and sucrose osmotic dehydration: shrinkage, porosity, density and microscopic features. Journal of Food Engineering **2004**, 61 (2), 269–278.

35. Lazarides, H. N. Reasons and possibilities to control solids uptake during osmotic treatment of fruits and vegetables. Osmotic dehydration and vacuum impregnation: Applications in food industries. In Fito P., Chiralt A., Barat J.M., Spiess, W.E.L and Behsnilian D. Eds.; Technomic Publ. Co: USA, **2001**; 33-42.

36. Nieto, M. B. Structure and Function of Polysaccharide Gum-Based Edible Films and Coatings. In Edible Films and Coatings for Food Applications, Embuscado, M. E. and Huber, K. C. Eds; Springer: New York, **2009**.

37. Chiralt, A.; Talens, P. Physical and chemical changes induced by osmotic dehydration in plant tissues. Journal of Food Engineering **2005**, 67 (1-2), 167–177.

38. Rojas-Grau M.A.; Soliva-Fortuny, R.; Martín-Belloso O. Edible coatings to incorporate active ingredients to fresh-cut fruits: A review. Trends Food Science & Technology **2009**, 20 (10), 438-447.

39. Rojas-Grau, M.A.; Tapia, M.S.; Martín-Belloso, O. Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples. LWT- Food Science and Technology **2008**, 41(1), 139-147.

40. Soliva-Fortuny, R.C.; Griglemo-Miguel, N.; Hernando I.; LLuch, M.A.; Martín-Belloso, O. Effect of minimal processing on the textural and structural properties of fresh-cut pears. Journal of the Science of Food and Agriculture **2002**, 82 (14), 1682-1688.

41. Sapers, G.M.; Miller, R.L. Browning inhibition in fresh-cut pears. Journal of Food Science **1998**, 63 (2), 342–346.

42. Bett, K.L.; Ingram, D.A.; Grimm, C.C.; Lloyd, S.W.; Sapnier, A.M.; Gross, K.C.; Balwin, E.A.; Vinyard, B.T. Flavor of fresh-cut Gala apples in barrier film packing as affected by storage time. Journal of Food Quality **2001**, 24(2), 141-156.

43. Soliva-Fortuny, R.C.; Martín-Belloso, O. New advances in extending the shelf-life of fresh-cut fruits: a review. Trends in Food Science and Technology **2003**, 14 (9), 341-353.

44. Ferrari, C.C.; Arballo, J.R.; Mascheroni, R.H. Mass transfer and texture variation during osmotic dehydration of pears. In Proceedings of 4th Inter-American Drying Conference **2009**, 610–616 (IV-17).

45. Torres, J.D.; Talens, P.; Escriche, I.; Chiralt A. Influence of process conditions on mechanical properties of osmotically dehydrated mango. Journal of Food Engineering **2006**, 74 (2), 240-246.

46. Arballo, J.R.; Ferrari, C.C. and Mascheroni, R.H. Modeling of mass transfer during osmotic dehydration process of pears in solutions of sucrose and sorbitol. In Proceedings of Ciencia y Tecnología de los Alimentos: Avances en Ingeniería y

Tecnología, III Congreso Internacional de Ciencia y Tecnología de los Alimentos **2009**, 3, 97-106.

47. Lenart A.; Piotrowski D. Drying characteristics of osmotically dehydrated fruits coated with semipermeable edible films. Drying Technology **2001**, 19(5), 849-877.

48. Wais, N. Secado combinado de frutas: deshidratación osmótica y microondas. Phd Thesis Facultad de Ingeniería de la Universidad Nacional de La Plata, Argentina, **2011**.

49. Rzaca, M.; Witrowa-Rajchert, D.; Tylewicz, U.; Dalla Rosa, M. Mass exchange in osmotic dehydration process of kiwi fruits. ZYWNOSC Nauka Technologia Jakośė **2009**, 67, 140-149.

Table 1: Comparison of Soluble Solids of pumpkin sticks with and without coating during of different osmotic treatments.

TREATMENTS	Time (min)	Control Sample		A-CC		CC-A-CC	
SUCROSE 60%	0	6.500	±0.42 [a]	9.450	±0.26 [a]	14.075	±0.56 [a]
	30	14.750	±1.57 [b]	17.025	±1.33 [b]	19.900	±1.01 [b]
	60	18.333	±0.98 [b,c]	17.325	±1.45 [b]	23.275	±1.95 [b,c]
	120	21.033	±0.76 [c,d]	17.767	±1.36 [b]	27.175	±0.82 [c]
	180	22.600	±2.40 [d]	18.867	±1.81 [b]	26.550	±2.33 [c]
GLUCOSE 60%	0	12.050	±0.35 [a]	10.175	±0.19 [a]	9.250	±0.19 [a]
	30	20.700	±0.28 [b]	19.125	±0.66 [b]	15.100	±0.76 [b]
	60	24.800	±2.12 [b,c]	20.925	±0.33 [b]	23.250	±1.03 [c]
	120	27.950	±2.33 [c,d]	24.800	±0.62 [c]	26.250	±0.07 [c]
	180	31.450	±0.77 [d]	25.300	±0.00 [d]	29.500	±0.64 [c]

SUCROSE 40%	0	7.675	±0.29 [a]	9.525	±0.05 [a]	7.575	±0.38 [a]
	30	14.625	±0.61 [b]	14.300	±0.42 [b]	15.225	±1.28 [b]
	60	14.925	±0.64 [b]	17.625	±1.11 [b,c]	15.725	±0.59 [b]
	120	16.975	±0.96 [b,c]	20.550	±0.46 [c]	20.875	±0.88 [c]
	180	20.625	±1.11 [c]	25.250	±0.93 [d]	24.875	±0.50 [d]
GLUCOSE 40%	0	6.850	±0.10 [a]	5.525	±0.21 [a]	8.500	±0.14 [a]
	30	12.675	±0.56 [b]	13.125	±0.32 [b]	15.250	±0.44 [b]
	60	16.975	±0.17 [b]	20.150	±0.92 [c]	19.275	±0.59 [c]
	120	21.050	±0.94 [c]	23.725	±0.67 [c,d]	24.275	±1.06 [d]
	180	24.300	±0.08 [c]	26.650	±0.91 d	27.725	±1.18 [d]

Table 2: Comparison of Water Content (WC) of pumpkin sticks with and without coating during of different osmotic treatments

TREATMENTS	Time (min)	Control Sample		A-CC		CC-A-CC	
SUCROSE 60%	0	93.72	±0.17 [a]	90.457	±0.28 [a]	86.486	±0.23 [a]
	30	88.59	±0.55 [b]	78.251	±0.83 [b]	75.364	±1.98 [ab]
	60	86.45	±0.07 [b]	78.029	±0.86 [b,c]	70.405	±0.74 [b]
	120	82.20	±1.04 [b]	76.402	±1.05 [c,d]	66.356	±6.52 [b,c]
	180	79.65	±0.84 [b]	74.318	±6.20 [d]	61.349	±1.79 [c]
GLUCOSE 60%	0	91.01	±0.21 [a]	90.239	±0.17 [a]	90.859	±0.10 [a]
	30	81.10	±0.15 [b]	80.961	±0.26 [b]	79.038	±0.65 [b]
	60	78.56	±0.94 [b]	77.486	±0.29 [b,c]	73.583	±0.63 [b]
	120	74.82	±0.97 [b,c]	73.028	±0.28 [c,d]	66.083	±4.39 [c]
	180	72.23	±0.31 [c]	68.34	±0.65 [d]	62.76	±0.00 [c]

				4		7	
SUCROSE 40%	0	92.659	±0.31 [a]	90.660	±0.24 [a]	91.525	±0.01 [a]
	30	87.399	±0.11 [b]	82.018	±0.03 [b]	81.066	±0.40 [ab]
	60	86.263	±0.93 [b,c]	80.953	±0.51 [b,c]	78.008	±1.75 [a,b,c]
	120	83.775	±0.31 [b,c]	79.219	±0.35 [b,c]	75.550	±2.13 [b,c]
	180	80.246	±0.12 [c]	75.452	±0.13 [c]	71.989	±0.70 [c]
GLUCOSE 40%	0	93.884	±0.14 [a]	93.590	±0.14 [a]	88.053	±0.34 [a]
	30	87.527	±0.22 [a,b]	83.774	±0.16 [b]	80.057	±0.19 [b]
	60	85.262	±0.16 [b]	81.092	±0.45 [b,c]	77.039	±1.15 [b,c]
	120	81.079	±0.30 [b,c]	75.170	±1.09 [c,d]	72.119	±1.82 [c,d]
	180	78.323	±0.83 [c]	73.146	±1.02 [d]	69.922	±0.32 [d]

Table 3: Weight Reduction of pumpkin sticks with and without coating during different osmotic treatments.

TREATMENTS	Time (min)	Control Sample		A-CC		CC-A-CC	
SUCROSE 60%	0	0.000	±0.000	0.000	±0.000	0.000	±0.000
	30	18.812	±1.599	23.146	±1.182	13.158	±2.941
	60	29.858	±2.544	29.105	±3.361	13.722	±0.162
	120	39.372	±1.385	34.041	±0.604	27.899	±19.559
	180	42.391	±7.376	39.647	±0.129	12.143	±0.083
GLUCOSE 60%	0	0.000	±0.000	0.000	±0.000	0.000	±0.000
	30	22.149	±0.365	26.168	±1.334	19.495	±1.248
	60	28.324	±0.692	35.474	±0.634	21.157	±0.079
	120	36.446	±0.313	43.341	±1.406	21.272	±4.846
	180	39.352	±0.370	50.734	±2.558	29.008	±0.480
SUCROSE 40%	0	0.000	±0.000	0.000	±0.000	0.000	±0.000
	30	20.398	±0.335	21.195	±1.828	15.350	±0.049
	60	19.800	±1.414	28.452	±0.168	17.060	±0.436
	120	31.953	±0.139	35.567	±1.509	22.941	±4.028
	180	36.551	±0.608	39.904	±0.722	28.990	±2.194
GLUCOSE 40%	0	0.000	±0.000	0.000	±0.000	0.000	±0.000
	30	26.336	±1.120	22.562	±1.662	10.459	±0.015
	60	37.004	±0.523	34.695	±2.199	16.109	±0.626
	120	41.673	±1.780	37.710	±0.501	16.850	±1.583

	180	47.899	±2.581	44.453	±0.852	19.775	±1.005

Table 4: Fitting parameters of Eq 5.

Samples	TREATMENTS	*C*	*K*	R^2
Control Sample	Sucrose 60%	-8.44E-04	-8.60E-04	0.95
	Sucrose 40%	-6.96E-04	-7.10E-04	0.92
	Glucose 60%	-1.08E-03	-1.13E-03	0.84
	Glucose 40%	-9.16E-04	-9.40E-04	0.93
A-CC	Sucrose 60%	-7.86E-04	-8.40E-04	0.80
	Sucrose 40%	-8.06E-04	-8.40E-04	0.81
	Glucose 60%	-1.34E-03	-1.40E-03	0.92
	Glucose 40%	-1.21E-03	-1.27E-03	0.88
CC-A-CC	Sucrose 60%	-1.63E-03	-1.72E-03	0.90
	Sucrose 40%	-1.08E-03	-1.14E-03	0.82
	Glucose 60%	-1.84E-03	-1.95E-03	0.91
	Glucose 40%	-1.14E-03	-1.19E-03	0.90

Figure 1: Water content of the coated products, the coating and the vegetable tissue during osmotic dehydration (sucrose 40%, temperature 20 ºC).

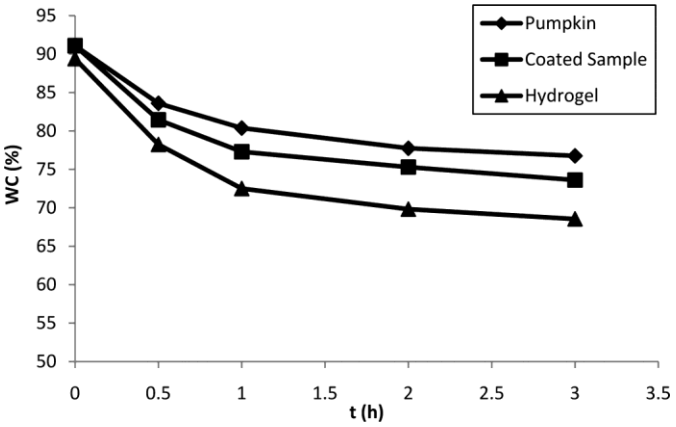

Figure 2: Normalized force values of dehydrated pumpkin sticks under different conditions of OD a) Sucrose 60%, b) Glucose 60%, c) Sucrose 40% and d) Glucose 40%.

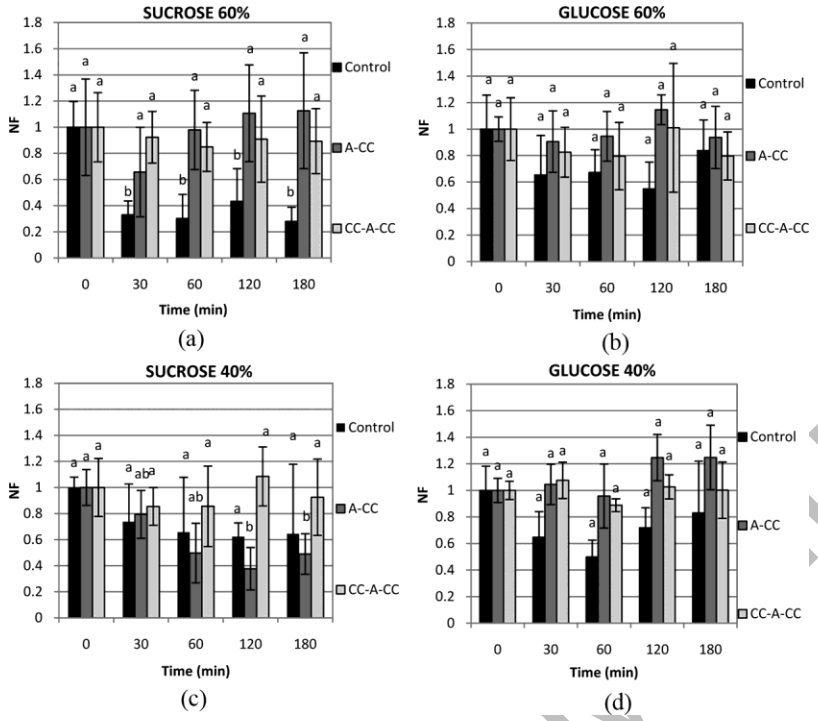

Figure 3: Micrographs ESEM of pumpkin sticks of fresh samples (a); coated samples with A-CC previous to the OD process: surface (b) and cross-section (c and d) and cross-section of coated sample with A-CC after 180 minutes of the OD with sucrose solution 60% (e).