Influence of pretreatments on oil absorption of plantain and cassava chips

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Abstract The objective was to evaluate the effect of pretreatments of CaCl_2 and osmotic dehydration (OD) on oil absorption in plantain and cassava chips. Plantain and cassava slices (1 mm thickness and 35 mm diameter) were prepared. Pretreatment with and without 5% CaCl_2 solution before applying OD with sucrose solutions at 30 and 45%, and NaCl at 3 and 6% in a product/solution ratio of 1:25, at 40 °C were employed. OD kinetics and diffusivity were estimated by Page's model and Fick's law, respectively. Best OD treatments for plantain chips were 45% sucrose with CaCl_2 and 6% NaCl without CaCl_2 . However, for cassava chips, the best OD treatments were 45% sucrose without CaCl_2 and 3% NaCl with CaCl_2 . Page's model predicted the OD experimental results with an $R^2 = 0.94\text{--}0.97$. Effective diffusivity of water (EDW) and effective diffusivity of solids (EDS) for osmo-dehydrated cassava samples, with and without CaCl_2 , decreased as the concentration of the osmotic solutions was increased. However, in general, the inverse effect was obtained for plantain samples for EDW and EDS. Use of CaCl_2 when applying OD reduced EDW and EDS in plantain and cassava chips. In general, it was observed that when increasing the concentration of the osmotic solution, oil absorption capacity decreased. Treatments that showed the lowest oil absorption were 45% sucrose OD in plantain chips pretreated with CaCl_2 (11.49%) and fresh cassava chips with 45% sucrose OD (10.72%). The results and effectiveness

will depend on food, process conditions and type of osmotic agent.

Keywords Osmotic dehydration · Diffusivity · Plantain · Cassava

List of symbols

A and B	Page's constant values
$D_{\beta\omega}$	Diffusivity of water or solids in the product (m^2/s)
EDW	Effective diffusivity of water
EDS	Effective diffusivity of solids
LD	Diffusion characteristic length (m)
M_0	Initial mass of the product (kg)
M_t	Mass of the product at time t (kg)
OAC	Oil absorption capacity
OD	Osmotic dehydration
S_0	Initial mass of solute at time 0 of OD (kg)
S_t	Mass of solute at time t of OD (kg)
SG	Solids gain (kg solids/kg fresh product)
t	Process time (s)
$X_{\alpha 0}$	Initial mass fraction of a given component of the food product
$X_{\alpha t}$	Mass fraction at time t
WL	Water loss (kg water /kg fresh product)
$\Delta_{\omega\infty}$	Water loss or solids gain in OD mass balance (kg water or solids/kg fresh product)
$\Delta_{\omega t}$	Water loss or solids gain at time t (s) of the OD
A	Volume ratio between the osmotic solution and the fruit, divided by the partition coefficient
Λ_n	Equilibrium distribution coefficient

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Introduction

Fried snacks are popular products around the world, with a market that has been continuously increasing in value (Carvalho and Ruiz-Carrascal 2018). The deep-fat frying process can be defined as a cooking and drying process in which the product is put in contact with hot oil and is one of the more important operations in the food processing industry (van Koerten et al. 2016). The oil is heated to high temperatures, above water's boiling point (Manjunath et al. 2014). As a consequence of heat and mass transfer from the oil to the food, several physical and chemical transformations take place, such as loss of water from the food, migration of soluble components, migration of oil to food, mechanical deformation, expansion, matrix changes, pore formation, bark formation, moisture retention, oil uptake and fracture force, chemical reactions (for example, Maillard reactions), protein degradation and physical–chemical transformations such as gelatinization, retrogradation or the vitreous transition of carbohydrates (Kaur et al. 2008; Manjunath et al. 2014). To obtain snacks with lower oil content, it has been proposed to apply pretreatments, such as the osmotic dehydration (OD) process, which consists of the partial removal of water, in which cellular materials (such as fruits and vegetables) are placed in concentrated solutions of soluble solutes. A driving force for the elimination of water is established as a consequence of the difference in osmotic pressure between the food and its surrounding solution (García-Toledo et al. 2016). The complex cellular structure of the food acts as a semipermeable membrane (Montoya-Ballesteros et al. 2017). As a consequence of the application of OD, two opposite matter-transfer flows take place: the diffusion of water from the food to the solution, and the diffusion of solutes from the solution to the food (García-Toledo et al. 2016). Ren et al. (2018) investigated the effects of pretreatments on the quality of vacuum-fried shiitake mushroom slices; blanching, osmotic dehydration, and coating pretreatment could improve color and sensory evaluation and minimize the oil uptake, but this process also caused the highest reduction of TPC. The objective of our work was to evaluate the effects of the application of pretreatments of CaCl_2 and osmotic dehydration on the absorption of oil in plantain (*Musa paradisiaca* AAB) and cassava (*Manihot esculenta* Crantz) model chips.

Materials and methods

Raw materials

Plantain (*Musa paradisiaca* AAB) in stage 2 of maturation (Emaga et al. 2007) was obtained from the community of San Bartolo, Tuxtepec, Oax, México. Cassava (*Manihot*

esculenta Crantz) in commercial maturity was acquired in a local market in the city of Tuxtepec, Oax, México.

Pretreatment of fresh plantain and cassava

Peeling of plantain and cassava was done manually, and samples were cut into slices 1 mm in thickness and 35 mm in diameter. Before performing the OD, samples were pretreated with anhydrous CaCl_2 at 5% food grade with a product:solution ratio of 1:25 at 30 °C, applying constant agitation at 200 rpm for 30 min. These conditions were established in preliminary tests based on previous work (García-Toledo et al. 2016; Herman-Lara et al. 2013).

Determination of the experimental kinetics of OD in the samples (fresh and pretreated)

OD kinetics were performed on both fresh samples (without pretreatment) and pretreated samples (CaCl_2). Concentrations of 3 and 6% (w/w) of NaCl were used, as well as 30 and 45% of sucrose at 200 rpm with a product:solution ratio of 1:25 at 40 °C. Fresh and pretreated samples were submerged in osmotic solutions in 2000-mL crystallizers. Temperature was regulated by an electronic temperature control model A419 (Johnson Controls, Inc., Wisconsin, USA). The solutions were hermetically coated with polyethylene film to reduce the evaporation and concentration of the osmotic solutions. Samples of plantain and cassava immersed into the OD solutions were removed and weighed at different time intervals until reaching equilibrium, and the excess osmotic solution was removed with an absorbent towel. The moisture content and the dry matter (AOAC 2005) of both fresh and osmotically dehydrated samples were determined using a convective flow-drying oven (Binder Co., Germany). These data were used in the determination of water loss (WL) and solids gain (SG) in the time t of the OD using Eqs. 1 and 2, respectively (Ruiz-López et al. 2011).

$$\text{WL} = \frac{M_0 \times X_{x0} - M_t \times X_{xt}}{M_0} \quad (1)$$

$$\text{SG} = \frac{S_t - S_0}{M_0} = \frac{M_t \times 1 - X_{xt} - M_0 \times 1 - X_{x0}}{M_0} \quad (2)$$

Prediction of WL and SG kinetics during OD

Kinetics obtained experimentally for both WL and SG of plantain and cassava (fresh and pretreated) were modeled by Page's equation (Eq. 3) and estimated by nonlinear regression using the software MATLAB (version 13.0). The quality of the adjustment between the experimental data and the values predicted by Page's equation were analyzed through the coefficient of determination (R^2).

$$WL \text{ o SG} = \exp - At^B \quad (3)$$

Estimation of the matter transfer rate

The rate of the transfer of matter during the OD was studied through the effective diffusivity of water and solids. The values were estimated by applying the standard Fickian model (Eq. 4), considering the sample as an infinite flat plate, using the concentration of the constant osmotic solution, considering the process to be an isothermal OD, and assuming the absence of any external resistance to mass transport.

$$1 - \frac{\Delta_{ot}}{\Delta_{o^\infty}} = \sum_{n=1}^{\infty} \frac{2 \propto 1 + \propto}{1 + \propto + \propto^2 \lambda_n^2} \exp - \frac{D_{\beta o} \lambda_n^2 t}{L_D^2} \quad (4)$$

Frying conditions in plantain and cassava model chips

Plantain and cassava slices after OD processing were subjected to a deep-fat frying process using commercial soybean oil for 3.5 min at $170 \pm 5^\circ\text{C}$ and drained to remove excess surface oil (Rodríguez-Miranda et al. 2018).

Fat content in plantain and cassava chips

Quantification of the oil content in plantain and cassava chips for all treatments described above was performed and reported as % oil absorption in order to delineate the effect of the pretreatments used (CaCl_2 and OD) on the oil absorption capacity (OAC) by means of the method (948.22) of the AOAC (2005).

Statistical analysis

Completely randomized design with a factorial disposition was used (Table 1), with two samples (fresh and with CaCl_2), two concentrations of NaCl (3 and 6%) and two concentrations of sucrose (30 and 45%) for the two samples of plantain and cassava for OD. An analysis of variance (ANOVA) and a Fisher's test were performed to determine the minimum significant difference between means ($P < 0.05$).

Results and discussion

Experimental and simulated OD kinetics for WL

Figure 1a–d shows the experimental and predicted kinetics of WL in fresh plantain and fresh cassava, and pretreated

Table 1 Experimental conditions of OD kinetics in slices of plantain and cassava at 40°C

Run no.	Treatment	NaCl (%)	Sucrose (%)
1	Fresh	3	–
2	Fresh	6	–
3	Fresh	–	30
4	Fresh	–	45
5	Fresh	3	–
6	Fresh	6	–
7	Fresh	–	30
8	Fresh	–	45
9	CaCl_2	3	–
10	CaCl_2	6	–
11	CaCl_2	–	30
12	CaCl_2	–	45
13	CaCl_2	3	–
14	CaCl_2	6	–
15	CaCl_2	–	30
16	CaCl_2	–	45

with CaCl_2 , using different concentrations of NaCl (3 and 6%) and sucrose (30 and 45%) at a constant temperature of 40°C . The WL in plantain increased as the NaCl concentration increased. The WL increased exponentially as the OD time elapsed until reaching equilibrium, with the highest WL occurring during the OD of the plantain without CaCl_2 pretreatment using 6% NaCl. With samples of fresh plantain and samples pretreated at 25 and 27 min, the equilibrium of the system was achieved at 3 and 6% NaCl, respectively; that is, zero-order kinetics (Fig. 1a). The equilibrium values were 0.12 and 0.13 g of water/g in fresh plantain when applying concentrations of 3 and 6% NaCl, respectively, while the equilibrium values were 0.10 and 0.12 g of water/g in the pretreated plantain when applying the same concentrations of NaCl. The degree of correlation between these experimental and predicted kinetics was obtained from the regression coefficient (R^2), with values in all of the treatments above 0.95. In the cassava samples, it was observed that the WL decreased as the concentration of the osmotic medium increased; similar results were reported by Silva et al. (2013) with pineapple OD. Kinetics were simulated with fresh cassava samples, and the WL value for 3% NaCl was 0.1757 g of water/g of fresh cassava and for 6% NaCl was 0.1281 g of water/g of fresh cassava. In samples where pretreatment with CaCl_2 was applied, the kinetics simulated WL values at equilibrium at 3% NaCl of 0.2987 g of water/g in pretreated cassava, and equilibrium values at 6% NaCl of 0.1617 g of water/g in pretreated cassava. The R^2 average obtained from the experimental and simulated kinetics was 0.97 (Fig. 1b). Page's model adequately predicted the

Fig. 1 Experimental and simulated kinetics of WL during OD with and without pretreatment of CaCl_2 **a** 3 and 6% NaCl in plantain **b** 3 and 6% NaCl in cassava **c** 30 and 45% sucrose in plantain **d** 30 and 45% sucrose in cassava

experimental behavior of the WL in the kinetics of OD in plantain and cassava samples. The effect of WL on the osmotic solutions is generated by the increase in the concentration of the osmotic medium, as reported by İspir and Toğrul (2009), although it also depends on the dimensions of the sample and sample/solution ratio because WL is favored by decreasing the proportion. On the other hand, it was observed in OD kinetics that samples of fresh cassava dehydrated osmotically had lower WL, while samples of cassava pretreated with CaCl_2 had higher WL; this may be due to the use of calcium salts in the solutions, osmotically increasing the rate of water loss, reducing water activity and increasing the calcium content in fruits and vegetables (Heredia et al. 2007; Silva et al. 2013). The presence of calcium in cassava samples dehydrated osmotically could possibly generate a greater selective permeability of the cell membrane, causing a higher WL, taking into account the transport of small molecules such as water but restricting the solids gain (Silva et al. 2013). In this work, low concentrations of NaCl were used in comparison to what was reported by Rodrigues and Fernandes (2007), who noted that the use of salt increases the rate of WL, but in high concentrations, it increases the gain of solids, making the food saltier. Due to this, in this work, concentrations of 3 and 6% were used in the osmotic NaCl solution. The increase in WL was due to the synergistic effect of salt caused by its high osmotic potential (Sutar

and Gupta 2007; Mercali et al. 2012). Figure 1c shows plantain OD kinetics with and without CaCl_2 pretreatment using sucrose; experimental and simulated kinetics did not show the same behavior of WL compared to NaCl. We observe that WL was favored in sucrose solutions—the opposite of the behavior in samples osmotically dehydrated with NaCl when applying the pretreatment of CaCl_2 . Values of WL with CaCl_2 pretreatment at equilibrium were 0.2256 g of water/g sample for 30% sucrose and 0.3037 g of water/g sample for 45% sucrose. The R^2 average obtained for the experimental and simulated kinetics was 0.95. In Fig. 1d, an increase in WL was observed as the sucrose concentration increases. The highest WL occurred within the first 32 min of the process; the equilibrium values of the simulated kinetics with samples of fresh cassava at 30% sucrose were 0.3107 g of water/g of fresh cassava and 0.3237 g of water/g of fresh cassava for 45% sucrose. Where pretreatment with CaCl_2 was applied in the simulated kinetics, the WL value at equilibrium for 30% sucrose was 0.1635 g of water/g of pretreated cassava and 0.2482 g of water/g of pretreated cassava for 45% sucrose. The R^2 average of the experimental and simulated kinetics was 0.97. In both cases, first-order kinetics were obtained, where the WL was proportional to the immersion time of the samples. It was observed that there was higher WL in the samples of plantain pretreated with CaCl_2 compared to the samples of fresh plantain. This behavior could be

because CaCl_2 increased WL, as has been reported by Lewicki et al. (2002) during the OD of tomatoes pretreated with CaCl_2 , because this salt together with the pectins of the cell walls form pectates of calcium, producing a new texture of the vegetable, and a bond type, *crossed union*, which allows greater water diffusion (Wu et al. 2010). However, in cassava, this effect was inverted, which may be because CaCl_2 saturated the pores of the fibrous tissue of cassava, reducing WL (Chiralt and Talens 2005). A maximum value of sucrose concentration of 45% was used because at higher concentrations, it is more difficult to dissolve solids at 40 °C, and the solution tends to be very viscous, making stirring difficult. According to Ferrari et al. (2010), when working with high sucrose concentrations (higher than 50%), the excess sucrose forms a superficial crust on the product and could act as a barrier, not only for the transfer of solids but also for water diffusion.

Experimental and simulated OD kinetics for SG

Experimental and simulated OD kinetics of fresh plantain and pretreated with CaCl_2 using 3 and 6% NaCl at a constant temperature of 40 °C are shown in Fig. 2a. Similar to WL kinetics, the SG increased as the osmo-dehydrating solution concentration was increased; this was due

to the osmotic potential of salt. The highest SG occurred within the first 27 min of the process at the two concentrations of NaCl used, where the SG was proportional to the immersion time of the samples. After 27 min, an increase in OD time did not produce appreciable changes in the SG of fresh and pretreated plantain samples. The equilibrium values were 0.0155 g of solids/g fresh plantain and 0.0571 g of solids/g pretreated plantain with 3% NaCl, while with 6% NaCl were 0.0445 g of solids/g fresh plantain and 0.0837 g of solids/g pretreated plantain. Page's model adequately predicted the exponential behavior of the SG (R^2 average of 0.98) for all the experimental kinetics of SG in plantain. This same trend was reported by Sutar and Gupta (2007) in the OD of sliced onions and by Domeneghini et al. (2012) for sliced plantain (*Musa sapientum*, shum). It should be mentioned that the characteristics of the final product are influenced by the absorption of the solute. In some cases, the absorption of solutes is desirable due to consumer acceptability since it improves the taste of the final product, while in other cases, a large absorption of solute is undesirable, since it impacts the nutritional profile (Lewicki and Porzecka-Pawlak 2005). On the other hand, it was observed that samples with CaCl_2 treatment had higher SG in the two salt concentrations than those samples that were not pretreated. The SG in cassava OD and the experimental kinetics

Fig. 2 Experimental and simulated kinetics of SG during OD with and without pretreatment of CaCl_2 a 3 and 6% NaCl in plantain b 3 and 6% NaCl in cassava c 30 and 45% sucrose in plantain d 30 and 45% sucrose in cassava

simulated by Page's model by applying different concentrations of NaCl (3 and 6%) pretreated and untreated with CaCl_2 and at a constant temperature of 40 °C are presented in Fig. 2b. There was a higher SG in cassava when the osmo-dehydrating NaCl solution was increased only in the case of samples not pretreated with CaCl_2 because of the permeability of the membrane, which allows access to substances of higher molecular weight, as is the case of NaCl compared with water, as reported by Nieto et al. (2004). An inverse effect was observed in the samples that were pretreated. A similar effect was found in WL kinetics of pretreated or non-pretreated samples. According to the literature, geometry influences the OD times to achieve the balance of the SG in OD of cassava samples, as reported by Lewicki and Porzecka-Pawlak (2005). Equilibrium is reached at 32 min; in simulated kinetics of fresh cassava SG values of 0.0525 g solids/g fresh cassava for 3% NaCl and 0.0750 g solids/g fresh cassava for 6% NaCl are obtained, respectively. Cassava samples pretreated with CaCl_2 in simulated kinetics yielded SG values of 0.1369 g solids/g pretreated sample at 3% NaCl and 0.0671 g solids/g pretreated sample at 6% NaCl. On the other hand, the use of CaCl_2 could form calcium pectates on the surface, which, in turn, act as a partial barrier to the diffusion of molecules such as NaCl in tissues (Barrera et al. 2009; Silva et al. 2013). Figure 2c depicts the experimental and predicted SG kinetics of OD for fresh and pretreated plantain with CaCl_2 using sucrose at 30 and 45%. As in the WL kinetics, the SG increased as the sucrose concentration increased. Equilibrium values were 0.0385 g solids/g fresh plantain and 0.0901 g solid/g pretreated plantain for 30% sucrose, and 0.0509 g solids/g fresh plantain and 0.1512 g solids/g pretreated plantain for 45% sucrose. Kinetics of OD for SG (experimental and predicted) for fresh and pretreated cassava with CaCl_2 using sucrose at 30 and 45% are presented in Fig. 2d. As mentioned above, the SG increased as the sucrose concentration increased, as in fresh and pretreated samples. Equilibrium values were 0.0532 g solids/g fresh cassava and 0.1004 g solid/g pretreated cassava for 30% sucrose, and 0.1512 g solids/g fresh cassava and 0.1689 g solids/g pretreated cassava for 45% sucrose. The use of CaCl_2 substantially increased the SG compared to those samples that were not pretreated. On the other hand, when the impregnation or SG near the surface begins, it has been reported that structural changes occur that lead to compacting of the surface layers and increasing the resistance to mass transfer of both water and solids (Moyano and Pedreschi 2006). According to Ruiz-López et al. (2011) the effect of the type of solute on the mass transfer rate both for water loss and solids gain have been reported by many authors, but with different conclusions, which have been described as largely dependent on the product and experimental procedures.

Effective diffusivity of water (EDW) and solids (EDS) during the OD of fresh and pretreated plantain and cassava

The EDW and EDS coefficients of osmotically dehydrated plantain and cassava, both with and without CaCl_2 pretreatment and using 3 and 6% NaCl solutions and 30 and 45% sucrose solutions, are presented in Table 2. The EDW values in all employed treatments in plantain slices showed a significant difference ($P < 0.05$). EDW values were increased as the concentration of the osmo-dehydrating solution increased. However, these EDW values decreased when CaCl_2 was applied in osmo-dehydrating solutions of NaCl. EDS values for both plantain samples with and without CaCl_2 pretreatment increased as the NaCl concentrations increased (Table 2). In sucrose solutions only, this behavior was observed in the plantain without pretreatment ($P < 0.05$), since the pretreated plantain did not show a significant difference ($P > 0.05$) when increasing the sucrose concentration. EDW results for both osmo-dehydrated cassava samples with and without pretreatment with CaCl_2 decreased as the concentration of the osmotic solutions increased, showing a significant difference ($P < 0.05$). EDS values for both osmo-dehydrated cassava samples with and without pretreatment decreased as the concentration of the osmotic solutions was increased; these values showed a significant difference ($P < 0.05$), except for cassava without pretreatment at 30 and 45% sucrose. It was observed that the presence of calcium significantly reduced the EDW and EDS in plantain and cassava slices ($P < 0.05$), except for EDW and EDS in plantain and cassava slices, respectively, at 30 and 45% sucrose. Similar results were reported by Silva et al. (2013), where they compared the diffusivity components in pineapple samples osmotically dehydrated in sucrose solutions with and without calcium lactate, finding that calcium decreases the diffusivity of water and sucrose. Other authors found a similar reduction in solids diffusivity by the use of calcium salts in osmotic solution (Ferrari et al. 2010). In addition, if the calcium reacts and remains immobilized, the porosity of the cell wall decreases and, consequently, the diffusivity of solids may decrease, probably due to changes in the microstructure of the cell membrane that generate cell tissue resistance (Mercali et al. 2011; Silva et al. 2013). Likewise, it was observed that in fresh cassava (without pretreatment) the EDW values were higher in the samples that were dehydrated with 30% sucrose solutions compared to samples where NaCl was used; this was probably because the low NaCl concentrations did not exert sufficient osmotic pressure compared to the sucrose concentration. The effect of the solute type on the mass transfer rate has been reported by other authors, but different conclusions have been described depending on the product

Table 2 Effective diffusivity of water (EDW) and solids (EDS) in plantain with and without Pretreatment

Treatments	Effective diffusivity (EDW $\times 10^{-10}$, m ² /s)				Effective diffusivity (EDS $\times 10^{-10}$, m ² /s)			
	NaCl (%)		Sucrose (%)		NaCl (%)		Sucrose (%)	
	3	6	30	45	3	6	30	45
Plantain								
Without CaCl ₂	8.55 $\pm$ 0.10 ^{b,A}	10.51 $\pm$ 0.13 ^{b,B}	3.86 $\pm$ 0.09 ^{a,A}	9.70 $\pm$ 0.01 ^{a,B}	7.77 $\pm$ 0.04 ^{b,A}	8.74 $\pm$ 0.08 ^{b,B}	6.14 $\pm$ 0.06 ^{b,A}	7.32 $\pm$ 0.04 ^{b,B}
**With CaCl ₂	5.62 $\pm$ 0.04 ^{a,A}	5.74 $\pm$ 0.03 ^{a,B}	11.06 $\pm$ 0.12 ^{b,A}	14.41 $\pm$ 0.02 ^{b,B}	5.66 $\pm$ 0.02 ^{a,A}	5.73 $\pm$ 0.04 ^{a,B}	5.18 $\pm$ 0.11 ^{a,A}	5.14 $\pm$ 0.04 ^{a,A}
Cassava								
Without CaCl ₂	9.38 $\pm$ 0.07 ^{b,B}	8.61 $\pm$ 0.06 ^{b,A}	11.35 $\pm$ 0.39 ^{b,B}	7.15 $\pm$ 0.07 ^{b,A}	9.31 $\pm$ 0.06 ^{b,B}	8.69 $\pm$ 0.03 ^{b,A}	4.14 $\pm$ 0.12 ^{a,A}	3.84 $\pm$ 0.15 ^{a,A}
**With CaCl ₂	8.71 $\pm$ 0.08 ^{a,B}	4.58 $\pm$ 0.18 ^{a,A}	5.86 $\pm$ 0.06 ^{a,B}	5.62 $\pm$ 0.08 ^{a,A}	4.82 $\pm$ 0.12 ^{a,B}	4.25 $\pm$ 0.10 ^{a,A}	7.87 $\pm$ 0.12 ^{b,B}	4.21 $\pm$ 0.17 ^{b,A}

Different lowercase letters (a, b) in the same column (Treatment) and different capitals letters (A, B) in the same row (concentration of different solute) indicate significant difference ($P < 0.05$)

*Mean of three repetitions. Different lowercase letters in the same column (Treatment) and different capitals in the same row (concentration of different solute) indicate significant difference ($P < 0.05$)

**CaCl₂ concentration at 5%

and experimental procedures. EDS values in NaCl solutions were higher than in those obtained with sucrose solutions, except in data reported for 30% sucrose solution with CaCl₂ pretreatment, due to the difference in molecular weights because chemical substances with lower molecular weight tend to have a greater capacity to diffuse through plant tissue compared to substances with higher molecular weight (Ruiz-López et al. 2011).

Oil absorption capacity (OAC)

The effect of OD with different concentrations of osmotic solution on oil absorption in both fresh and pretreated plantain and cassava chips is presented in Fig. 3a. OAC percentages in fresh plantain chips subjected to OD with saline solutions at 3 and 6% NaCl were 27.99 and 20.88%, respectively. In fresh plantain chips subjected to OD in sugar solutions at 30 and 45% sucrose, values were 19.13 and 15.47%, respectively; in both cases, results showed significant differences ($P < 0.05$). On the other hand, oil absorption values in plantain pretreated chips with CaCl₂ were 16.03 and 16.32% in the osmo-dehydrating solutions of 3 and 6% NaCl, respectively, and values of oil absorption with sucrose solutions at 30 and 45% were 12.98 and 11.49%, respectively; in both cases, the results were not significantly different ($P > 0.05$). The application of CaCl₂ pretreatment in OD reduced the OAC because the pectins present in the plantain could be interacting with the calcium ions, which can generate cross-linked bonds, reinforcing the cell wall and thereby reducing the porosity in the samples, as reported by Anino et al. (2006). Furthermore, when increasing the concentration of the osmotic solution, a greater incorporation of solutes into the cell membrane and/or the generation of a surface crust that impedes the absorption of oil in the frying process may be taking place (Moyano and Pedreschi 2006). It has been reported that OD is an effective pretreatment in the reduction of OAC, whose effectiveness depends on the solution used and its concentration (Mellema 2003). According to Ikoko and Kuri (2007), who reported that the use of OD pretreatment affects the final content of absorption in the product, this is a result of the reduction of the initial moisture content in the product and, on the other hand, due to the partial gelatinization of the starch molecules in the samples after frying. The percentages of oil absorption in fresh cassava chips subjected to OD (Fig. 3b) with saline solutions at 3 and 6% NaCl were 16.57 and 14.89%, respectively, while in fresh cassava chips subjected to OD in sugar solutions at 30 and 45% sucrose, the values were 13.39 and 10.72%, respectively; in both cases, the results showed significant differences ($P < 0.05$). The OAC values in cassava pretreated chips with CaCl₂ were 17.64 and 15.37% in the osmo-dehydrating solutions of 3

Fig. 3 Absorption of oil in chips **a** plantain and **b** cassava applying OD with and without CaCl₂ pretreatment

and 6% NaCl, respectively, and the oil absorption values with the sucrose solutions at 30 and 45% were 17.18 and 13.74%, respectively; in both cases, the results showed significant differences ($P < 0.05$). Unlike the plantain chips, in cassava chips, it was observed that the pretreatment with CaCl₂ increased the absorption of oil; this was because calcium may be generating disorders or damage in the cell membrane, as reported by Anino et al. (2006), or it may be a consequence of the stress developed during dehydration, which affected the water binding and retention capacity of tissues (Lewicki and Porzecka-Pawlak 2005). The probable rupture in the structure of the cassava chips caused by the presence of CaCl₂ induces the release of water in the tissue; the water that is lost during the pretreatments and the water that is lost during the frying process opens space in the cellular tissue, which can cause a greater distribution of oil, as reported by Moreno and Bouchon (2008) for dehydrated potato cylinders. In this work, in general, it was observed that when increasing the concentration of the osmotic solution, the OAC decreased. Most of the OD and frying conditions showed a significant difference ($P < 0.05$), while under the conditions where the highest OAC was observed (cassava pretreated chips with CaCl₂ osmotically dehydrated with 3% NaCl and 30% sucrose), both conditions showed no significant difference ($P < 0.05$). The treatments that showed the lowest oil absorption were at 45% of sucrose OD in plantain chips pretreated with CaCl₂ and fresh cassava chips at 45% of sucrose OD.

Conclusions

The best OD treatments for plantain were 45% sucrose solution with CaCl₂ and 6% NaCl solution without CaCl₂. However, for cassava, the best OD treatments were 45%

sucrose solution without CaCl₂ and 3% NaCl solution with CaCl₂. Page's model predicted the OD experimental results with an R^2 above 0.94. Use of CaCl₂ in OD reduced EDW and EDS in plantain and cassava samples. The treatments that showed the lowest oil absorption were with OD at 45% sucrose solution in plantain chips pretreated with CaCl₂ and fresh cassava chips with OD at 45% sucrose solution. The results and effectiveness will depend on food, process conditions and type of osmotic agent.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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