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Effect of agitation and antagonism between sucrose and sodium chloride on mass transfer during osmo-dehydration in plant materials

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Abstract: Osmotic dehydration studies on two varieties of apple (Golden Delicious and Cox), potato and banana found that the amount and rate of water loss occurred in the following descending order: Golden Delicious > Cox > potato > banana. However, minimal improvement on the mass transfer in the amount of water loss and solids gain and their corresponding rates was observed in the presence of sodium chloride and agitation of the osmotic solution especially for the first 30 minutes of osmotic dehydration for all the plant materials. Concentration of the osmotic solution and immersion time of samples in the osmotic solution had a significant effect on amount and rate of water loss from all commodities. The mass transfer in all the studied commodities depicted two distinct phases for the amount of water loss and rate of water loss. A corresponding uptake of solids from the osmotic solution occurred, the rate been greatest over the first 30 minutes, before declining significantly thereafter. For the mass transfer the rate of water loss was 3 - 8 times higher than solids gain.

Keywords: Reynolds number, mass transfer, osmotic dehydration, agitation, water loss, solid gain

Introduction

The mass transfer in osmotic dehydration is a complex heterogeneous system, which occurs when foods are immersed in a saline or sugar solution. It consist of a simultaneously occurring water outflow from the food tissue to the osmotic solution, a solute transfer from the osmotic solution to the food tissue and a leaching out of the food tissues own solute. The process obtain de-watering and direct formulation of a product is possible by introducing the desired amount of an active principle, a preservative agent, any solute of nutritional interest, or a sensory quality improver into the food tissue (Raoult-Wack, 1994; Torreggiani, 1995).

The mass transfer in osmotic dehydration have been reported to be influenced by several factors such as solution concentration (Karathanos *et al*., 1995), solution temperature (Beristain *et al*., 1990), type of osmotic agent (Torreggiani, 1995), process duration (Kowalska and Lenart, 2001), level of agitation (Marouzé *et al*., 2001), sample size and geometry (Nieuwenhuijzen *et al*., 2001) and species, variety and maturity level in the case of plant/animal materials (Torreggiani, 1993; Shi and Maupoey, 1993).

Whereas, Marouzé *et al*. (2001) and Kowalska and Lenart (2001) reported that the mass transfer of osmotic dehydration is enhanced by agitation or circulation of the osmotic solution around the sample there are suggestions that it might be more beneficial if agitation is not used when consideration is given to equipment needs and the breaking of fruit as it has no effect on the mass transfer. However, Raoult-Wack *et al*. (1989) observed that agitation favours water loss of the mass transfer, especially at lower temperatures (< 30°C), where viscosity is high, and during the early stages of osmosis. The extent of water loss increased with agitation and reached a certain plateau after which agitation has no effect on water loss. On the other hand, the rate of solids gain decreased with agitation. The authors further stated that for short process periods agitation has no effect on the solids gain and for longer process periods solids gain decreased drastically with agitation. Further, the authors concluded that agitation has no direct impact on solids gain throughout the entire osmotic process, since external transfer of the osmotic solute is not limiting. The authors attributed the agitation-induced decrease in the rate of solids gain for longer osmosis periods to an indirect effect of higher water loss

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(due to agitation) altering the solute concentration gradient inside the food particle. Since diffusion of solutes into natural tissue is slow, most of the solute accumulates in a thin sub-surface layer.

Reports from the authors clearly show that the effect of agitation on the mass transfer in osmotic dehydration is not conclusive. In addition, reports on the influence of agitation and sodium chloride behaviour during osmotic dehydration is lacking in literature although it is expected that starchy fruits may have characteristic behaviour different from non-starchy fruits during osmotic dehydration as a result of starch presence (Tortoe, 2007). Further studies are therefore required to unearth the influence of agitation and the antagonistic behaviour of sugar and salt during osmotic dehydration. This study was conducted to investigate the effect of agitation and the antagonism between sucrose and sodium chloride during osmotic dehydration of two varieties of apple (non-starchy plant material), banana and potato (starchy plant material) on mass transfer rates without affecting the quality significantly.

Materials and Methods

Plant materials and chemicals

Apple (Malus domestica Borkh) varieties Golden Delicious and Cox with maturity levels of 150 days after full bloom (DAFB) were obtained from Horticultural Research International, East-Malling, Kent, England. Banana (Musa spp.) cultivar Cavendish and potato (Solanum tuberosum L.) variety Estima were purchased from a local supermarket in Chatham, Kent, England, and used immediately. In the case of banana, fruit from a single bunch was used for each experiment. The peel colour of all the banana fruits used in the experiments were checked for an early stage of ripeness by comparing it with colour plates on a standard banana ripening chart to select fruits at stage four of ripeness, more yellow than green (CIGAR, 1992, 1993; Dadzie, 1994). Sucrose, sodium chloride and ascorbic acid were purchased from Sigma-Aldrich Chemical Company Limited, United Kingdom.

Experimental design

Sodium chloride solution (0.5%) was used at four levels of sucrose concentration; 40, 50, 60 and 70% at 55°C to check for the possibility of increase in the mass transfer process rate of osmotic dehydration as a result of its presence. A minimum Reynolds number of 79 for minimum agitation was employed for 0.5% sodium chloride and 40, 50, 60, 70% sucrose concentration solutions at 55°C to witness its slightest effect on the mass transfer. All experiments were performed in triplicate and the values reported are the means.

Determination of water loss

Golden Delicious and Cox apple varieties, banana and potato were peeled and cut into cylindrical segments (20.0 mm length, 12.0 mm diameter) using a metallic cork borer. The following sucrose solutions (40, 50, 60 and 70%) were prepared in distilled water as the osmotic solution and 2% ascorbic acid was added to the osmotic solution as an anti-browning solution. From the stock osmotic solution, 6 ml was pipetted into a 30 ml Pyrex bottle and the prepared samples were transferred into the osmotic solution with the aid of a wire. Three replicates were prepared for each treatment for osmotic dehydration. The bottles were transferred into a temperature-controlled water bath set at 55°C (Grant SS40-D Shaking Bath, Grant Instruments (Cambridge) Ltd., England).

Osmotic dehydration was performed using 40, 50, 60, 70% sucrose solution at a temperature of 55°C for 0 - 3 hours with 30 minutes interval recordings. At each sampling period, the dehydrated samples were blotted between two filter papers to remove surface solution, weighed and transferred into a pre-weighed stainless steel dish. The dish was transferred into an oven (Gallenhamp Hotbox Oven, England) to dry until constant weight at 60°C. The soluble solids contents of the plant materials were measured using a refractometer (ATAGO, 0-90%, Japan) at 20°C and the total moisture contents were determined by placing the samples in an oven at 60°C for 24 hours.

Determination of agitation effect

Minimum agitation was employed to assess the possibility to increase the process rate of the mass transfer without breakage of the treatment sample. The agitation was performed at 79 Reynolds number in sucrose concentration solutions (40, 50, 60, 70%) at 55°C for 3 hours at 30 minutes intervals sampling time. Reynolds number (Re) calculation was performed according to Mavroudis *et al*. (1998) and Reiser *et al*. (1995) by the following equation:

$$Re = N \times D^2 / (\mu / \rho) \qquad \text{Equation (1)}$$

where N is the revolutions per second (rev/s) of the shaft = 0.2 rev/s; D is the diameter of the impeller = 0.12 m; and the μ and ρ are the viscosity and density of the fluid, respectively. The agitator is a stainless steel embedded in a waterbath.

Table 1. Percentage mean water loss and rate of water lose of Golden Delicious and Cox apple over 30 minutes and one hour of osmotic dehydration at 55°C and different sodium chloride/sucrose concentration

Sample	Sodium Chloride / sucrose treatment	Osmotic dehydration			
		30 minutes		1 hour	
		Mean water loss (%) ± S.E	Rate (g/g min)	Mean water loss (%) ± S.E	Rate (g/g min)
Golden	T0	40.30 ± 2.33fg	0.01343	48.30 ± 2.05i	0.00805
Delicious	T1	40.41 ± 0.33f	0.01336	51.17 ± 0.52j	0.00853
	T2	41.54 ± 0.50g	0.01384	51.21 ± 1.50j	0.00854
	T3	24.32 ± 1.14d	0.00811	35.71 ± 1.34g	0.00595
	T4	21.71 ± 2.20bd	0.00724	28.06 ± 0.12e	0.00468
	T5	19.19 ± 1.00c	0.00639	21.88 ± 1.30cd	0.00365
	T6	9.11 ± 0.88a	0.00304	12.89 ± 0.85b	0.00215
Cox	T0	32.80 ± 0.33e	0.01093	42.17 ± 0.33h	0.00703
	T1	38.04 ± 0.10f	0.01268	46.00 ± 1.80hi	0.00777
	T2	41.06 ± 1.50fg	0.01369	46.70 ± 1.36hi	0.00779
	T3	30.16 ± 0.68e	0.01005	33.28 ± 0.68g	0.00555
	T4	19.05 ± 0.70c	0.00635	22.46 ± 0.33d	0.00374
	T5	15.68 ± 1.44b	0.00523	19.5 ± 1.59c	0.00325
	T6	8.55 ± 1.10a	0.00285	10.71 ± 1.10a	0.00179

The sodium chloride/sucrose concentration solutions treatments are denoted as follows; T0 = 70% sucrose solution; T1 = 70% sucrose plus 0.5% sodium chloride; T2 = 70% sucrose plus 0.5% sodium chloride with agitation; T3 = 60% sucrose plus 0.5% sodium chloride with agitation; T4 = 50% sucrose plus 0.5% sodium chloride with agitation; T5 = 40% sucrose plus 0.5% sodium chloride with agitation; T6 = 0.5% sodium chloride with agitation).
Means within each column followed by a different letter are significantly different at ($p < 0.05$); n = 3.

Determination of sodium chloride effect

Sodium chloride solution (0.5%) was employed to test its effect on the process rate of the mass transfer in various sucrose concentration solutions in binary and ternary solutions conducted at 55°C. The sodium chloride and/or sucrose concentration solutions treatments were prepared as denoted: T0 = 70% sucrose; T1 = 70 % sucrose plus 0.5% sodium chloride; T2 = 70% sucrose plus 0.5% sodium chloride plus agitation; T3 = 60% sucrose plus 0.5% sodium chloride plus agitation; T4 = 50 % sucrose plus 0.5% sodium chloride plus agitation; T5 = 40% sucrose plus 0.5% sodium chloride plus agitation; T6 = 0.5% sodium chloride plus agitation.

Gravimetric methods – calculations

The water loss and solid gain were expressed in gram per gram initial mass in order to account for the initial mass differences between samples (Shi *et al*., 1995; Azuara *et al*., 1998; Sereno *et al*., 2001). Calculations were based on the following relations:

Water loss (WL) in relation to initial fresh mass of sample (gg-1) =

$$[(m_o - m) + (s - s_o)] / m_o \quad \text{Equation (2)}$$

$$[gg^{-1}min^{-1}] = \{[m_o - m) + (s - s_o)] / m_o\} / t \quad \text{Equation (3)}$$

Solid gain (SG) in relation to initial fresh mass of sample (gg^{-1}) =

$$(s - s_o) / s_o \quad \text{Equation (4)}$$

$$\text{Rate of solid gain } [gg^{-1}min^{-1}] = [(s - s_o) / s_o] / t \quad \text{Equation (5)}$$

where m_o , m are the initial mass and mass of sample after sampling period, s_o , s are the initial mass of solids and mass of solids of sample after sampling

Table 2. Percentage mean solids gain and rate of solids gain of Golden Delicious and Cox apple over 30 minutes and one hour of osmotic dehydration at 55°C and different sodium chloride/sucrose concentration

Sample	Treatment	Osmotic dehydration			
		30 minutes		1 hour	
		Solids gain (%) ± S.E	Rate (g/g min)	Solids gain (%) ± S.E	Rate (g/g min)
Golden	T0	7.10 ± 0.10e	0.00237	8.26 ± 0.45f	0.00138
Delicious	T1	7.15 ± 0.40e	0.00238	8.36 ± 0.07f	0.00279
	T2	7.30 ± 0.44e	0.00243	8.46 ± 0.36f	0.00282
	T3	7.26 ± 0.38 e	0.00242	7.60 ± 0.90e	0.00253
	T4	6.97 ± 0.36e	0.00232	7.23 ± 0.50e	0.00241
	T5	5.47 ± 0.50d	0.00182	5.87 ± 0.10d	0.00196
	T6	3.21± 0.50ab	0.00107	3.52 ± 0.50ab	0.00059
Cox	T0	4.50 ± 0.15c	0.00150	5.23 ± 0.10c	0.00087
	T1	4.64 ± 0.21c	0.00155	5.34 ± 0.28c	0.00178
	T2	5.08 ± 0.20d	0.00169	5.89 ± 0.40cd	0.00196
	T3	4.44 ± 0.20c	0.00148	4.84 ± 0.85bc	0.00161
	T4	4.00 ± 0.19b	0.00133	4.31 ± 0.26b	0.00144
	T5	3.75 ± 0.10b	0.00125	4.00 ± 0.15b	0.00133
	T6	3.10 ± 0.16a	0.00103	3.50 ± 0.20a	0.00058

The sodium chloride/sucrose concentration solutions treatments are denoted as follows; T0 = 70% sucrose solution; T1 = 70% sucrose plus 0.5% sodium chloride; T2 = 70% sucrose plus 0.5% sodium chloride with agitation; T3 = 60% sucrose plus 0.5% sodium chloride with agitation; T4 = 50% sucrose plus 0.5% sodium chloride with agitation; T5 = 40% sucrose plus 0.5% sodium chloride with agitation; T6 = 0.5% sodium chloride with agitation).
Means within each column followed by a different letter are significantly different by ($p < 0.05$); n = 3.

period, respectively and t = duration of osmotic dehydration treatment i.e. the sampling period.

Data analysis

ANOVA on water loss and solid gain were conducted. Mean separation was done using Least Significant Difference (LSD) t-test at $p < 0.05$. All experiments were conducted in triplicate and the mean values reported followed by a different letter are significantly different at $p < 0.05$.

Results and Discussion

Agitation and sodium chloride effect on the mass transfer

The results for agitation depicted statistically minimal improvement on the mass transfer for water loss but not on solids gain in apple varieties, banana and potato (Tables 1- 4). Agitation was observed to improve the mass transfer thereby increasing osmotic dehydration during the early stages of osmosis. Similar observation was reported by Kowalska and Lenart (2001), Marouze *et al*. (2001), Mavroudis *et al*. 1998 and Raoult-Wack *et al*. (1989), where during short process periods agitation has minimal impact on water loss and no effect on the solids gain as was observed in the varieties of apples, banana and potato at 30 minutes and 1 hour of treatment (Tables 1- 4). This is attributed to the continuous contact of the sample surface with the osmotic solution thereby securing a large gradient at the product and solution interface.

The mass transfer for water loss and solids gain in sodium chloride plus sucrose solution plus agitation was statistically significant higher than in comparable single osmotic solutions without agitation for 30 minutes and for 1 hour osmotic dehydration in both apple varieties, banana and potato, particularly Golden Delicious (Tables 1- 4).

Comparable significant difference (LSD, $p < 0.05$) was observed for water loss and solids gain

Table 3. Percentage mean water loss and solids gain and their corresponding rates of banana over 30 minutes and one hour of osmotic dehydration at 55°C and different sodium chloride/sucrose concentration solution

Sodium Chloride / sucrose treatment	Osmotic dehydration			
	30 minutes		1 hour	
	Mean water loss (%) ± S.E	Rate (g/g min)	Mean water loss (%) ± S.E	Rate (g/g min)
T0	26.04 ± 0.38e	0.00868	31.30 ± 0.70e	0.00522
T1	29.06 ± 0.56f	0.00969	34.58 ± 0.65f	0.00576
T2	33.68 ± 0.67g	0.01123	35.94 ± 2.04f	0.00599
T3	22.39 ± 1.54d	0.00746	26.56 ± 0.33d	0.00443
T4	14.42 ± 1.31c	0.00481	16.23 ± 0.39c	0.00271
T5	9.43 ± 2.50b	0.00314	12.30 ± 2.33b	0.00205
T6	4.89 ± 0.10a	0.00163	5.92 ± 0.10a	0.00099
	Solids gain (%) ± S.E	Rate (g/g min)	Solids gain (%) ± S.E	Rate (g/g min)
T0	4.27 ± 0.46e	0.00142	5.14 ± 0.27e	0.00086
T1	3.50 ± 0.20cd	0.00117	4.11 ± 0.18cd	0.00069
T2	3.84 ± 0.22d	0.00128	4.28 ± 0.06d	0.00071
T3	3.30 ± 0.14c	0.00110	4.45 ± 0.15d	0.00074
T4	3.22 ± 0.10c	0.00107	4.05 ± 0.09c	0.00068
T5	2.90 ± 0.06b	0.00097	3.82 ± 0.10b	0.00064
T6	1.80 ± 0.09a	0.00060	3.36 ± 0.13a	0.00056

The sodium chloride/sucrose concentration solutions treatments are denoted as follows; T0 = 70% sucrose solution;T1 = 70% sucrose plus 0.5% sodium chloride; T2 = 70% sucrose plus 0.5% sodium chloride with agitation; T3 = 60% sucrose plus 0.5% sodium chloride with agitation; T4 = 50% sucrose plus 0.5% sodium chloride with agitation; T5 = 40% sucrose plus 0.5% sodium chloride with agitation; T6 = 0.5% sodium chloride with agitation). Means within each column followed by a different letter are significantly different at ($p < 0.05$); n = 3.

in all the sucrose concentration solutions as well as the combinations of sucrose plus sodium chloride concentration solutions for all the plant materials studied (Tables 1- 4).

Figures 1 - 4 shows the behaviour of all the plant materials in term of water loss and corresponding rates in 70% sucrose plus 0.5% sodium chloride treatments and 70% sucrose plus 0.5% sodium chloride plus agitation treatments. Similar plots of the water loss and solids gain and their corresponding rates were obtained for all the other treatments. The plots depicted two distinct phases of the mass transfer for the amount of water loss and rate of water loss. There was a first phase of sharp decrease of water loss occurring in the first 30 minutes followed by a second phase of slow decrease of water loss from the sample. The first phase is probably due to the water removal from the cut surfaces, damage cells and the initiation of water transfer from cells near the surface of the tissue. The second phase may be as a result of water loss due to the movement of free water from the intercellular spaces of the sample to the external solution. A general tend observed in all the treatments shows that both the percentage water loss and their corresponding rates were higher in Golden Delicious. A descending order of water loss and rate of water loss is presented as follows: Golden Delicious > Cox > potato > banana. In all the plant materials, the highest rates were observed in 70% sucrose plus 0.5% sodium chloride solution plus agitation (T2) and the lowest rates recorded in 0.5% sodium chloride solution (T6).

In addition, Figs. 1 - 4 depicts minimal improvement of the mass transfer for water loss although significantly different ($p < 0.05$) from treatments without agitation for all the commodities studied. For example, the rate of water loss in Golden Delicious in 70% sucrose plus 0.5% sodium

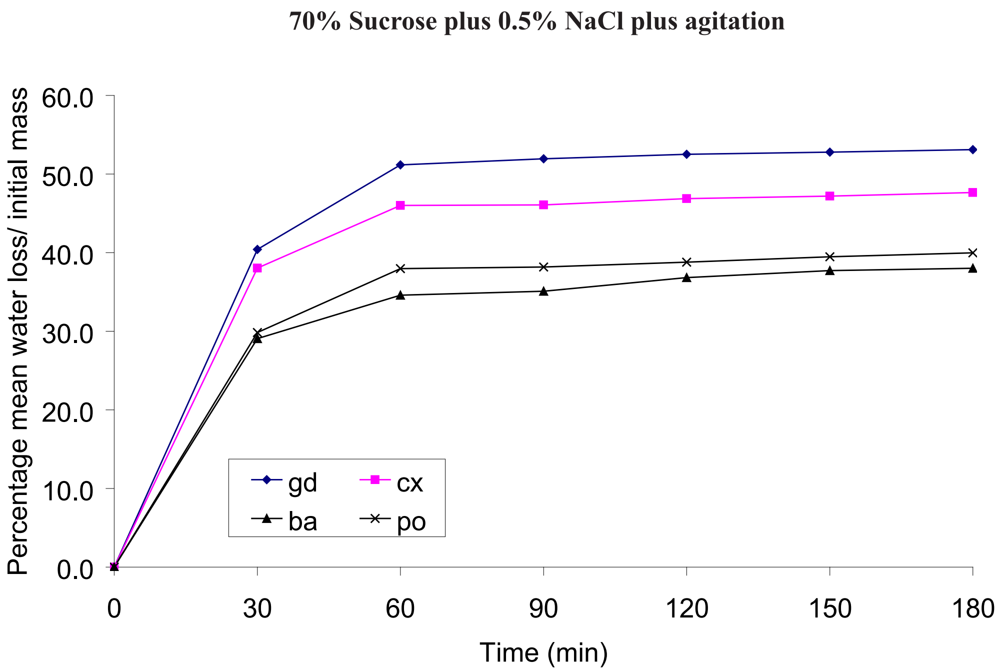

Figure 1. Percentage mean water loss in relation to initial mass of osmotically dehydrated plant materials in 70% sucrose plus 0.5% sodium chloride solution. The vertical bars represent S.E at $p < 0.05$. (gd = Golden Delicious; cx = Cox; ba = Banana; po = potato)

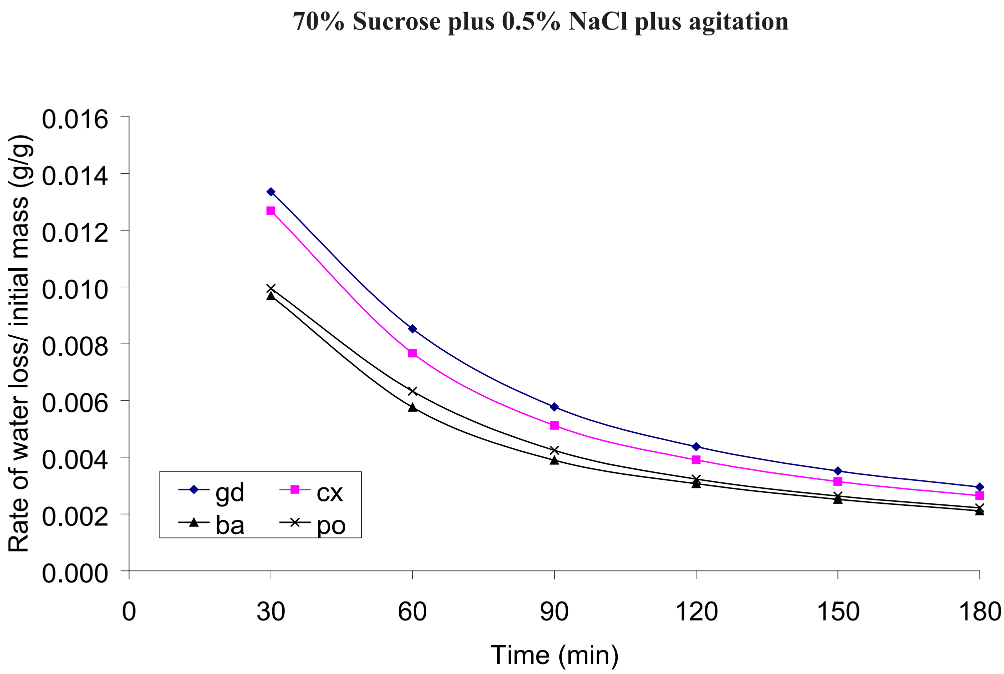

Figure 2. Rate of water loss in relation to initial mass of osmotically dehydrated plant materials in 70% sucrose plus 0.5% sodium chloride solution. (gd = Golden Delicious; cx = Cox; ba = Banana; po = potato)

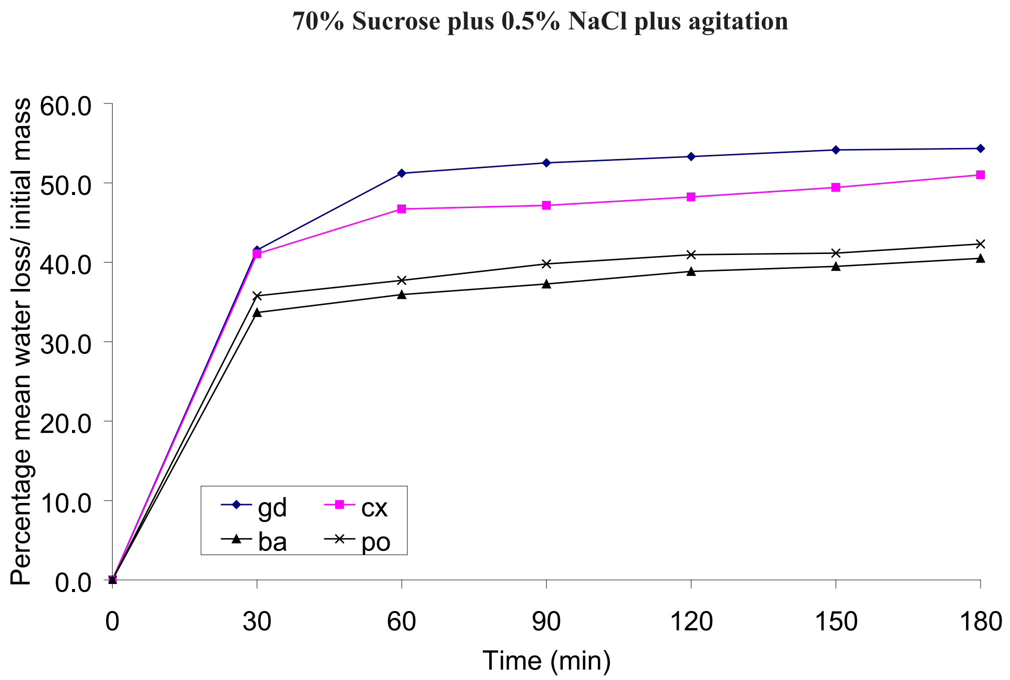

Figure 3. Percentage mean water loss in relation to initial mass of osmotically dehydrated plant materials in 70% sucrose plus 0.5% sodium chloride solution plus agitation. The vertical bars represent S.E at $p < 0.05$. (gd = Golden Delicious; cx = Cox; ba = Banana; po = potato)

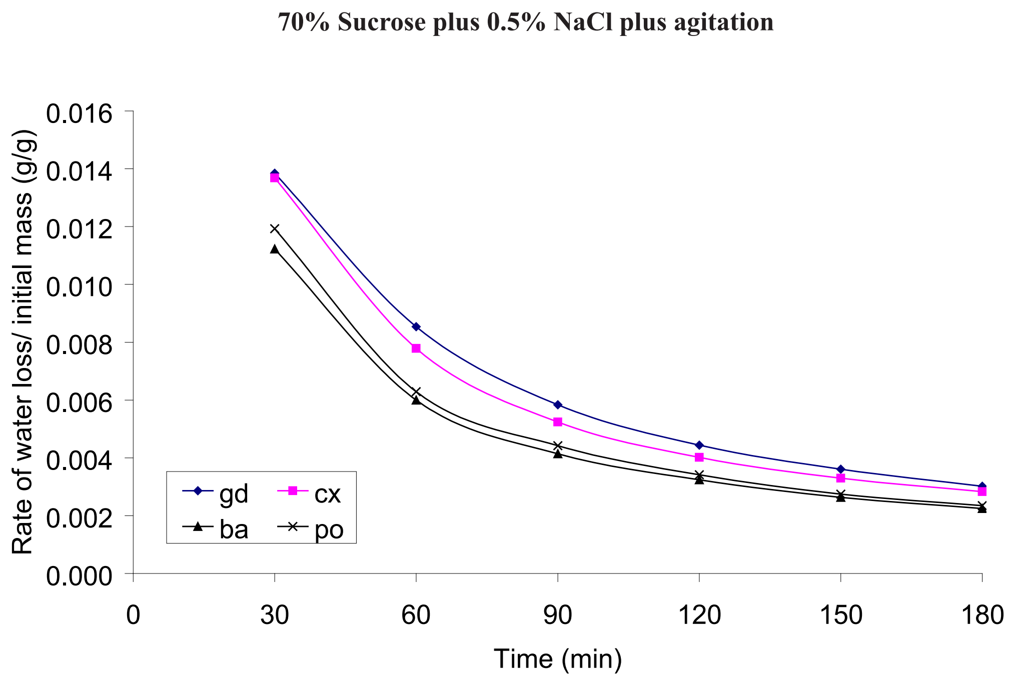

Figure 4. Rate of water loss in relation to initial mass of osmotically dehydrated plant materials in 70% sucrose plus 0.5% sodium chloride solution plus agitation. (gd = Golden Delicious; cx = Cox; ba = Banana; po = potato)

Table 4. Percentage mean water loss and solids gain and their corresponding rates of potato over 30 minutes and one hour of osmotic dehydration at 55°C and different sodium chloride/sucrose concentration solution

Sodium Chloride / sucrose treatment	Osmotic dehydration			
	30 minutes		1 hour	
	Mean water loss (%) ± S.E	Rate (g/g min)	Mean water loss (%) ± S.E	Rate (g/g min)
T0	28.20 ± 0.71e	0.00940	33.66 ± 0.34e	0.00561
T1	29.85 ± 0.91e	0.00995	37.97 ± 1.99e	0.00633
T2	35.77 ± 1.08f	0.01192	37.72 ± 0.64e	0.00629
T3	23.65 ± 1.90d	0.00788	29.10 ± 1.13d	0.00485
T4	16.60 ± 1.29c	0.00553	18.00 ± 0.29c	0.00300
T5	10.01 ± 0.60b	0.00334	13.48 ± 0.49b	0.00225
T6	5.77 ± 0.11a	0.00192	6.87 ± 0.33a	0.00114
	Solids gain (%) ± S.E	Rate (g/g min)	Solids gain (%) ± S.E	Rate (g/g min)
T0	4.35 ± 0.15e	0.00145	5.22 ± 0.34e	0.00087
T1	3.80 ± 0.25d	0.00127	4.35 ± 0.19c	0.00073
T2	3.92 ± 0.23d	0.00131	4.52 ± 0.20cd	0.00075
T3	3.75 ± 0.12d	0.00125	4.88 ± 0.26d	0.00081
T4	3.43 ± 0.15c	0.00114	4.36 ± 0.10c	0.00073
T5	3.06 ± 0.13b	0.00102	3.91 ± 0.06b	0.00065
T6	2.00 ± 0.06a	0.00067	3.57 ± 0.46a	0.00060

The sodium chloride/sucrose concentration solutions treatments are denoted as follows; T0 = 70% sucrose solution; T1 = 70% sucrose plus 0.5% sodium chloride; T2 = 70% sucrose plus 0.5% sodium chloride with agitation; T3 = 60% sucrose plus 0.5% sodium chloride with agitation; T4 = 50% sucrose plus 0.5% sodium chloride with agitation; T5 = 40% sucrose plus 0.5% sodium chloride with agitation; T6 = 0.5% sodium chloride with agitation). Means within each column followed by a different letter are significantly different at ($p < 0.05$); n = 3.

chloride plus agitation was 2.43 x 10^{-3} ($gg^{-1}min^{-1}$) for 30 minutes of osmotic dehydration whereas the rate of water loss for 70% sucrose plus 0.5% sodium chloride was 2.38 x 10^{-3} ($gg^{-1}min^{-1}$) for 30 minutes of osmotic dehydration. Higher rate indicates more driving force for water loss thereby improving the mass transfer of the commodity during osmotic dehydration. This buttresses the report that agitation or circulation enhances the mass transfer for water loss but not the solids gain in osmotic dehydration for foods (Mavroudis *et al*., 1998; Raoult- Wack, 1989; Reiser *et al*., 1995; Kowalska and Lenart, 2001; Marouze *et al*. 2001).

Antagonistic effect of sodium chloride and sucrose

The antagonistic effect of sodium chloride and sucrose was observed in all the plant materials (Tables 1 - 4; Figs 1 - 4). It resulted in the delimiting effect of the sodium chloride diffusion through the plant material as a result of a barrier formation by sucrose due to its larger molecular weight than sodium chloride (Collignan and Raoult-Wack, 1994; Bohuon *et al*., 1997; Bohuon *et al*., 1998). Due to the high molecular weight of sucrose (342 g/mol), its diffusion will be much slower than sodium chloride (58.4 g/mol) diffusion through the material, and most of the sucrose remains mainly in the extracellular space whilst sodium chloride can penetrate into the cell leading to the reduction of the osmotic pressure gradient. As sodium chloride penetrates into the cell it enhances the release of the water thereby improving the process rate of the mass transfer for water loss for the tissues.

In aqueous ternary solutions containing water, salt and sugar, the highly antagonistic effects on the solute gain in processed products have been reported (Collignan and Raoult-Wack, 1994; Bohuon *et al*., 1998). Salt uptake is especially limited by the presence of sugar. The barrier effect of sugar on salt penetration in animal, fruit and vegetable products has been reported (Collignan and Raoult-Wack, 1994; Bohuon *et al*. 1997; Bohuon *et al*., 1998; Giempero *et al*., 2001). According to the authors this phenomenon is due to the formation of highly concentrated sugar on the surface of the material which subsequently reduces the salt diffusion coefficient (Bohuon *et* *al*., 1998). The decrease is mainly due to the high viscosity of the ternary solution (Bohuon *et al*., 1997).

Behaviour of starch during osmotic dehydration

Generally, the presence of starch in tissues competes for the removal of water during osmotic dehydration and the amount of starch may contribute to the differences of the amount and rate of water loss affecting the mass transfer as observed for non-starchy plant material (Golden Delicious and Cox) and starchy plant material (banana and potato) presented in Tables 1 - 4 and Figs. 1 - 4.

The reason is attributed to the hygroscopic nature of starch, which competes for water thereby hindering the diffusion of water out of the tissues. In addition the presence of high temperature causes the starch to swell to expose more hydrophilic parts. The amount of starch in the cell may therefore be influential on the amount of water available for release, which affects the process rate of the mass transfer. The amount of starch present is influenced by the species and stage of maturity of the produce, although the release of more simple sugars in the cells will equally have an influence on water loss (Tortoe, 2007). A general observation was that higher rates of water loss were observed for the two varieties of apple, which are cellulosic than banana and potato, which are starchy in nature.

Conclusions

The highest water loss and solid gain form the mass transfer in all the treatments took place during the first 30 minutes of osmotic dehydration. Interesting, the ratio of water loss to solid gain was 8:3 and was significantly dependent on osmotic solution concentration and immersion time during the osmotic dehydration. Agitation and sodium chloride interaction was minimal on the mass transfer for water loss and solid gain for all the plant materials during osmotic dehydration. Similarly, the antagonistic effect of sucrose and sodium chloride positively influenced water loss over solid gain. In addition, the presence of starch in tissues probably contributed to the differences in the amount and rate of water loss and solid gain.

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References

Azuara, E., Beristain, C.I. and Gutierrez, G.F. 1998. A method for continuous kinetic evaluation of osmotic dehydration. Lebensmittel-Wissenschaft und-Technologie 31(4): 317-321.

Beristain, C.L., Azuara, E., Cortes, R. and Garcia, H.S. 1990. Mass transfer during osmotic dehydration of pineapple rings. International Journal of Food Science and Technolology 25(4): 576-582.

Bohuon, P., Collignan, A., Rios G.M. and Raoult-Wack, A.L. 1998. Soaking process in ternary liquids: experimental study of mass transport under natural and forced convection. Journal of Food Engineering 37(4): 451-469.

Bohuon, P., LeMaguer, M. and Raoult-Wack, A.L. 1997. Densities and viscosities of ternary systems on NaCl-Sucrose-Water from 283.15 to 303.15 K. Journal of Chemical Engineering Data 42(2): 266-269.

CIGAR, 1992. Future priorities and strategies. CGIAR Technical Advisory Committee. TAC Secretariat, FAO, Rome, Italy.

CIGAR, 1993. Progress report by the CIGAR task force on banana and plantain research. CGIAR Secretariat, World Bank, Washington, D.C., USA.

Collignan, A. and Raoult-Wack, A.L. 1994. Dewatering and salting of cod by immersion in concentrated salt and sugar solutions. Lebensmittel-Wissenschaft und-Technologie 27(2): 259-264.

Dadzie, B.F., 1994. Quarterly report for the INIBAP/FHIA/NRI (ODA Holdback) project on post-harvest cooking banana and plantain characteristics (October-December 1994). p. 1-64. Chatham, United Kingdom: Natural Resources Institute.

Giempero, S., Gianotti, A. and Dalla Rosa, M. 2001. Sucrose-salt combined effects on mass transfer kinetics and product acceptability. Study on apple osmotic treatments. Journal of Food Engineering 49: 163-173.

Karathanos, V.T., Kostarropoulos, A.E. and Saravacos, G.D. 1995. Air drying kinetics of osmotically dehydrated fruits. Drying Technology 13(12): 1503-1512.

Kowalska, H. and Lenart, A. 2001. Mass exchange during osmotic pre-treatment of vegetables. Journal of Food Engineering 49(2): 137-140.

Marouzé, C., Giroux, F., Collignan, A. and River, M. 2001. Equipment design for osmotic treatments. Journal of Food Engineering 49(3): 207-221.

Mavroudis, N.E., Gekas, V. and Sjoholm, I. 1998. Osmotic dehydration of apples. Effects of agitation and raw material characteristics. Journal of Food Engineering 35(2): 191-209.

Raoult-Wack, A.L., Lafont, F., Rios, G. and Guilbert, S. 1989. Osmotic Dehydration: Study of the Mass Transfer in Terms of Engineering Properties. In Mujumdar, A.S. and Roques, M. (Eds). Drying 89, p. 487-495. New York: Hemisphere Publishing Corporation.

Nieuwenhuijzen, N., Zareifard M.R. and Rasmaswamy, H.S. 2001. Osmotic drying kinetics of cylindrical apple slices of different sizes. Drying Technology 19: 525-545.

Raoult-Wack, A. L. 1994. Recent advances in the osmotic dehydration of foods. Trends in Food Science and Technology 5(8): 255-260.

Reiser, P., Birch, G.G. and Mathlouthi, M. 1995. Physical Properties: Sucrose Properties and Applications. pp: 186-221. London: Blackie Academic and Professional.

Sereno, A.M., Moreira, R. Martinez, E. 2001. Mass transfer coefficients during osmotic dehydration of apple in single and combined aqueous solutions of sugar and salt. Journal of Food Engineering 47(1): 43-49.

Shi, X.Q., Fito, P. and Chiralt, A. 1995. Influence of vacuum treatment on mass transfer during osmotic dehydration of fruits. Food Research International 28(5): 445-454.

Shi, X.Q. and Maupoey, P.F. 1993. Vacuum osmotic dehydration of fruits. Drying Technology 11(6): 1429-1442.

Torreggiani, D. 1995. Technological Aspects of Osmotic Dehydration in Foods. In: Food preservation by moisture control: fundamentals and applications, ISOPOW Practicum II. Barbosa-Canovas, G.V. and Welti-Chanes, J. (Eds.), p. 281-304. Lancaster, PA, Technomic Publishing.

Torreggiani, D. 1993. Osmotic dehydration in fruit and vegetable processing. Food Research International 26(1): 59-68.

Tortoe, C., Orchard, J. and Beezer, A. 2007. Comparative behaviour of cellulosic and starchy materials during osmotic dehydration. Journal of the Science Food and Agriculture 87(7): 1284-1291.