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Osmotic Dehydration of New Zealand Chestnuts with and without Shell and Pellicle

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Abstract: Osmotic dehydration offers an alternative to air-drying for reducing moisture content at ambient temperature. Of four different solutes investigated, 22% (mass basis) sodium chloride (NaCl) and 60% (mass basis) sucrose solutions were the most successful, with each achieving approximately a 10% reduction in wet basis moisture content after 8 h without significant detrimental side effects, although NaCl solutions cause noticeable darkening in the pits on the surface of the chestnuts. The presence of the shell and pellicle did not significantly affect the dehydration rate. Osmotic dehydration by NaCl or sucrose prior to mechanical shell removal produced a small increase in efficiency of the shell removal process.

Keywords: osmotic dehydration, chestnuts, mechanical shell removal

1 Introduction

For centuries, chestnuts have been a source of carbohydrates for people living in many areas of Asia, South Europe, North Africa and most countries bordering the Mediterranean Sea [1]. Freshly harvested chestnuts have relatively high moisture contents and a texture more akin to a fruit than a nut. The postharvest treatment to extend storage time is more comparable to that for fruits or vegetables than nuts [2]. In particular, there is the risk of germination unless the storage temperature is sufficiently low or the moisture content is reduced to 0.4 kg/kg (wet basis).

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Chestnuts were first introduced to New Zealand by some of the earliest European settlers in the 1800s and planted throughout New Zealand, mostly as specimen and ornamental trees. They are fast growing and are not threatened by many of the pests or diseases common in other chestnut-growing regions. However, the nuts are highly susceptible to fungal rotting, and also to significant discolouration during air-drying [3]. Drying trials [4] have shown previously that nuts could not be air-dried at temperatures above 30°C without significant damage occurring. Although large-scale drying facilities for commercial food crops exist in New Zealand, these are not suitable for most chestnut growers as they are expensive, far from most growers, and not always available during chestnut harvest time.

Osmotic dehydration is an alternative to air-drying for reducing moisture content. When a chestnut is placed in a concentrated aqueous solution there will be a chemical potential driving force that causes water from within the chestnut to migrate to the aqueous solution, a process that can be thought of as a form of osmosis. The migration of water will continue until the chemical potential of water within the chestnut is equal to the chemical potential of water within the aqueous solution [5]. At the same time, the solute in the aqueous solution will migrate into the chestnut, while other chemical components within the chestnut will also migrate out of the chestnut into the solution. Equilibrium is achieved once the chemical potential of each chemical species is the same in the chestnut as it is in the aqueous solution. The relative rates of migration of the different chemical species depend on the difference in chemical potential (which is proportional to concentration) for each species in the chestnut and aqueous solution, and also the rate of diffusion (which is generally inversely proportional to the size of the molecule) of the chemical species. Ideally, water, which is a small molecule, experiences significantly higher transfer rates than any other chemical species in the system.

Several studies have investigated the effectiveness of osmotic dehydration for European chestnut varieties. Chenlo et al. [6] used different concentrations of sodium chloride (NaCl) solutions to osmotically dehydrate a Spanish variety of chestnuts. Samples immersed in

saturated NaCl solution (approximately 26.5% mass basis NaCl) had the highest dehydration rates and the highest solids uptake rate. The optimal NaCl concentration was 22% (mass basis); these chestnuts had higher moisture reduction to solids absorption ratio than saturated solutions and also discoloured less.

Chenlo et al. [7] used three different glucose concentrations (40%, 50% and 56.5% mass basis) and a range of temperatures to osmotically dehydrate the same variety of Spanish chestnuts. Dehydration rates increased with temperature and glucose concentrations, as expected from theory. The lowest ultimate moisture content was achieved with the most concentrated glucose solution. The optimum osmotic solution concentration was 56.5% (mass basis) glucose because there was appreciable water removal without too much glucose being absorbed by the chestnut tissue. While operating at temperatures higher than ambient achieved slightly higher dehydration rates, it was concluded that the increase did not justify the increased cost of operating above ambient temperatures, and 25°C was found to be the optimum processing temperature.

Chenlo et al. [8] also performed similar experiments using sucrose as the osmotic solute and concluded that 60% (mass basis) sucrose solution was optimal for moisture removal and solids uptake, and that operating at ambient temperature was most economical.

Other research by the same group [9] indicated that osmotic dehydration as a pre-treatment reduced air-drying time. Also, osmotic dehydration had a lower impact on the chestnut cellular structure than air-drying [10] and there was a significant decrease in non-enzymatic discolouration [11].

There does not appear to be any other published studies on osmotic dehydration of chestnuts other than the work of the group, including Chenlo, Moreira and coworkers [6–11]. Their work typically used only two to seven chestnuts weighing approximately 10 g each per trial. Also, the outer shell and pellicle were removed or the chestnuts were cut to expose the kernel to the osmotic dehydration solution. As the experiments typically only lasted for 8 h, a pseudo-equilibrium (essentially the ultimate achievable moisture content) was often not reached.

The first aim of this investigation was to determine what rates of dehydration could be achieved for bulk-packed New Zealand chestnuts using osmotic dehydration. The moisture content of New Zealand chestnuts affects the efficiency of mechanical shell and pellicle removal [2]; therefore, the second aim of this investigation was to determine the effect of osmotic dehydration on the mechanical shell removal process.

2 Materials and methods

2.1 Materials

All chestnuts used in this study were of New Zealand variety "1015", which had been manually harvested and stored with shell and pellicle intact in ventilated bags for approximately 2 months at 2°C. To prepare chestnuts for the experiments, they were "floatation graded" (i.e. submersed in water to see whether they sank or floated). Experience has shown that a high proportion of New Zealand chestnuts that float in water are rotten, even though there may be no indication of rotting on the surface of the chestnut, but chestnuts that sink contain very few with rot [12]. Only chestnuts, each weighing approximately 15 g, which sank were used in these trials.

The following solutes were used to make up osmotic solutions with concentrations (mass basis) based on published recommendations [6–8]: 15% and 22% NaCl, 50% calcium chloride ($CaCl_2$), 40% glucose (dextrose) and 50% and 60% sucrose. All solutes were commercial grade and only a single solute was used in each solution. The ratio of mass of osmotic solution to chestnuts was greater than 10 to ensure changes in solution concentration due to solute and water transfer were negligible.

2.2 Osmotic dehydration trials

Before the dehydration trials, average moisture content of the chestnuts was measured (to determine the initial moisture content in the context of the osmotic dehydration process). For each trial, batches of at least 1 kg of chestnuts, either with intact shells or with shells manually removed, were immersed in the osmotic solution in a 20 L pail. At regular intervals (typically every 2 h) a subsample containing five chestnuts (approximately 80 g total) was removed and the moisture content determined. These nuts were not returned to the pail. Sampling was continued for up to 24 h. All trials were performed at room temperature (approximately 20°C).

Moisture contents of the chestnuts were determined by drying the subsample at 105°C to constant mass (approximately 48 h). The wet basis moisture content was determined from the following relationship:

$$W \underline{\underline{\text{def}}} \frac{m_w}{m_w + m_s} = \frac{m_i - m_f}{m_i} \quad (1)$$

where W = the wet basis moisture content (kg/kg); m_f = the mass of the sample once a stable mass has been

reached (kg); m_i = the initial mass of the sample (kg); m_s = the mass of solids within the sample (kg); m_w = the mass of water within the sample (kg).

The right-hand side of eq. (1) is based on the assumption that once the mass stops changing over time, the sample is moisture free and $m_s = m_f$.

Unlike most drying applications where the amount of solids in the sample is assumed to be constant, the solids in osmotic dehydration will change because solute(s) from the dehydrating solution enter(s) the sample and non-water components may diffuse from the sample into the solution (although the rate of the latter transfer is expected to be significantly less than the transfer of water and solutes from the osmotic solution to the sample). As the solids content of the sample does not remain constant, the wet basis moisture content was deemed to be more useful for dehydration rate analysis than the dry basis moisture content.

The change in solids content could be determined from a mass balance based on the change in total mass of the sample and the difference in moisture content between the initial and final states:

$$\Delta m_s = \frac{m_{T,i}}{\frac{W_i}{1-W_i}+1} - \frac{m_{T,f}}{\frac{W_f}{1-W_f}+1} \quad (2)$$

where m_T is the total mass of the sample and the subscripts i and f refer to the initial and final states, respectively.

2.3 Mechanical shell removal trials

To determine the effect of osmotic dehydration on the efficiency of mechanical shell removal, samples of chestnuts were de-shelled using a customized chestnut shelling machine commonly used in New Zealand. The control sample was chestnuts of variety 1015 that had not been subjected to osmotic dehydration, but had been dried in air at 30°C. Approximately 1 kg of chestnuts was immersed in 60% (mass basis) sucrose or 22% NaCl for 4, 6 and 8 h. The sample of nuts was then passed through the shelling machine. Shell removal efficiency (or "recovery") was defined as the mass of whole nuts with shells removed divided by the total mass of nuts fed to the machine.

3 Results and discussion

3.1 Osmotic dehydration trials

Trials using glucose solutions were not successful since no clear trends were observed (most likely due to a procedural error) so the data have not been presented. Similarly, data for trials with 15% NaCl and 50% sucrose were not as conclusive as data for the more concentrated solutions, so these are not presented.

The change in wet basis moisture content and normalized moisture content (NMC = $W/W_{t=0}$) when 1 kg samples of chestnuts, with and without shell and pellicle, were immersed in 22% NaCl, 50% $CaCl_2$ and 60% sucrose is summarized in Table 1.

The greatest reduction in normalized moisture content occurred when chestnuts were immersed in $CaCl_2$ solutions. However, there was significant softening and darkening of the nuts so this solution was not used for further trials or analysis because the chestnuts would not be saleable.

The dehydration rates obtained were comparable but slightly lower than reported previously [6, 8]. In addition to the nuts being different cultivars, the differences in

Table 1: Dehydration rates for New Zealand chestnuts in NaCl, sucrose and $CaCl_2$ solutions.

Time (h)	NaCl (22%)				$CaCl_2$ (50%)				Sucrose (60%)			
	S&P intact		S&P removed		S&P intact		S&P removed		S&P intact		S&P removed	
	W	NMC	W	NMC	W	NMC	W	NMC	W	NMC	W	NMC
0	0.60	1.00	0.62	1.00	0.52	1.00	0.55	1.00	0.50	1.00	0.54	1.00
2	0.58	0.96	0.60	0.96	0.49	0.94	0.49	0.88	0.49	0.96	0.51	0.94
4	0.56	0.94	0.58	0.94	0.47	0.91	0.48	0.87	0.46	0.91	0.51	0.94
6	0.54	0.90	0.57	0.92	0.42	0.82	0.45	0.81	0.45	0.90	0.50	0.92
8	0.53	0.89	0.56	0.90	0.40	0.77	0.43	0.78	0.45	0.89	0.48	0.90
10	0.54	0.89	0.56	0.90	0.43	0.84	0.43	0.77	0.46	0.92	0.50	0.92
24	0.54	0.89	0.54	0.87								
Error est.		±3%		±1%		±2%		±1%		±3%		±1%

drying rate are probably due to New Zealand chestnuts being larger (15 g) than the Spanish nuts (9–10 g) and also to being packed in bulk whereas the trials reported in the literature were based on using two to seven chestnuts.

The initial trials in this study were performed for up to 24 h; however, since the dehydration rate reduced significantly after 8 h, the length of the experiments was reduced to 8 h for subsequent trials. This is similar to the reported dehydration rates [6–8], where experimental trials were performed for up to 8 h.

It is interesting to note that the presence of the shell and pellicle did not significantly affect dehydration rates. By contrast, Biju Cletus and Carson [4] reported that air-drying rates of peeled and unpeeled chestnuts of the same variety were significantly different. The reason that the presence of the shell and pellicle had no apparent effect on osmotic dehydration is due to the differences in microstructure between the shell/pellicle and the kernel, with the former being more porous.

The rates of solute transfer into chestnuts immersed in 22% NaCl and 60% sucrose solutions were similar (although generally smaller) than the rate of water removal from the chestnut, as indicated by the ratios of moisture lost to solids gained being greater than unity (Table 2). These ratios are similar to the results obtained in the Spanish trials [6, 8]. The migration of sucrose or NaCl into the chestnut may not be a problem (and in fact may be desired) if it is destined for further processing (e.g. if it is ground and as an ingredient in a snack food).

Table 2: Comparison of dehydration to solute up-take rates.

Time (h)	Water loss/solids gain (w/w)	
	NaCl (22%)	Sucrose (60%)
2	1.2	1.6
4	1.3	1.2
6	1.3	1.0
8	1.5	1.3
Error est.	±10%	±10%

3.2 Visual assessment of osmotically dehydrated chestnuts

Figure 1(a) and 1(b) shows samples of the chestnuts with the shell removed (but pellicle intact) after osmotic dehydration with NaCl (22%) and sucrose (60%) solutions, while Figure 1(c) shows a control sample that has not been subjected to osmotic dehydration. Using sucrose as the osmotic dehydration agent did not have a significant effect on the colour of the chestnuts (Figure 1(b)) but chestnuts dehydrated in NaCl solution (Figure 1(a)) darkened significantly, particularly in the pits. This agrees with the observations of Chenlo et al. [6], who observed "small but very dark zones on the surface" when chestnuts were dehydrated in NaCl solutions. The significance of discolouration will depend on the intended use of the chestnuts. If they are being crumbed or milled, this level of discolouration may be acceptable.

3.3 Effect of osmotic dehydration on mechanical shell removal

Mechanical shelling removes the chestnut shells by abrasion while the chestnuts are vigorously agitated. The chestnuts are then separated from the lighter shell material. When the chestnuts leave the machine, they are graded into one of three categories (Figure 2(a)–2(c)): whole nuts with shell removed entirely (Figure 2(a)), whole nuts with some shell attached (Figure 2(b)) and broken nuts with or without shell (Figure 2(c)).

A two-factor analysis of variance test (without replicate) with a 0.05 level of significance suggested a small reduction of the number of chestnuts with shells intact if the nuts had been osmotically dehydrated (Figures 3 and 4). Osmotic dehydration tends to make chestnut tissue more brittle [6], increasing the chance that they will be broken during the mechanical shell removal process.

The recovery of whole chestnuts without shells was much lower for chestnuts immersed in sucrose solutions than in NaCl solutions. These chestnuts had been harvested much later than chestnuts for the NaCl trials and also had higher moisture contents before and after osmotic dehydration; and therefore direct comparisons between the two sets of data are difficult to make.

Biju Cletus [2] used a machine that operated under a similar principle to the machine used in these trials to remove shells from the same variety of chestnuts and reported that recovery increased as chestnut moisture reduced. She suggested that wet basis moisture contents

Figure 1: Chestnuts with shell removed: (a) after 8 h in 22% (w/w) NaCl solution, (b) after 8 h in 60% sucrose solution and (c) control (not subjected to osmotic dehydration.

of 0.4 kg/kg or lower would allow consistent recoveries of greater than 80%. It is assumed that the increase in recoveries due to osmotic dehydration may simply be because the nuts have lower moisture contents rather than solutes migrating into the chestnuts.

3.4 Practical implications

Osmotic dehydration offers an alternative to air-drying for reducing the moisture content of freshly harvested chestnuts. If osmotic dehydration is done under ambient conditions such that energy demands are lower than for air-drying there may be a reduction in operating costs, although this will be offset by the cost of the solute needed for the dehydration solutions. The process appears to be as effective with the shell and pellicle intact as without, which increases the practicality of this processing option. Mechanical removal of the shell is marginally more efficient from osmotically dehydrated chestnuts than from air-dried chestnuts. However, osmotic dehydration on its own is insufficient to reduce moisture content of New Zealand chestnuts to a level (0.4 kg/kg, wet basis) that allows them to be stored at room temperature and therefore must be combined with further processing such as air-drying or refrigeration.

Chestnuts that have been osmotically dehydrated in 22% NaCl solutions had comparable solute absorption rates and moisture content reduction rates to chestnuts dehydrated in 60% sucrose solutions. However, lower concentrations of NaCl than sugar (22% compared to 60%) can be used, decreasing the cost of solutes for the process. Using sucrose causes significantly less discolouration, which may be significant in terms of product quality. Neither solute substantially increased the recovery of peeled whole chestnuts over the conventional air-dried process. Although osmotic drying appears to have

Figure 2: Classification of chestnuts after mechanical shell removal: (a) whole nuts, shell removed; (b) whole nuts, some shell remaining; and (c) broken nuts.

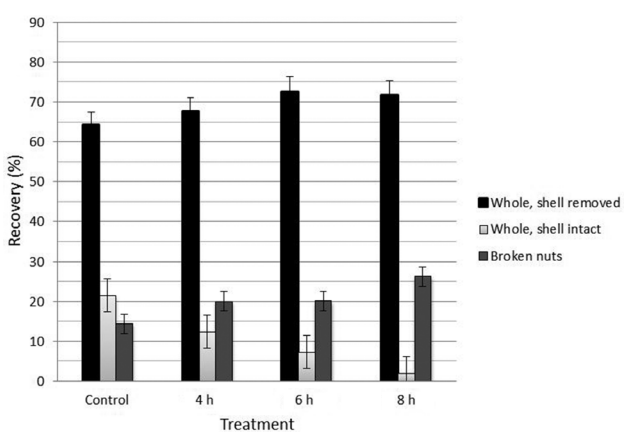

Figure 3: Shell removal efficiency after 8 h osmotic dehydration in 22% (w/w) NaCl solution.

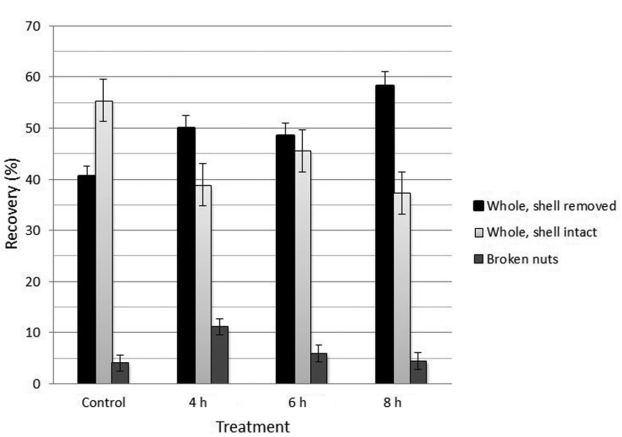

Figure 4: Shell removal efficiency after 8 h osmotic dehydration in 60% (w/w) sucrose solution.

definite advantages over conventional air-drying, selecting which solute to use will probably depend on individual preference, intended product use and desired product quality.

4 Conclusions

Osmotic dehydration using 22% w/w NaCl or 60% w/w sucrose achieved a normalized moisture content

reduction of approximately 10% after 8 h for New Zealand chestnuts packed in bulk. Removing the shell and pellicle of the chestnut did not significantly affect the dehydration rates. Osmotic dehydration in NaCl or sucrose solutions before mechanical shell removal improved de-shelled whole-nut recovery compared to chestnuts that had not been dehydrated. The pits on the surface of the chestnuts that had been dehydrated in NaCl darkened significantly but there was no observable discolouration with sucrose solutions.

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Nomenclature

m	Mass (kg)
NMC	Normalized moisture content ($W/W_{t=0}$)
W	Wet basis moisture content (kg/kg)

Subscripts

f	Final value
i	Initial value
s	Solids
T	Total
w	Water

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