

## Rehydration Kinetics of Un-Osmosed and Pre-Osmosed Carrot Cubes

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**Abstract:** The rehydration kinetics of osmo-convectively dehydrated carrot cubes were studied by immersing in water at 30° temperature for 12 hours. Prior to convective dehydration, carrot cubes were osmotically pretreated with osmotic solutions in 10% NaCl solution, 55°Brix sucrose syrup and 50°Brix +10% NaCl at temperatures of 35, 45 and 45°C, for durations of 90, 180 and 180 minutes, respectively, with sample to solution ratio 1:5. The convective dehydration was performed in cabinet drier at 65°C temperature up to final moisture content of 4-5% (wet basis). During rehydration water gain, solute loss and percentage shrinkage were studied at different intervals of time. Peleg's model well represented the experimental data water gain and solute loss during rehydration of un-osmosed and pre-osmosed carrot cubes. The highest shrinkage was observed in the un-osmosed samples. Shrinkage was negligible for the samples osmotically pretreated with mixture of sucrose-salt mixture followed by sucrose solution..

**Key words:** Rehydration kinetics • carrots • osmosis • pelegs equation

### INTRODUCTION

Vegetables are highly seasonal and available in plenty at particular times of the year. In the peak season, the selling price decreases and this can lead to heavy losses by the grower. Also, due to the abundant supply during the season, a glut in the market may result in the spoilage of large quantities. Preservation of these vegetables can prevent the huge wastage and make them available in the off-season at remunerative prices [1].

Carrot (*Daucus carota* L.) is one of the important root vegetable crops and is highly nutritious as it contains appreciable amount of vitamins B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub> and B<sub>12</sub> besides being rich in  $\beta$ -carotene. It also contains many important minerals.  $\beta$ -carotene is a precursor of vitamin A and is reported to prevent cancer [2]. Its maximum retention is utmost important for the preservation of the attractive appearance and dietary value of the product. Carrots have a moisture content of 80-90% (wb) at the time of harvest [3]. They are seasonal in nature and highly susceptible to moisture loss leading to wilting and loss of fresh appeal.

Out of various methods of extending the shelf life of perishable crops, osmotic dehydration is one of the simple and inexpensive alternate process, which is not only energy intensive and low capital investment but also

offer a way to make available this low cost, highly perishable and valuable crop available for the regions away from production zones and also during off season. It is the process in which water is partially removed from the cellular materials when these are placed in a concentrated solution of soluble solute. Osmotic dehydration, which is effective even at ambient temperature and preserves the color, flavor and texture of food from heat and used as a pretreatment to improve the nutritional, sensorial and functional properties of food. The amount of water remaining in the material, however, does not ensure its stability, as water activity is generally higher than 0.9. When shelf stability is an ultimate process objective, other, complementary methods of water removal, such as convective drying, freeze drying, freezing etc are suggested [4]. A number of researchers conducted studies on the osmotic dehydration of carrots [5, 6]. Various osmotic agents such as sucrose, glucose, fructose, corn syrup, sodium chloride and so on plus their combination have been used for osmotic dehydration. Generally sucrose solutions are used for fruits and sodium chloride solution is used for vegetables. Addition of small quantities of sodium chloride to osmotic solutions increased the driving force of the drying process and synergistic effects between sucrose and sodium chloride have been reported [7].

There has been extensive study to assess the rate of water intake by food materials. Rehydration behaviour was studied in grapes by Gabas *et al.* [8], Nameko and shitake by Kalbarczyk and Widenska [9], carrots by Ramos *et al.* [10] and Reyes *et al.* [11], vegetables like potato, carrots, celery and parsley roots by Bobic *et al.* [12], osmotically dehydrated pineapple by Rastogi *et al.* [13] and brocolli florets by Sanjuan *et al.* [14] by using different process parameters, like immersion time and water temperature. These researchers reported that, the temperature increases the rehydration rate due to decreased viscosity of the immersion medium and effect of temperature on the structure of food material.

Most of studies to assess the water intake rate by food materials were based on Fick's laws of diffusion using appropriate experimental equations [15-18]. To simplify the mode of water absorption and solute outflow, non-exponential empirical equation was proposed by Peleg [19], which has been successfully applied to milk powder, rice, dasheen leaves, cherry tomato and various legumes [18, 20, 21]. The Peleg's equation is as below:

$$M_t = M_o + \frac{t}{K_1 + K_2 t} \quad (1)$$

$$\text{At } t \rightarrow 0 \quad \frac{dM}{dt} = \frac{1}{K_1}$$

$$\text{And as } t \rightarrow \infty \quad M_e = M_o + \frac{1}{K_2}$$

$$\frac{t}{(M_t - M_o)} = K_1 + K_2 * t \quad (2)$$

A plot of  $t/(M_t - M_o)$  against time,  $t$ , gives a straight line with  $K_1$  as the ordinate-intercept and  $K_2$ , the gradient of the line. Such plot allows the characteristics of the constants to be studied. Although some published data were tested with this equation, more soaking experiments were required to investigate its wide range. With particular reference to the two constants, herein called Peleg's constants  $K_1$  and  $K_2$ , the variability of these constants has been studied by the various scientists with temperature of water [18, 20, 21]. As the osmotic pretreatment before convective dehydration plays a major role in moisture absorption, there is a need to study the effect of osmotic pretreatment on the constants. The osmotic pretreatment

and blanching significantly affects the shrinkage behaviour during rehydration of the dehydrated product.

The objectives of this study were to assess the applicability of the Peleg's equation and to determine whether food materials could be characterized with either or both of the constants of the Peleg equation to model water absorption. The shrinkage behaviour with respect to osmotic pretreatment and blanching were also studied during rehydration process.

## MATERIALS AND METHODS

**Preparation of sample:** Fresh well graded, carrots were washed and peeled manually. A manually operated vegetable dicer was fabricated and used to prepare carrot cubes of dimensions 1 cm x 1cm x 1 cm. The initial moisture content of the fresh carrot cubes varied from 90.9-91.15% (wet basis).

**Osmotic dehydration:** Carrot cubes were osmotically pretreated with osmotic solutions in 10% NaCl solution, 55°Brix sucrose syrup and 50°Brix +10% NaCl at temperatures of 35, 45 and 45°C, for durations of 90, 180 and 180 minutes, respectively, with sample to solution ratio 1:5. The osmotic pretreatments resulted into approximated average moisture loss of 8, 15 and 22%, respectively. Corresponding to these osmotic pretreatments, the approximated values of solute gain were 2, 13 and 18 g/100 g fresh carrot cubes, respectively [22]. To one lot of the carrots, no blanching was done prior to osmosis as it has been reported to be detrimental to osmotic dehydration process due to the loss of semi-permeability of cell membrane and reduction of  $\beta$ -carotene of carrots [23-25].

However, to study the effect of blanching on rehydration kinetics, carrots cubes were blanched in hot water (near boiling water) for 3 minutes to inactivate enzymes. The carrots were immediately rinsed with cold water to stop the reaction. After blanching the carrot cubes were dipped in 0.3% solution of Sodium metabisulphite for 3 minutes to retain the colour and vitamins [26].

**Convective dehydration:** The amount of water remaining in the material, however, does not ensure its stability, as water activity is generally higher than 0.9. When shelf stability is an ultimate process objective, other, complementary methods of water removal, such as

convective drying, freeze-drying, vacuum drying, freezing etc are suggested [27, 4].

To prepare shelf stable product having final moisture content 4-5% (w.b.), osmotically pretreated and un-osmosed carrot cubes were placed in thin layer and subjected to convective dehydration at an air temperature of 60°C and an air velocity of 1.5 m/s with direction of air flow through the product.

#### Rehydration kinetics of dehydrated carrot cubes:

Rehydration kinetics study was carried out at 30°C water temperature assuming that the average temperature of the water in the summer season (off season for carrots) would be 30°C. The beakers containing water and fruit were kept in water bath pre-set at 30°C. The approximate ratio of dried fruit and water volume was kept as 1:30 [28, 29]. The rehydrated fruit was spread on absorbent paper for the removal of free water on the surface of fruit. The change in weight and volume were recorded after a regular interval of time. Then the rehydrated samples were put in pre-weighed petridish for determination of water gain and solid loss by hot air oven method. The maximum time of immersion of fruit sample was 12 hours. The rehydration ratio was computed by using the equation

$$\text{Rehydration Ratio} = \frac{\text{Weight of rehydrated carrots (g)}}{\text{Weight of dehydrated carrots (g)}} \quad (3)$$

#### Calculations

**Water gain and solute loss during rehydration:** To measure water gain and solute loss during rehydration the known weight of dried sample was immersed in water and after required time interval the sample was re-weighed and kept in pre-weighed petridish. The sample was kept in oven at 70°C and was dried when the weight between two successive intervals becomes constant.

$$\text{Water gain g/g initial dry matter of dried fruit} = \frac{(W_t - W_o) + (S_o - S_t)}{S_o} \quad (4)$$

$$\text{Solute loss/g initial dry matter dried fruit} = \frac{S_o - S_t}{S_o} \quad (5)$$

The initial dry matter of dried carrots ( $S_o$ ) includes the dry matter of carrots and mass of solute penetrated during osmotic dehydration. This penetrated solute has to be lost into water during rehydration.

**Measurement of Shrinkage:** The bulk shrinkage of the carrot cubes during rehydration of dehydrated carrot cubes was measured by displacement method using water [30]. Shrinkage was calculated as the percentage change from the initial apparent volume. The % shrinkage was calculated as

$$\% \text{ Shrinkage} = \left[ 1 - \left( \frac{V_t}{V_o} \right) \right] * 100 \quad (6)$$

## RESULTS AND DISCUSSION

#### Effect of osmotic pretreatment on rehydration ratio:

It is clear from Fig. 1 that the rehydration ratio is significantly affected by osmotic pretreatment. The rehydration ratio is highest for un-osmosed samples and lowest for the osmotically pre-treated samples with Sucrose-salt mixture. This behaviour of low rehydration ratio of osmotically dehydrated carrot cubes may be explained on the basis that, the osmotically pretreated sample contain 8-12 % solute which got infused during osmotic dehydration and leached in to water during rehydration process without contributing to the rehydrating process. So it was only the dried matter of carrot cubes (and not the infused solute), which is responsible for absorption of water during rehydration. However, Bhuvanewari *et al.* [31] reported that rehydration ratio of osmotically treated peas was higher than those of untreated samples.

#### Effect of osmotic pretreatment on water uptake, solute loss during rehydration:

Water uptake during rehydration of osmotically pretreated samples also depends on the kind of osmotic substance (Fig. 2). The figure indicates that during the rehydration, the carrot cubes, osmotically pretreated with sucrose-salt samples give a lower water uptake as compared to samples treated with sucrose solution followed by samples treated with salt and un-osmosed ones. This may be due to the variation of porosity of carrot cubes due to different osmotic pretreatments applied before convective dehydration [32]. All the samples exhibited an initial high rate of moisture sorption and solute loss followed by slower water absorption and solute loss in the later stages of rehydration process. This is due to the fact that the capillary imbibition is important at early stages, which leads to an almost instantaneous uptake of water. Similar results were reported by Sopade and Obekpa [20]. As

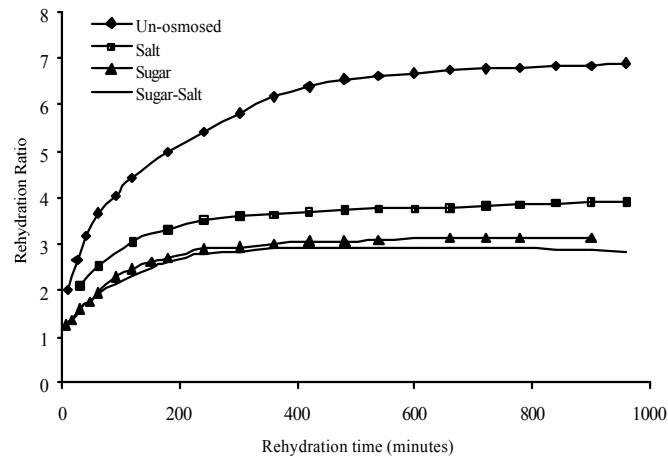


Fig. 1: Effect of osmotic pretreatment on rehydration ratio of carrot cubes

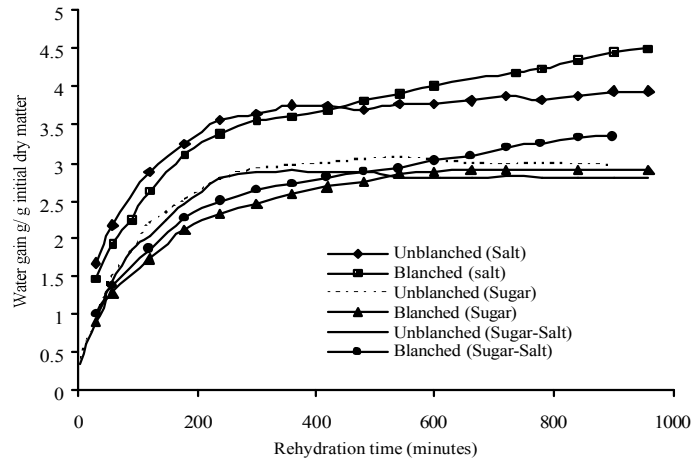


Fig. 2: Effect of osmotic pretreatment on water gain kinetics during rehydration of carrot cubes at 30°C water temperature

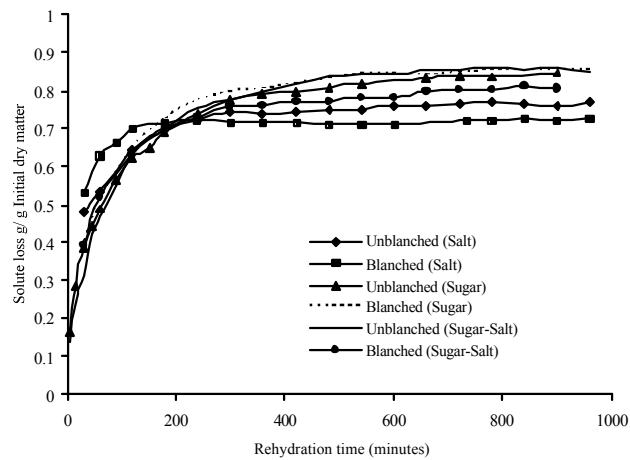


Fig. 3: Effect of osmotic pretreatment on solute loss kinetics during rehydration of carrot cubes at 30°C water temperature

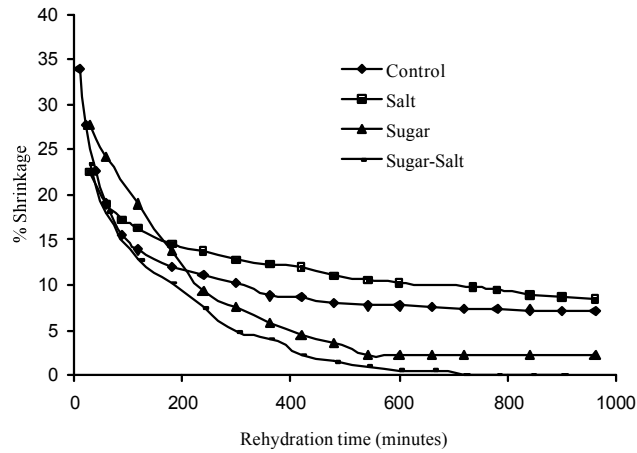


Fig. 4: Effect of osmotic pretreatment on percentage shrinkage of rehydrated carrot cubes at 30°C water temperature

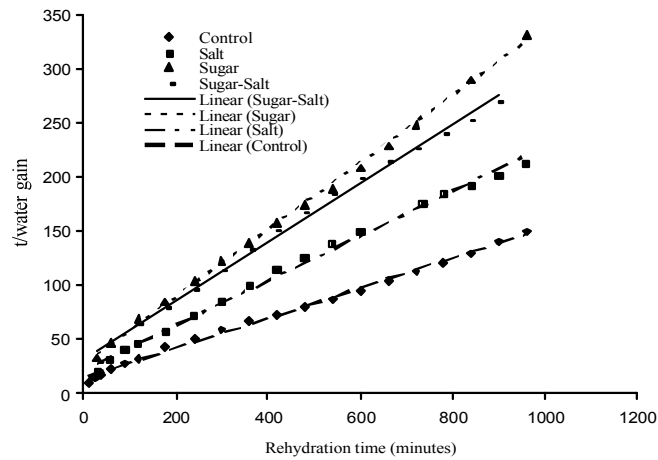


Fig. 5: Plot for verification of Peleg's model for water gain during rehydration of carrot cubes

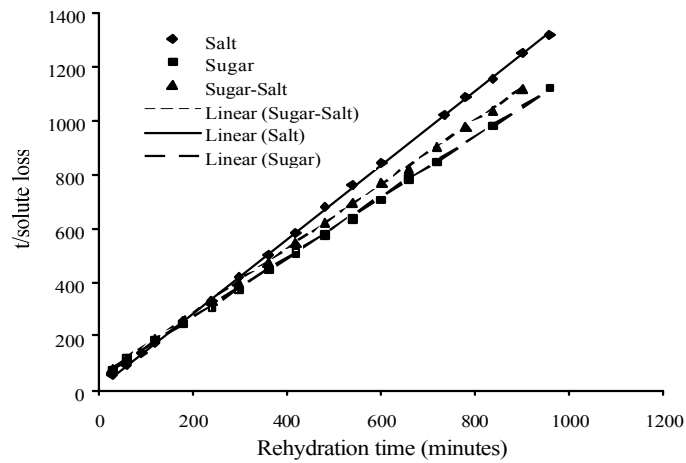


Fig. 6: Plot for verification of Peleg's model for solute loss during rehydration of carrot cubes

Table 1: Peleg's constants for water gain and solute loss during rehydration of carrot cubes

Treatment	Osmotic treatment	Water Gain			Solid Loss		
		K <sub>1</sub>	K <sub>2</sub>	R <sup>2</sup>	K <sub>1</sub>	K <sub>2</sub>	R <sup>2</sup>
un-blanchd	NaCl salt	11.035	0.2441	0.9994	27.973	1.2749	0.9998
	Sucrose	16.655	0.3085	0.9963	48.965	1.1305	0.9993
	Sucrose-salt	14.839	0.3347	0.9966	53.395	1.1013	0.9994
Blanchd	Un-osmosed	14.066	0.1387	0.9964	-	-	-
	NaCl salt	21.799	0.2064	0.996	10.657	1.3725	0.9998
	Sucrose	27.412	0.3098	0.9985	44.762	1.1146	0.9998
	Sucrose-salt	31.096	0.2715	0.9961	44.541	1.1899	0.9958

indicated in Fig. 2, with prolonged soaking, the moisture content increases to maximum value and remains almost constant by further increase in soaking time. The Fig. 3 indicates the behaviour of solute loss (penetrated into carrot cubes during osmotic dehydration) into water during rehydration process.

#### Effect of osmotic pretreatment on shrinkage behaviour:

It is clear that after rehydration of 350 minutes, there is no shrinkage of rehydrated carrot cubes, which were osmotically pretreated with sucrose-salt mixture (Fig. 4). Maximum shrinkage was observed for samples, which were osmotically pretreated with salt and followed by un-osmosed (blanchd) samples, which is consistent with results of Torringa *et al.* [33]. This is because; drying induces many non-reversible physical and chemical changes in the food material, which could not be restored by simply adding water. Highest shrinkage for salt treated carrot cubes may be due to the structural changes occurred due to some chemical reaction. Neumann [34] observed that polyhydroxyl compounds like glucose, sucrose improved the rehydration characteristics of fruit and vegetables.

**Effect of osmotic pretreatment on Peleg's constants for rehydration process:** Peleg's equation adequately (with  $R^2 > 0.98$ ) described the water absorption and solute loss behaviour of previously blanchd and un-blanchd osmotically pre-treated carrot cubes at hydration temperature of 30°C (Fig. 5 and 6) and predicted the equilibrium moisture content, initial hydration and solute loss rates. The values of Peleg's constants for various pretreatments are as shown in Table 1.

The Peleg's constant  $K_2$  describes a characteristic sorption parameter, which is inversely related to the absorption ability of foods [20]. The reciprocal of constant  $K_2$  could be used to predict the equilibrium moisture content, which does not vary with temperature

[18-20]. Peleg's constant,  $K_2$  (for water gain) is found to be lower for un-osmosed carrot cubes (Table 1). For pre-osmosed carrot cubes, the lowest value of  $K_2$  is for salt treatment followed by pretreatment with sucrose and sucrose-salt mixture. The low  $K_2$  values observed for samples osmotically pretreated with salt indicate the increased absorption ability and high equilibrium moisture content (water gain) of samples. This is due to the low solute concentration in the carrot cubes osmotically pretreated with salt as compared to samples osmotically pretreated with sucrose and sucrose-salt mixture. This is in accordance with the hydration curves shown in Fig. 2. The curves show that the water uptake for osmotically pretreated carrot cubes with salt is in excess than that of samples osmotically pre-treated with sucrose and sucrose-salt mixture. Similar pattern is found for solute loss during rehydration process as indicated in Fig. 3 and Table 1.

Sopade and Obekpa [20] and Maharaj and Sankat [18] found that Peleg's constant  $K_1$  is inversely related to temperature and its reciprocal ( $1/K_1$ ) (% mc db/minute) is equivalent to initial rate of hydration. In the present study, a change in Peleg's constant  $K_1$  is observed even at constant water temperature during rehydration. The change in  $K_1$  may be due to the different osmotic pretreatments used before convective dehydration. The values of Peleg's constant  $K_1$  for water gain are higher for blanchd samples as compared to un-blanchd ones. This indicates that the initial rate of hydration was more in un-blanchd samples as compared to blanchd ones. This may be due to change in structure of fruit by blanching. Peleg's constant  $K_1$  for water gain and solute loss decreases significantly with osmotic pretreatment. Its value is highest for the samples osmotically pretreated with sucrose-salt mixture followed by pretreatment with sucrose, salt and un-osmosed samples. Initial hydration rate is more pronounced for salt treated un-blanchd carrot cubes, where  $K_1$  values are the lowest (Table 1).

This unexpected increase in hydration rate for un-blanching (treated with salt) is attributed to the changes in properties of the carrot cubes due to osmotic pretreatment.

## CONCLUSIONS

The osmotic and blanching pretreatment before convective dehydration have bearing effect on the rehydration kinetics and shrinkage behaviour. The Peleg's model well represented the rehydration kinetics of dehydrated carrot cubes. The effect of these treatments is also pronounced on the Peleg's constants.

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