

Effect of Blanching and Osmotic Pre-treatment on Drying Kinetics, Shrinkage and Rehydration of Chayote (*Sechium edule*) during Convective Drying

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ABSTRACT

The influence of brine pretreatment and blanching on drying kinetics, area shrinkage and rehydration of oven-dried chayote slices was investigated. Chayote slices (4±1 mm thick) were blanched in hot water at 80 °C or osmo-dehydrated in 10% brine for 3 min, or left untreated as control and subsequently dried at 65 °C. Shrinkage of dried samples, rehydration ratio and effective diffusivity of samples were determined. Experimental drying data was fitted by non-linear regression to 10 selected thin layer drying models. Modified Henderson and Pabis model gave the best fit for untreated chayote ($R^2 = 0.9993$) and brine-treated ($R^2 = 0.9991$) chayote while Midilli *et al* model best described the blanched chayote ($R^2 = 0.9970$). Effective moisture diffusivities ranged from $1.09 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ and $1.30 \times 10^{-8} \text{ m}^2\text{s}^{-1}$, rehydration ratios over a period of 270 min decreased from blanched > control > brine-treated while shrinkage was highest in

blanched samples and lowest in brine-treated samples. The results indicate that blanching and osmo-dehydration in brine pre-treatment prior to oven-drying affect the drying kinetics, shrinkage and rehydration parameters of chayote slices.

Keywords: Chayote, Osmo-dehydration, Blanching, Kinetics, Rehydration, Shrinkage, Convective drying

1. INTRODUCTION

Chayote (*Sechium edule*) is a perennial climbing subtropical vegetable native to South Americas but cultivated in Ghana because of its culinary importance (Abbiw, 1997). Although it remains largely underutilized, it is rich in amino acids and minerals, especially potassium but low in proteins and fat, with more than 90 % moisture. It has been reported to exhibit diuretic and anti-inflammatory properties (Ordonez *et al.*, 2006). The vegetable, popularly known in Ghana as “Chocho” could be used in soups and sauces to enhanced consistency and in vegetable salads. The high moisture content of chayote creates suitable conditions for chemical and microbial action that leads to extensive degradation and loss of the produce a few days after harvest. These losses can however be reduced by processing the vegetable into more stable forms by drying. The underlying principle of preservation by drying is to obtain a final product which is stable as a result of a reduction, primarily, in moisture content. This reduction in moisture also lowers its availability for microbial and chemical activity as well as physical changes during storage (Mujumdar and Law, 2010). Conventional methods such as hot air-drying have been applied severally in the processing and preservation of fruits and vegetables. This method, however, have been reported to impart certain undesirable physical and nutritional characteristics to the finished

dry product. As a result, pre-treatments have been applied prior to drying fruits and vegetables to control the objectionable changes in colour, texture (low porosity and low rehydration characteristics) and flavor that occurs (McMinn and Magee, 1997, Jayaraman and Gupta, 2006, Aguilera *et al.*, 2003 and Grabowski *et al.*, 2002; Falade and Omojola, 2010; Aversa *et al.*, 2010). Blanching and osmotic dehydration are two common pre-treatments applied to food produce prior to drying (Senadeera *et al.*, 2000; Sablani 2006; Fernandes *et al.*, 2010). Blanching generally involves dipping the product in hot water or exposing it to steam, ostensibly to inactivate enzymes that are responsible for hydrolysis of lipids and browning as well as soften tissues and enhance mass transfer during drying (Moreno-Perez *et al.*, 1996; Senadeera *et al.*, 2000). Osmotic pretreatment on the other hand is achieved by dipping the product in a hypertonic solution prior to drying. This reduces the initial moisture content of the starting material by osmosis or modifies tissue structures in a way that increases mass transfer (Fernandes *et al.*, 2008; Pan *et al.*, 2003) and reduces total processing time (Fernandes *et al.*, 2006). This method has been employed extensively during fruits and vegetable processing (Gonzalez-Martinez *et al.*, 2006; Pan *et al.*, 2003; Tortoe *et al.*, 2007; Sunjka and Raghavan, 2004). The difficulty with osmo-dehydration, however, is the inability to control leaching of soluble components and solute uptake as an overload of solutes adds on to the resistance to mass transfer from the inner to the outer surface of the product (Wang and Sastry, 2000). Subsequent physical changes that occur due to drying alter the texture and transport properties of the final dried product (Yan *et al.*, 2007). In the present study, the influence of hot water-blanching and osmotic treatment in brine on drying kinetics of Chayote is determined by fitting experimental drying data to selected mathematical models for thin-layer drying. The effect of these pre-treatments on shrinkage and rehydration are also considered.

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69 2. MATERIALS AND METHODS

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71 2.1 Vegetable samples

72 Chayote (ivory-white colored) was purchased from a local market at Aburi in the Eastern Region
 73 of Ghana. The vegetables were sorted, cleaned and washed before slicing manually into a
 74 thickness of 4 ± 1 mm using stainless-steel blade knife. The initial moisture content of the
 75 vegetable, determined by standard method (AOAC, 1990) was 94.2 % (w.b). The samples were
 76 split into three batches; two of them were pretreated (blanching and osmotic dehydration) before
 77 drying, while no treatment was applied to the third batch, which served as control.

78

79 2.2 Pretreatments

80 Blanching was accomplished by placing vegetable slices in stainless steel sieve and immersing
 81 them in hot water at 80 °C. After 3 min, the sieve with its content was removed and cooled to
 82 room temperature while excess water drained from the samples before drying.

83 Osmotic dehydration was done by immersing the vegetable slices in salt solution (10% w/v) at
 84 room temperature (28.4 °C) for 3 min. The samples were drained of excess water and blotted
 85 with tissue paper before drying. Salt was chosen as the osmotic dehydration agent on the basis of
 86 the intended end use of the product and the fact that it is known to provide high osmotic pressure
 87 (Mayor *et al.*, 2006).

88

89 2.3 Drying of samples

Samples drying was conducted in a convective hot air dryer (Gallenkamp, England) at 65 °C air drying temperature. The drying system was preheated to attain steady conditions (65 ± 1 °C) before samples were loaded. Samples (in triplicate) weighing 50 ± 1g were thinly spread in trays and loaded into the dryer. Changes in weight of samples (in triplicate) were measured with an electronic balance with an accuracy of ± 0.001 (Kern 510, Kern & Sohn, GmbH, Germany) at 30 min interval until constant weight loss. Final moisture content of the dried samples were also determined (AOAC, 1990).

2.4 Model fitting and data analysis

The moisture ratio of chayote slices for thin layer drying was calculated using the following equation:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where MR is the moisture ratio, M_t , M_0 and M_e are moisture content after time t (kg water/kg dry matter), initial moisture content and equilibrium moisture content respectively. However, M_e compared with M_0 and M_t is very small and could be neglected and the MR simplified (Doymaz, 2004; Goyal *et al.*, 2007) and expressed as:

$$MR = \frac{M_t}{M_0} \quad (2)$$

Experimental results of moisture ratio vs. drying time were fitted to selected and widely applicable models for describing thin layer drying kinetics (Table 1) by Non-linear regression analysis (XLSTAT 7.5.2).

The coefficient of determination (R^2) was the primary criterion for selecting the best model to describe the drying curve. Also, the reduced chi square (X^2) and the Root Mean Square Error (RMSE) were used to determine the goodness of fit between predicted and experimental data. A

113 higher value of R^2 and lower values of X^2 and RMSE corresponds to a better goodness of fit
 114 (Akpınar *et al.*, 2003; Gunham *et al.*, 2005; Sobukola, 2009). The X^2 and RMSE were calculated
 115 from the following formulae:

$$116 \quad X^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - Z} \quad (3)$$

$$117 \quad RMSE = \left[\frac{1}{N} \sum_{i=1}^N (MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2} \quad (5)$$

118 where N is the number of observations, z is the number of constants, MR_{exp} and MR_{pre} are the
 119 experimental and predicted moisture ratios respectively.

120

121 2.5 Effective diffusivity

122 Generally, diffusion is assumed as the dominant transport mechanism during drying and
 123 the rate of moisture movement is therefore described by an effective diffusivity value, D_{eff} ,
 124 which is related to MR by equation 6 (Wang *et al.*, 2007).

$$125 \quad \ln MR = \ln \frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4L^2} \quad (6)$$

126 The effective moisture diffusivity was obtained by plotting the experimental drying data
 127 in terms of $\ln MR$ against time, t. From equation 6, a plot of $\ln MR$ against drying time, t, gives a
 128 straight line with slope, K, where

$$129 \quad K = \frac{\pi^2 D_{eff}}{4L^2} \quad (7)$$

130 2.6 Shrinkage

131 Area shrinkage of dried samples was estimated using image analysis software ImageJ
 132 1.46r (National Institutes of Health, USA). Images of raw, pretreated and dried samples were
 133 captured with a digital camera (Fujifilm FinePix Z900EXR) and transferred onto a computer to
 134 be processed with ImageJ Imaging software. In the software's environment, the colour threshold

of the image was adjusted to produce an outline of the sample picture and its particles analyzed to estimate its area. Area measurements were done in triplicates and their means used to calculate shrinkage. The extent of shrinkage was expressed as percentage shrinkage and calculated using the formula;

$$\% \text{ Shrinkage}_i = \frac{A_0 - A_d}{A_0} \times 100 \quad (8)$$

where A_0 and A_d are the areas of sample before and after drying, respectively.

2.7 Rehydration ratio

Samples for rehydration test were obtained after the period of drying. Five grams of dried samples were rehydrated in distilled water (sample:water of 1:40) at room temperature (28.4 °C) in glass beakers by soaking samples in them. Samples were removed at 30 min interval, adhering water carefully blotted with tissue paper, weighed with an electronic balance (Kern 510, Kern & Sohn, GmbH, Germany) and immediately returned to the same soaking water (Doymaz and Ismail, 2011). The test was carried out over a period of 5 hours and the rehydration ratio calculated with the relation:

$$\text{Rehydration Ratio} = \frac{\text{Mass of rehydrated sample}}{\text{Mass of dried sample}} \quad (9)$$

3. RESULTS AND DISCUSSION

The moisture content of the dried chayote samples in blanched, control and brine treated samples was 5.2 %, 6.1 % and 8.0 %, respectively. The experimental drying curve shows faster moisture removal corresponding to a greater decrease in moisture ratio for the blanched treated samples followed by the control and brine treated samples over the period of drying (Figure 1).

This observation is due to disruption and subsequent softening of tissues after blanching, which facilitates the transport of water to the surface of the product where it is evaporated. In the case of the control, there is no cell disruption prior to drying and therefore movement of water within the cell is confronted by all the resistive mechanisms of intact cell structures. Even though there is an extent of structure alteration during osmotic pretreatment which favors movement of water on the one hand, the treatment also results in the uptake of solutes, which cause additional resistance to the mass transfer of water and leads to a lower dehydration rate during further drying. The results further emphasize the close association between drying kinetics and structural changes that occur in plant tissues following osmotic dehydration and blanching as reported by Alzamora *et al.*, 2003. Similar effect on drying of blanching compared to untreated food products have been reported for chilli pepper (Tunde-Akintunde, 2010), eggplant slices (Doymaz and Gol, 2011) and pumpkin (Perez and Schmalko, 2009).

3.1 Non-linear regression modeling

Although modified Henderson and Pabis, Midilli *et al.* and Logarithmic models adequately described the experimental data generally, modified Henderson and Pabis was the best model for describing the kinetics of drying in the control and brine treated samples while Midilli *et al.* best fitted the drying data of blanched samples (Tables 2, 3 and 4). Compared to the various models, modified Henderson and Pabis as well as Midilli *et al.* which are semi-theoretical models derived from the Ficks 2nd law of diffusion and quite commonly based on the Henderson and Pabis model (Erbay and Icier, 2009) resulted in the highest R^2 and lowest X^2 and $RMSE$. The R^2 , X^2 and $RMSE$ for control, brine treated and blanched treated samples were 0.9993, 6.0×10^{-5} , 7.3×10^{-3} ; 0.9991, 8.0×10^{-5} , 8.5×10^{-3} ; 0.997, 3.0×10^{-4} , 1.6×10^{-2} , for the models that best described the

drying data. The effect of blanching is evident in the observation that its experimental data best fit a different model as opposed to the other samples. Modified Henderson and Pabis and Midilli *et al.* have been used to sufficiently describe blanched and other food products including pre-treated and none pre-treated (Doymaz, 2012; Togrul and Pehlivan, 2004)

3.2 Diffusivity

The moisture diffusivities for control, brine treated and blanched treated were $1.22 \times 10^{-8} \text{ m}^2\text{s}^{-1}$, $1.09 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ and $1.30 \times 10^{-8} \text{ m}^2\text{s}^{-1}$, respectively. Pre-treatment altered the integrity of the internal structure, thereby causing an enhancement as seen for blanched treated or a restriction in internal mass transfer of moisture as in the case of brine treated samples. Once blanched, cell membranes and cell walls lose their ability to resist water flux (Falade and Igbeka, 2007), making moisture diffuse easily and faster out of the tissues. Although some structural changes occur as well during osmotic dehydration, solutes taken up from the osmotic solution, to a significant, extent impede the movement of water out of plant tissues (Wang and Sastry, 2000) resulting in lower effective moisture diffusivity. A similar trend of lowering effective diffusivity between control and brine-treated chayote was observed by Ruiz-Lopez *et al.*, (2010). Generally, the effective moisture diffusivity values obtained are comparable to the range (10^{-13} to 10^{-6}) for drying food materials (Okos *et al.*, 2007, Marinos-Kouris and Maroulis, 2006).

3.3 Shrinkage

Shrinkage affects physical properties such as porosity, density and ultimately the shape, which is one of the major perceptive factors of a product and therefore an idea of its mechanism and effect of process variables reduces it greatly (Mayor and Sereno, 2004). In vegetables, shrinkage

increases with the amount of water removed (Ahmed, 2011) and therefore the greater the volume of water expelled, the greater the extent of shrinkage. Drying caused a reduction in the surface area of the sliced vegetable of 38 – 55% (Figure 2). Pretreatment influenced shrinkage as the extent to which the samples shrunk were significantly different ($p = 0.004$) from one another. Observed changes in area was highest in the blanched samples ($55.2 \pm 5.66\%$) and lowest in the brine-treated ($38.1 \pm 3.33\%$) and control ($42.2 \pm 2.01\%$). Shrinkage was lesser in brine-treated samples because sodium and chloride ions re-associate as NaCl crystals inside cellular compartment (Al-Harashseh *et al.*, 2009), following soaking taking-up some space previously occupied by water. As a result, contraction of the viscoelastic matrix is reduced. The extent of decline in surface area for blanched samples is accounted for by the fact that blanching caused greater damage to cell structure, resulting in more moisture removal and increased contraction stresses in the material (Ahmed, 2011).

3.4 Rehydration

The extent to which products rehydrate following drying is dependent on structural and chemical that occur, and is significantly affected if cell disintegration is prominent (Rastogi *et al.*, 2000). A rapid absorption of water at the beginning of rehydration as a result of surface and capillary suction was observed for all treatments (Figure 3). This is similar to observation reported by Sagar and Kumar, 2010. Although the rehydration ratio of blanched treated samples was seemingly higher compared to the other samples, it tapered off after 210 min, while the untreated sample reabsorbed moisture steadily (Figure 3). Generally, rehydration ratios were in the following order: blanched treated > control > brine-treated. This observation could be due to extent of cellular and structural disruption caused by the heat treatment or immersion in brine

(Krokida and Marinos-Kouris, 2003). According to Jayaraman *et al.*, 1990 irreversible cellular rapture results in reduced hydrophilic properties which are reflected in the inability of tissues to rehydrate fully as observed in this study. Although, reconstituting dehydrated products is desirable, a highly porous structure may lead to high leaching of soluble solids which is detrimental to the products (Marabi *et al.*, 2004).

Osmotic treatment followed by air-drying has been reported by Taiwo *et al.*, 2005 to significantly reduce mass transfer co-efficient during rehydration, similar to observation made for brine-treated samples of this study. Brine-treated samples had the lowest uptake of water, compared to the other samples, over the rehydration period. This is similar to reduced rehydration behaviors for brine treated products reported by Debnath *et al.*, 2004.

4. CONCLUSION

The Modified Henderson Pabis model was found to best describe drying untreated chayote slices as control while blanched samples was best fitted to the Midilli *et al.* model. Dried chayote moisture content was brine treated > control > blanched treated. Hot water blanching aided effective moisture diffusivity, while osmo-dehydration in brine seemed to have impeded the movement of water out of the tissues and hence lowered the effective moisture diffusivity. Shrinkage in surface area of the slices was more pronounce when blanching was applied compared to the control and brine-treated samples, while rehydration was smallest in blanched slices as opposed to the control and osmo-dehydrated. The two pretreatments changed the structural integrity of the vegetable and consequently affected drying kinetics and quality parameters of the final product.

REFERENCES

- Abbiw, D.K. (1997). Traditional Vegetables in Ghana. In: Guarino, L. (ed) Traditional African Vegetables. Promoting the conservation and use of underutilized and neglected crops, 16. Proceedings of the IPGRI International Workshop on Genetic Resources of Traditional vegetables in Africa: Conservation and use. 29 – 31 August 1995, ICRAF – HQ, Nairobi, Kenya. ICGCPR, Gatersleben/IPGRI, Rome, Italy.
- Aguilera, J.M, Chiralt, A., Fito, P. (2003). Food dehydration and product structure. *Trends in Food Science and Technology*, 14, 432-437.
- Ahmed, J. (2011). Drying of vegetables: principles and dryer design. In: Sinha, N. K. (ed) Handbook of vegetable and vegetable processing. Wiley-Blackwell, Iowa, pp. 279 – 298.
- Akpınar, E.K., Bicer, Y., Yildiz, C. (2003). Thin layer drying of red pepper. *Journal of Food Engineering*, 59, 99 – 104.
- Al-Harashseh, M., Al-Muhtaseb, A.H., Magee, T. R. A. (2009). Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. *Chemical Engineering and Processing*, 48, 524 – 531.
- Alzamora, S. M., Nieto, A., Castro, M. A. (2003). Structural effects of blanching and osmotic dehydration pretreatments on air drying kinetics of fruit tissues. In: Welti-Chanes, J.,

- 273 Velez-Ruiz, J. and Barbosa-Canovas, G.V. (eds), Transport phenomena in food
274 processing. CRC press LLC, Boca Raton.
275
- 276 AOAC (1990). Official Methods of Analysis, 15th edition, AOAC International, Washington
277 DC.
278
- 279 Aversa, M., Curcio, S., Calabrò, V., Iorio, G. (2010). Experimental Evaluation of quality
280 parameters during drying of carrot samples. *Food and Bioprocess Technology*.
281 doi:10.1007/s11947-009-0280-1.
282
- 283 Daghbandan, A., Zadeh, G.H., Ahrimankosh, M., Mohammadi, M. (2006). Modeling of moisture
284 distribution in thin layer drying process. In, Proceedings of the 11th Chemical
285 Engineering Congress (ICHEC 11), Tehran, Iran.
286
- 287 Debnath, S., Hemavathy, J., Bhat, K.K., Rastogi, N.K. (2004). Rehydration characteristics of
288 osmotic pretreated and dried onion. *Food and Bioproducts Processing*, 82(C4), 304 –
289 310.
290
- 291 Demir, V., Gunhan, T., Yagcioglu, A.K. (2007). Mathematical modeling of convection drying of
292 green table olives. *Biosystems Engineering*, 98, 47 – 53.
293
- 294 Doymaz, I., Ismail, O. (2011). Drying characteristics of sweet cherry. *Food and Bioproducts*
295 *Processing*, 89, 31 – 38.

296

297 Doymaz, I. (2004). Effect of pre-treatments using potassium metabisulphite and alkaline ethyl
298 oleate on the drying kinetics of apricots. *Biosystems Engineering*, 89, 281 – 287.

299

300 Doymaz, I. (2012). Drying of potato slices: effect of pretreatments and mathematical modeling.
301 *Journal of Food Processing and Preservation*, 36, 310 – 319.

302

303 Doymaz, I., Gol, E. (2011). Convective drying characteristics of eggplant slices. *Journal of Food*
304 *Processing Engineering*, 34, 1234 – 1252.

305

306 Erbay, Z., Icier, F. (2009). A review of thin layer drying of foods: theory, modeling and
307 experimental results. *Critical Reviews in Food Science and Nutrition*, 50, 441 – 464.

308

309 Falade, K.O., Omojola, B.S. (2010). Effect of processing methods on physical, chemical,
310 rheological, and sensory properties of okra (*Abelmoschus esculentus*). *Food and*
311 *Bioprocess Technology*. doi:10.1007/s11947-008-0126-2.

312

313 Falade, K.O., Igbeka, J.C. (2007). Osmotic dehydration of tropical fruits and vegetables. *Food*
314 *Reviews International*, 23, 373 – 405.

315

316 Fernandes, F.A.N., Oliveira, F.I.P., Rodrigues, S. (2008). Use of ultrasound for dehydration of
317 papayas. *Food and Bioprocess Technology*, 1, 339–345.

318

319 Fernandes, F.A.N., Rodrigues, S., Gaspareto, O.C.P. & Oliveira, E.L. (2006). Optimization of
320 osmotic dehydration of papaya followed by air-drying. *Food Research International*, 39,
321 492-498.

322
323 Fernandes, F.A.N., Rodrigues, S., Law, C.L. & Mujumdar, A.S. (2010). Drying of exotic tropical
324 fruits: a comprehensive review. *Food Bioprocess Technology*, doi: 10.1007/s11947-010-
325 0323-7.

326
327 Gonzalez-Martinez, C., Chafer, M., Xue, K. Chiralt, A. (2006). Effect of the osmotic pre-
328 treatment on the convective air drying kinetics of pear var Blanquilla. *International*
329 *Journal of Food Properties*, 9, 541 – 549.

330
331 Goyal, R.K., Kingsly, A.R.P., Manikanthan, M.R., Ilyas, S.M. (2007). Mathematical drying of
332 thin layer drying kinetics of plum in a tunnel dryer. *Journal of Food Engineering*, 79, 176
333 – 180.

334
335 Grabowski, S., Marcotte, M., Poirier, M., Kudra, T. (2002). Drying characteristics of osmotically
336 pretreated cranberries, energy and quality aspects. *Drying Technology*, 20, 1989-2004.

337
338 Gunham, T., Demir, V., Hancioglu, E., Hepbasli, A. (2005). Mathematical modeling of drying of
339 bay leaves. *Energy Conversion and Management*, 46, 1667 – 1679.

340

- 341 Henderson, S. M., Pabis, S. (1961). Grain drying theory I: Temperature effect on drying
342 coefficient. *Journal of Agricultural Engineering Research*, 6, 169 – 174.
343
- 344 Jayaraman, K. S., Das Gupta, D.K. (2006). Drying fruits and vegetables. In: A.S. Mujumdar (ed),
345 Handbook of Industrial Drying. Taylor and Francis Group LLC,
346
- 347 Jayaraman, K.S., Dasgupta, D.K., Babu Rao, N. (1990). Effects of pre-treatment with salt and
348 sucrose on the quality and stability of dehydrated cauliflower. *International Journal of*
349 *Food Science and Technology*, 25, 47 – 51.
350
- 351 Karathanos, V.T. (1999). Determination of water content of dried fruits by drying kinetics.
352 *Journal of Food Engineering*, 39, 337 – 344.
353
- 354 Kingsley, R.P., Goyal, R.K., Manikantan, M.R., Ilyas, S.M. (2007). Effect of pretreatment and
355 drying air temperature on drying behavior of peach slices. *International Journal of Food*
356 *Science and Technology*, 42, 65 – 69.
357
- 358 Krokida, M.K., Marinos-Kouris, D. (2003). Rehydration kinetics of dehydrated products,
359 *Journal of Food Engineering*, 57, 1 – 7.
360
- 361 Madamba, P.S. (2003). Thin layer drying models for osmotically pre-dried young coconut.
362 *Drying Technology*, 21, 1759 – 1780.
363

- 364 Marabi, A., Dilak, C., Shah, J., Saguy, I.S. (2004). Kinetics of solids leaching during rehydration
365 of particulate dry vegetables. *Journal of Food Science*, 69, 91-96.
366
- 367 Marinos-Kouris, D., Maroulis, Z.B. (2006). Transport properties in the drying of solids. In:
368 Mujumdar, A.S. (ed) Handbook of Industrial drying, 3rd edition. Taylor and Francis
369 group LLC.
370
- 371 Mayor, L., Moreira, R., Chenlo, F., Sereno, A.M. (2006). Kinetics of osmotic dehydration of
372 pumpkin with sodium chloride solutions. *Journal of Food Engineering*, 74, 253 – 262.
373
- 374 Mayor, L., Sereno, A.M. (2004). Modelling shrinkage during convective drying of food material:
375 A review. *Journal of Food Engineering*, 61, 373 – 386.
376
- 377 McMinn, W.A.M., Magee, T.R.A. (1997). Physical characteristics of dehydrated potatoes – Part
378 II. *Journal of Food Engineering*, 33, 49 – 55.
379
- 380 Midilli, A., Kucuk, H., Yapar, Z. (2002). A new model for single-layer drying. *Drying*
381 *Technology*, 20, 1503 – 1513.
382
- 383 Moreno-Perez, L.F., Gasson-Lara, J.H., Ortega-Rivas, E. (1996). Effect of low temperature-long
384 time blanching on quality of dried sweet potato. *Drying Technology*, 14, 1834 – 1857.
385

- 386 Mujumdar, A.S., Law, C.L. (2010). Drying technology: trends and application in postharvest
387 processing. *Food Bioprocess Technology*, 3, 843 – 852.
- 388
- 389 Okos, M.R., Campanella, O, Narsimhan, G., Singh, R.K. & Weitnauer, A.C. (2007). Food
390 dehydration. In: Heldman, D.R. and Lund, D.B. (eds). Handbook of Food Engineering,
391 2nd Edition. CRC Press, Boca Raton. pp. 601 – 744.
- 392
- 393 Ordonez, A.A.L., Gomez, J.D., Vattuone, M.A. Isla, M.I. (2006). Antioxidant activities of
394 sechium edule (Jacq.) Swartz extracts. *Food Chemistry*, 97, 452 – 458.
- 395
- 396 Pan, Y.K., Zhao, L.J., Zhang, Y., Chen, G., Mujumdar, A.S. (2003). Osmotic dehydration
397 pretreatment in drying of fruits and vegetables. *Drying Technology*, 20, 1989 – 2004.
- 398
- 399 Perez, N.E., Schmalko, M.E. (2009). Convective drying of pumpkin: influence of pretreatment
400 and drying temperature. *Journal of Food Process Engineering*, 32, 88 – 103
- 401
- 402 Rastogi, N.K., Angersbach, A., Niranjana, K., Knorr, D. (2000). Rehydration kinetics of high-
403 pressure pre-treated and osmotically dehydrated pineapple. *Journal of Food Science*, 65,
404 838-841.
- 405
- 406 Ruiz-Lopez, I.I., Huerta-Mora, I.R., Vivar-Vera, M.A., Maartinez-Sanchez, C.E., Herman-Lara,
407 E. (2010). Effect of osmotic dehydration on air-drying characteristics of chayote. *Drying*
408 *Technology*, 28, 1201 – 1212.

409

410 Sablani, S.S. (2006). Drying fruits and vegetables: retention of nutritional/functional quality.

411 *Drying Technology*, 24, 123 – 135.

412

413 Sagar, V.R., Kumar, S.R. (2010). Recent advances in drying and dehydration of fruits and

414 vegetables: a review. *Journal of Food Science and Technology*, 47, 15 – 26.

415

416 Senadeera, W., Bhandari, B., Young, G., Wijesinghe, B. (2000). Physical property changes of

417 fruits and vegetables during hot air drying. In: Mujumdar, A. S. (ed) Drying technology

418 in agriculture and food sciences, Enfield Science Publishers, pp. 159 – 161.

419

420 Sobukola, O. (2009). Effect of pre-treatment on the drying characteristics and kinetics of Okra

421 (*Abelmoschus esculenta* (L. Moench)) slices. *International Journal of Food Engineering*.

422 doi: 10.2202/1556-3758.1191

423

424 Sunjka, P.S., Raghavan, G.S.V. (2004). Assessment of pre-treatment methods and osmotic

425 dehydration for cranberries. *Canadian Biosystems Engineering*, 46, 335 – 340.

426

427 Taiwo, K.A., Angersbach, A., Knorr, D. (2002). Influences of high electric field pulses and

428 osmotic dehydration on the rehydration characteristics of apple slices at different

429 temperatures. *Journal of Food Engineering*, 52, 185 – 192.

430

- 431 Togrul, I.T., Pehlivan, D. (2004). Modelling of thin layer drying kinetics of some fruits under
432 open-air sun drying process. *Journal of Food Engineering*, 65, 413 – 425.
433
- 434 Tortoe, C., Orchard, J., Beezer, A. (2007). Osmotic dehydration kinetics of apple, banana and
435 potato. *International Journal of Food Science and Technology*, 42, 312 – 318.
436
- 437 Tunde-Akintunde, T.Y. (2010). Effect of pretreatment on drying time and quality of chilli
438 pepper. *Journal of Food Processing and Preservation*, 34, 595 – 608.
439
- 440 Verma, L.R., Bucklin, R.A., Ednan, J.B, Wratten, F.T. (1985). Effects of drying air parameters
441 on rice drying models. *Transactions of the ASAE*, 28, 296 – 301.
442
- 443 Wang, W., Sastry, S.K. (2000). Effects of Thermal and Electro-thermal pre-treatments on Hot air
444 drying rate of vegetable tissue. *Journal of Food Engineering*, 23, 299 – 319.
445
- 446 Wang, Z., J. Sun, F. Chen, X. Liao, L., Hu, X. (2007). Mathematical modeling on thin layer
447 microwave drying of apple pumice with and without hot-air pre drying. *Journal of Food*
448 *Engineering*, 80, 536–544.
- 449 Yaldiz, O., Ertekin, C. (2001). Thin layer solar drying of some vegetables. *Drying Technology*,
450 19, 583 – 597.
451

452 Yan, Z., Sousa-Gallagher, J.M., Oliveira, A.R.F. (2007). Shrinkage and porosity of banana,
 453 pineapple and mango slices during air-drying. *Journal of Food Engineering*, 83, 430 –
 454 440.

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457 **Nomenclature**

458

$a, b, c,$ Drying coefficient

g, k_o, k, k_1, n Drying constants

MC Moisture content

MR Moisture ratio

K Slope

L Half thickness of slices

459

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461 **Table 1. Selected Thin Layer Drying Models**

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Model name	Model	Reference
Lewis	$MR = \exp(-kt)$	Wang <i>et al.</i> , 2007
Page	$MR = \exp(-kt^n)$	Madamba (2003)
Parabolic	$MR = a+bt+ct^2$	Daghighbandan <i>et al.</i> (2006)
Henderson & Pabis	$MR = a \exp(-kt)$	Henderson & Pabis (1961)
Mod. Henderson & Pabis	$MR = a \exp(-kt) + b \exp(-gt) + c \exp(-ht)$	Karathanos (1999)
Logarithmic	$MR = a \exp(-kt) + c$	Kingsley <i>et al</i> (2007)
Two term	$MR = a \exp(-k_0t) + b \exp(-k_1t)$	Yaldiz & Ertekin (2001)
Diffusion model	$MR = a \exp(-kt) + (1 - a) \exp(-kbt)$	Demir <i>et al.</i> (2007)
Verma <i>et al.</i>	$MR = a \exp(-kt) + (1 - a) \exp(-gt)$	Verma <i>et al.</i> (1985)
Midilli <i>et al.</i>	$MR = a \exp(-kt^n) + bt$	Midilli <i>et al.</i> (2002)

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466 **Table 2. Models and selection criteria for best fit for control**

467

Model	R^2	X^2	$RMSE$
Lewis	0.9882	0.00304	0.05317
Page	0.9877	0.00124	0.03256
Parabolic	0.9866	0.00118	0.03177
Henderson and Pabis	0.9980	0.00020	0.01315
<i>Mod. Henderson and Pabis</i>	<i>0.9993</i>	<i>0.00006</i>	<i>0.00730</i>
Logarithmic	0.9990	0.00008	0.00864
Two term	0.9980	0.00020	0.01315
Diffusion model	0.9982	0.00020	0.01324
Verma <i>et al.</i>	0.9795	0.00272	0.04828
Midilli <i>et al.</i>	0.9737	0.00237	0.04505

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470 **Table 3. Models and selection criteria for best fit for brine-treated samples**

471

Model	R^2	X^2	$RMSE$
Lewis	0.9822	0.00354	0.05510
Page	0.9838	0.00162	0.03722
Parabolic	0.9906	0.00082	0.02648
Henderson and Pabis	0.9944	0.00057	0.02206
<i>Mod. Henderson and Pabis</i>	<i>0.9991</i>	<i>0.00008</i>	<i>0.00852</i>
Logarithmic	0.9968	0.00028	0.01543
Two term	0.9943	0.00057	0.02202
Diffusion model	0.9944	0.00056	0.02194
Verma <i>et al.</i>	0.9943	0.00057	0.02202
Midilli <i>et al.</i>	0.9649	0.00305	0.05115

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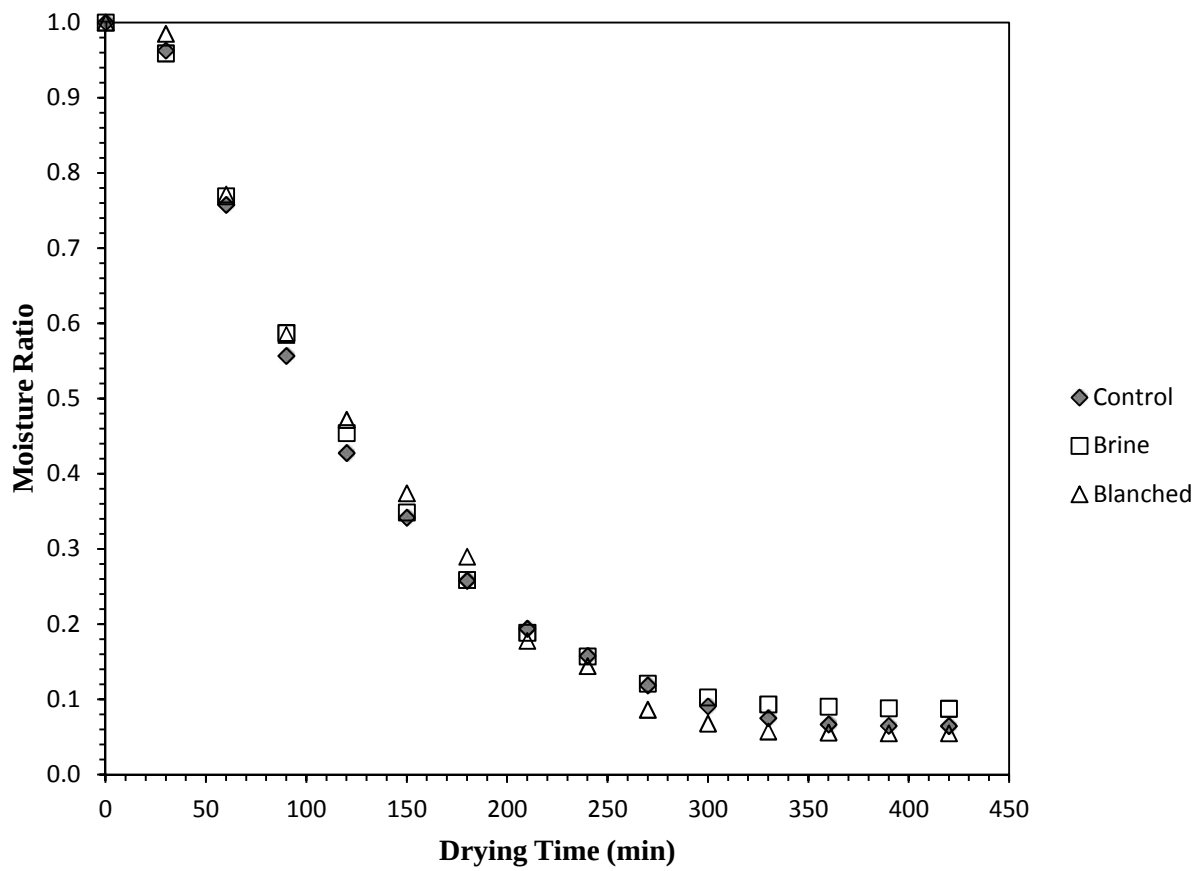
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Table 4. Models and selection criteria for best fit for blanched treated samples

Model	R^2	X^2	$RMSE$
Lewis	0.9899	0.00517	0.06666
Page	0.9908	0.00103	0.02974
Parabolic	0.9940	0.00059	0.02254
Henderson and Pabis	0.9954	0.00046	0.01977
Mod. Henderson and Pabis	0.9957	0.00042	0.01907
Logarithmic	0.9955	0.00044	0.01945
Two term	0.9954	0.00046	0.01977
Diffusion model	0.9740	0.00380	0.05705
Verma <i>et al.</i>	0.9760	0.00353	0.05501
<i>Midilli et al.</i>	<i>0.9970</i>	<i>0.00030</i>	<i>0.01607</i>

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Figure 1: Moisture ratio variation of samples over the period of drying

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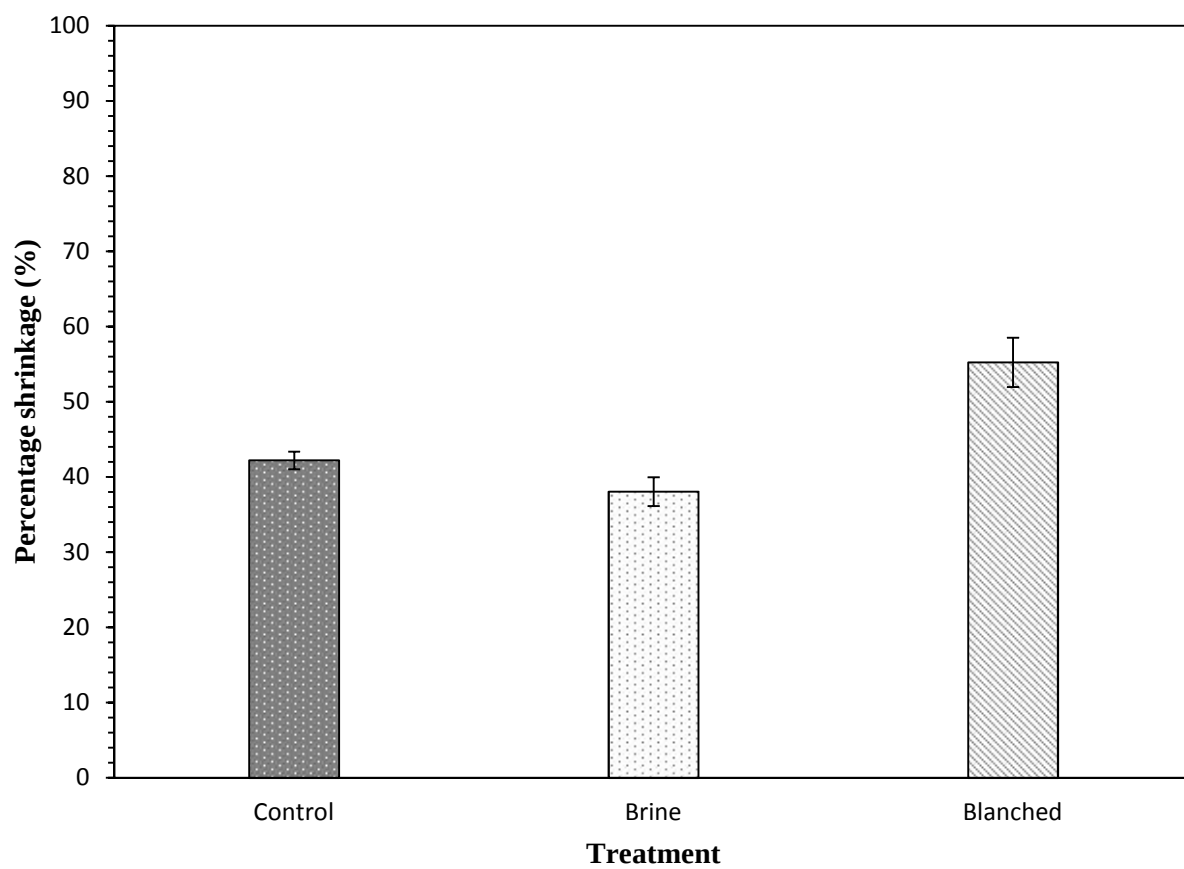
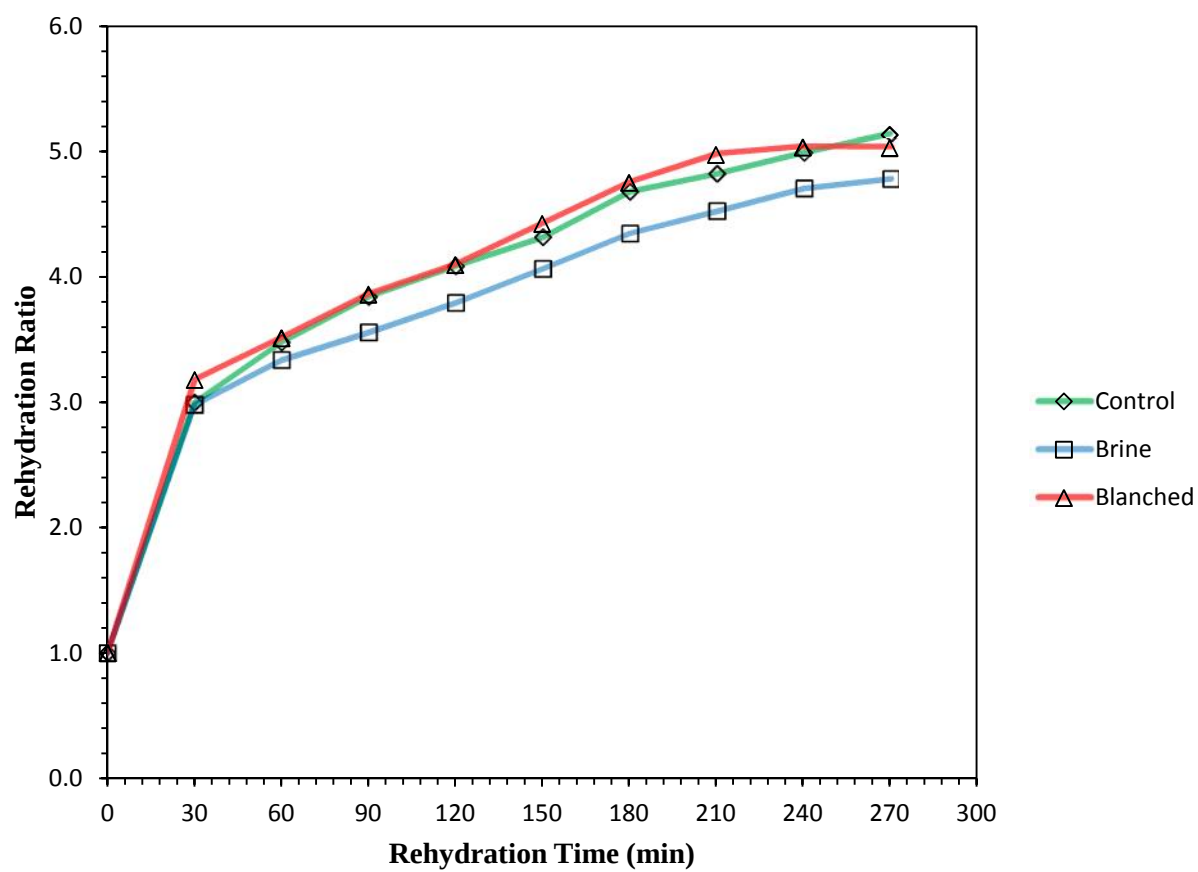


Figure 2. Percentage area shrinkage of dried samples

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492 Figure 3. Variation in rehydration ratios over time of rehydration at room temperature (28.4 °C)

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