British Journal of Applied Science & Technology
4(8): 1215-1229, 2014

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

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Authors' contributions

This work was carried out in collaboration between all authors. Authors PTA and CT designed the study, performed the laboratory analysis, and wrote the first draft of the manuscript. Author PTA performed the statistical analysis. Author CT supervised the study. All authors read and approved the final manuscript.

Original Research Article

Received 20th April 2013
Accepted 14th July 2013
Published 15th January 2014

ABSTRACT

Aims: The influence of brine pretreatment and blanching on drying kinetics, area shrinkage and rehydration of oven-dried chayote slices was investigated.
Study Design: Completely Randomized Block Design.
Place and Duration of Study: Food Processing and Engineering Division of the Food Research Institute between January 2012 and February 2013.
Methodology: Chayote slices (4±1 mm thick) were blanched in hot water at 80ºC or osmo-dehydrated in 10% brine for 3 min, or left untreated as control and subsequently dried at 65ºC. 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.
Results: 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 x 10^{-8} m^2s^{-1} and 1.30 x $10^{-8} m^2s^{-1}$, rehydration ratios over a period of 270 min decreased from blanched > control > brine-treated while shrinkage was highest in

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blanched samples and lowest in brine-treated samples.
Conclusion: 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 [1]. 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 [2]. 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 [3]. 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 [4-9].

Blanching and osmotic dehydration are two common pre-treatments applied to food produce prior to drying [10-12]. 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 [10,13]. 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 [14,15] and reduces total processing time [16]. This method has been employed extensively during fruits and vegetable processing [15,17-19]. 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 [20].

Subsequent physical changes that occur due to drying alter the texture and transport properties of the final dried product [21]. 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.

2. MATERIAL AND METHODS

2.1 Vegetable Samples

Chayote (Fig. 1) was purchased from a local market at Aburi in the Eastern Region of Ghana. The vegetables were sorted, cleaned and washed before slicing manually into a thickness of 4±1 mm using stainless-steel blade knife. The initial moisture content of the vegetable, determined in triplicate by standard method [22] was 94.2±0.12% (w.b). The samples were split into three batches; two of them were pretreated (blanching and osmotic dehydration) before drying, while no treatment was applied to the third batch, which served as control.

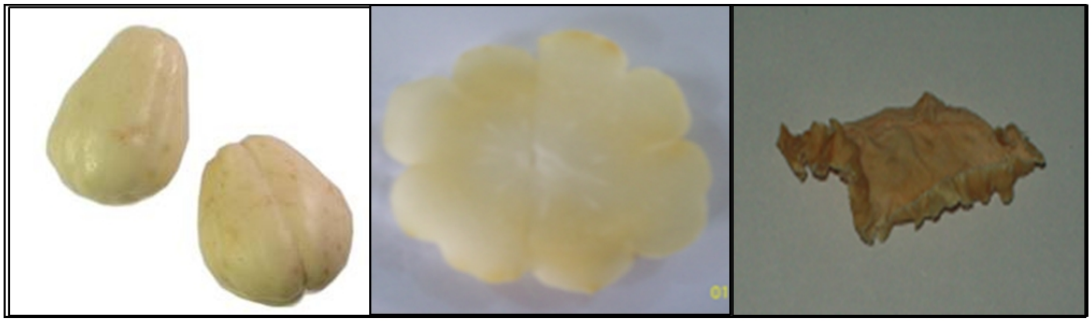

Fig. 1. Fresh, sliced and dried chayote

2.2 Pretreatments

Blanching was accomplished by placing vegetable slices in stainless steel sieve and immersing them in hot water (distilled water) at 80 °C. After 3 min, the sieve with its content was removed and cooled to room temperature and excess water was blotted with tissue paper before drying.

Osmotic dehydration was done by immersing the vegetable slices in sodium chloride (NaCl) solution (10% w/v) at room temperature (28°C) for 3 min. The samples were drained of excess water and blotted with tissue paper before drying. Salt was chosen as the osmotic dehydration agent on the basis of the intended end use of the product and the fact that it is known to provide high osmotic pressure [23].

2.3 Drying of Samples

Drying of the chayote slices (pre-treated and control) 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 30min interval until the weight was constant. Final moisture content of the dried samples was also determined in triplicate [22].

2.4 Model Fitting and Data Analysis

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

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

However, M_e compared with M_o and M_t is very small and could be neglected and the MR simplified [24,25] and expressed as:

$$MR = \frac{M_t}{M_0} \tag{2}$$

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 (χ^2) and the Root Mean Square Error (RMSE) were used to determine the goodness of fit between predicted and experimental data. A higher value of R^2 and lower values of χ^2 and RMSE corresponds to a better goodness of fit [26-28]. The χ^2 and RMSE were calculated from the following formulae:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - Z} \tag{3}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2\right]^{1/2} \tag{4}$$

Table 1. Selected Thin Layer Drying Models for fitting drying data for Chayote slices

Model name	Model	Reference
Lewis	$MR = \exp(-kt)$	Wang et al., [29]
Page	$MR = \exp(-kt^n)$	Madamba [30]
Parabolic	$MR = a+bt+ct^2$	Daghbandan et al. [31]
Henderson & Pabis	$MR = a\exp(-kt)$	Henderson & Pabis [32]
Mod. Henderson & Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Karathanos [33]
Logarithmic	$MR = a\exp(-kt) + c$	Kingsley et al. [34]
Two term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	Yaldiz & Ertekin [35]
Diffusion model	$MR = a\exp(-kt) + (1 - a)\exp(-kbt)$	Demir et al. [36]
Verma *et al.*	$MR = a\exp(-kt) + (1 - a)\exp(-gt)$	Verma et al. [37]
Midilli *et al.*	$MR = a\exp(-kt^n) + bt$	Midilli et al. [38]

2.5 Effective Diffusivity

Generally, diffusion is assumed as the dominant transport mechanism during drying and the rate of moisture movement is therefore described by an effective diffusivity value, D_{eff}, which is related to MR by equation 6 [29].

$$lnMR = ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4L^2} \tag{5}$$

The effective moisture diffusivity was obtained by plotting the experimental drying data in terms of lnMR against time, t (min). From equation 6, a plot of lnMR against drying time, t, gives a straight line with slope, K, where

$$K = \frac{\pi^2 D_{eff}}{4L^2} \tag{6}$$

2.6 Shrinkage

Area shrinkage of dried samples was estimated using image analysis software ImageJ 1.46r (National Institutes of Health, USA) before and after drying. Images of fresh, pretreated and dried samples were captured with a digital camera (Fujifilm Fine Pix Z900EXR) and transferred onto a computer to be processed with Image J 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;

$$\% Shrinka = \frac{A_0 - A_d}{A_0} x\ 100 \tag{7}$$

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 °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 [39]. The test was carried out over a period of 5 hours and the rehydration ratio calculated with the relation:

$$Rehydration\ Ratio = \frac{Mass\ of\ rehydrated\ sample}{Mass\ of\ dried\ sample} \tag{8}$$

3. RESULTS AND DISCUSSION

3.1 Moisture Content

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 (Fig. 2).

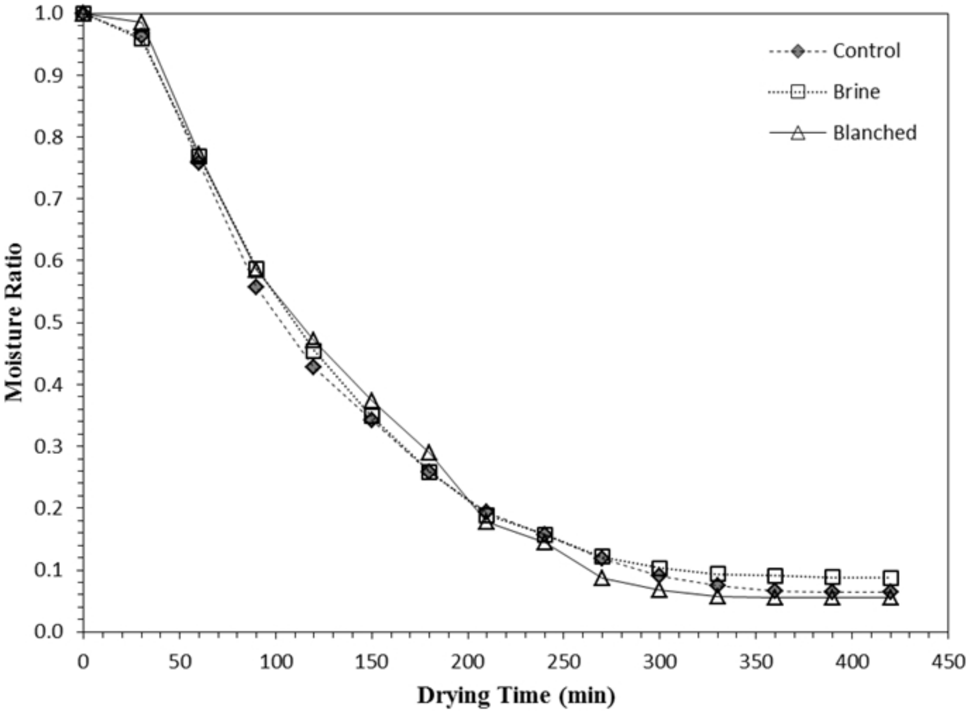

Fig. 2. Moisture ratio variation of pretreated and dried Chayote slices over the period of drying

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 [40]. Similar effect on drying of blanching compared to untreated food products have been reported for chilli pepper [41], eggplant slices [42] and pumpkin [43].

3.2 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). Fitted curves for best fitting models are also shown in Figs. 3 to 5. 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 [44] resulted in the highest R^2 and lowest χ^2 and *RMSE*. The R^2, χ^2 and *RMSE* for control, brine treated and blanched treated samples were 0.9993, 6.0x10^{-5}, 7.3x10^{-3}; 0.9991, 8.0x10^{-5}, 8.5x10^{-3}; 0.997, 3.0x10^{-4}, 1.6x10^{-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 [45,46]

Table 2. Drying models and selection criteria for best fit for "control" Chayote slices

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
Mod. Henderson and Pabis	*0.9993*	*0.00006*	*0.00730*
Logarithmic	0.9990	0.00008	0.00864
Two term	0.9980	0.00020	0.01315
Diffusion model	0.9982	0.00020	0.01324
Verma *et al*.	0.9795	0.00272	0.04828
Midilli *et al*.	0.9737	0.00237	0.04505

Table 3. Drying models and selection criteria for best fit for "brine-treated" Chayote slices

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
Mod. Henderson and Pabis	*0.9991*	*0.00008*	*0.00852*
Logarithmic	0.9968	0.00028	0.01543
Two term	0.9943	0.00057	0.02202
Diffusion model	0.9944	0.00056	0.02194
Verma *et al*.	0.9943	0.00057	0.02202
Midilli *et al*.	0.9649	0.00305	0.05115

Table 4. Drying models and selection criteria for best fit for "blanched" Chayote slices

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 et al.	0.9760	0.00353	0.05501
Midilli et al.	*0.9970*	*0.00030*	*0.01607*

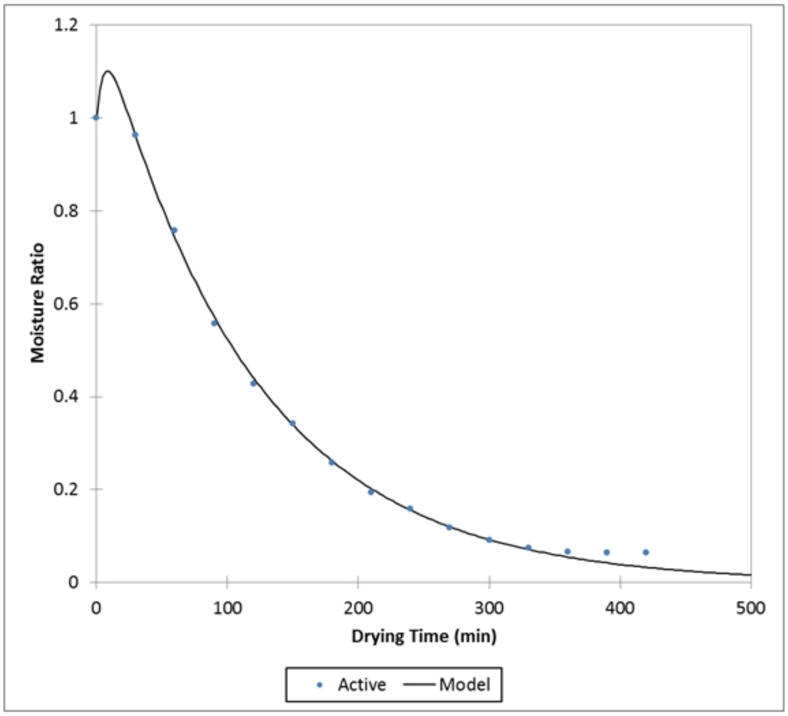

Fig. 3. Model Fit for “control” chayote slices, using modified Henderson and Pabis model

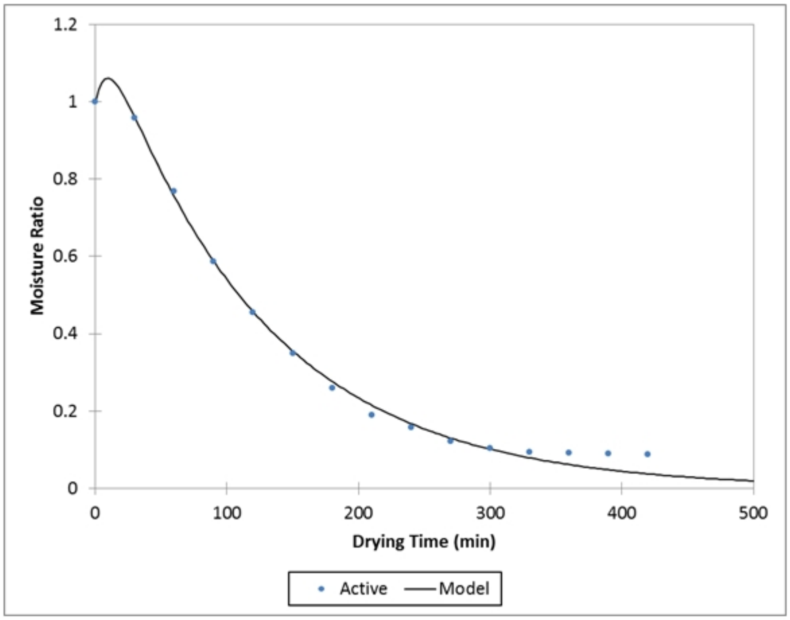

Fig. 4. Model Fit for brine-treated chayote slices, using modified Henderson and Pabis model

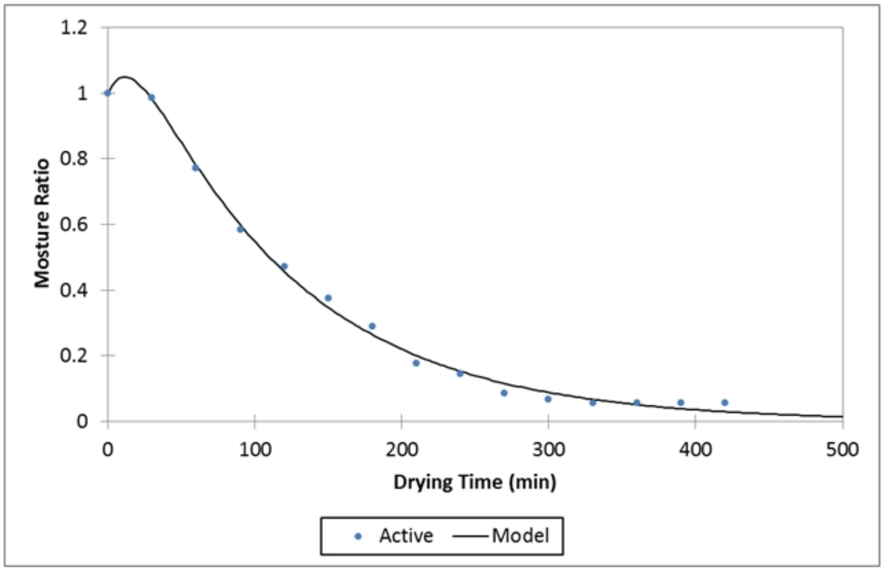

Fig. 5. Model Fit for blanched chayote slices, using modified Midilli et al. model

3.3 Diffusivity

The moisture diffusivities for control, brine treated and blanched treated were 1.22 x 10^{-8} m^2s^{-1}, 1.09 x 10^{-8} m^2s^{-1} and 1.30 x $10^{-8}m^2s^{-1}$, 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 [47], 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 [20] 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., [48]. Generally, the effective moisture diffusivity values obtained are comparable to the range (10^{-13} to 10^{-6}) for drying food materials [49,50].

3.4 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 [51]. In vegetables, shrinkage increases with the amount of water removed [52] 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% (Fig. 6). 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 ± 5.66%) and lowest in the brine-treated (38.1 ± 3.33%) and control (42.2 ± 2.01%). Shrinkage was lesser in brine-treated samples because sodium and chloride ions re-associate as NaCl crystals inside cellular compartment [53], 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 [52].

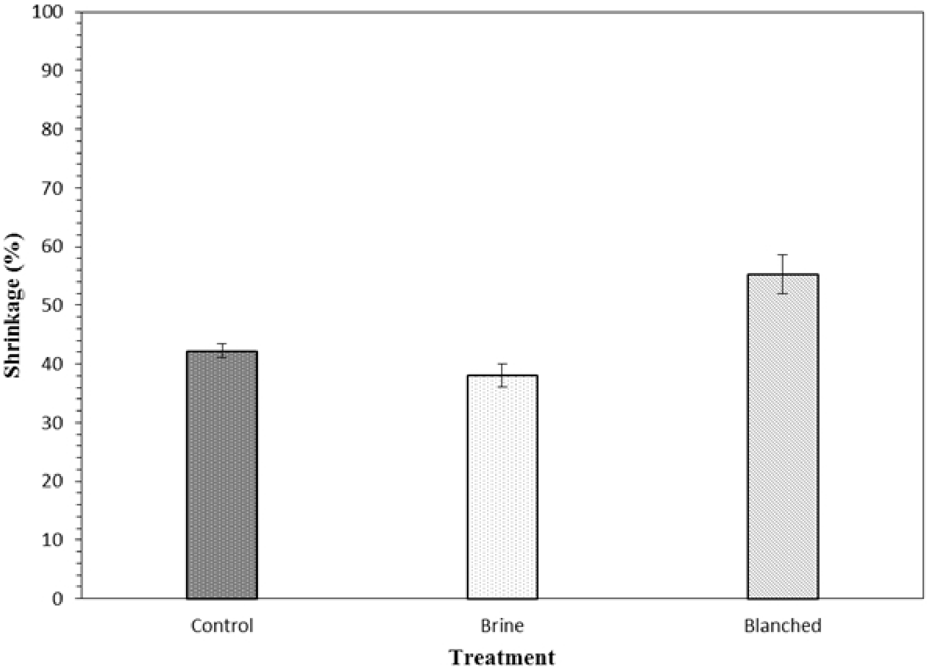

Fig. 6. Area shrinkage of pretreated and dried Chayote slices at 65 ºC

3.5 Rehydration

The extent of products rehydrate following drying is dependent on structural and chemical that occurs within the products. This is significantly affected if cell disintegration is prominent [54]. A rapid absorption of water at the beginning of rehydration as a result of surface and capillary suction was observed for all treatments (Fig. 7). This is similar to observation reported by Sagar and Kumar, [55]. 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 (Fig.7). 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 [56]. According to Jayaraman et al., [57] 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 [58].

Osmotic treatment followed by air-drying has been reported by Taiwo et al., [59] 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., [60].

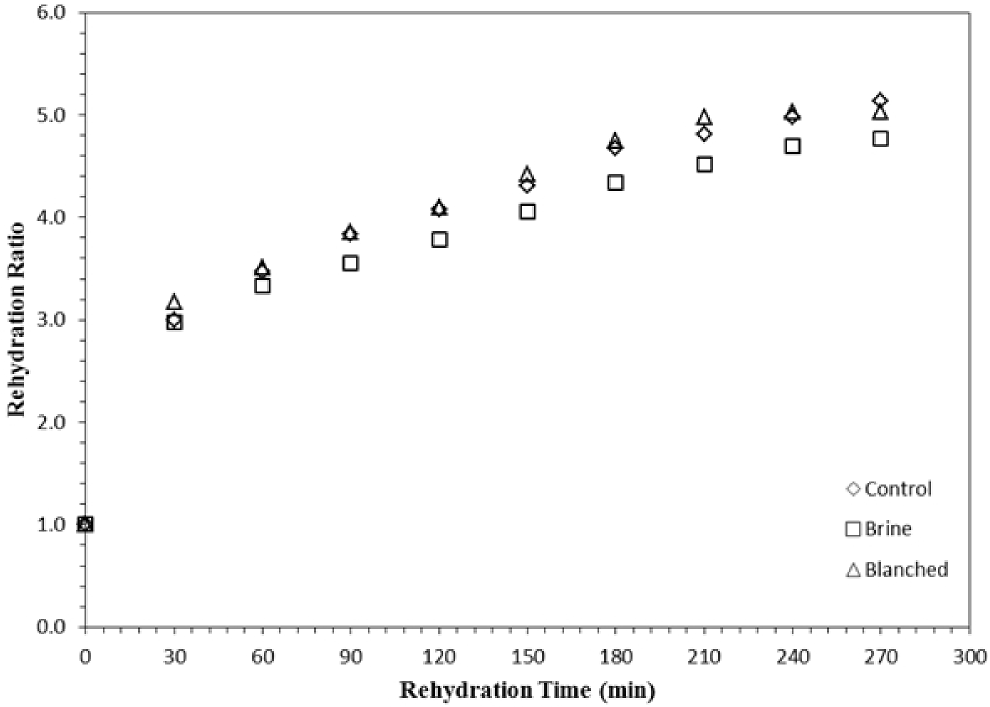

Fig. 7. Variation in rehydration ratios of pretreated and dried Chayote slices over time of rehydration at room temperature

4. CONCLUSION

The Modified Henderson and 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 osmo-dehydrated slices as opposed to the control and blanched. The two pretreatments changed the structural integrity of the vegetable and consequently affected drying kinetics and quality parameters of the final product.

COMPETING INTERESTS

The authors have declared that no competing interests exist.

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NOMENCLATURE

Symbol	Parameter	Unit
$a,b,c,$	Drying coefficient	
g,k_o,k,k_1,n	Drying constants	min^{-1}
MC	Moisture content	kg water/kg dry matter
MR	Moisture ratio	
K	Slope	
L	Half thickness of slices	m
t	Drying time	min
M_t	Moisture content after time t	kg water/kg dry matter
M_o	Initial moisture content	kg water/kg dry matter
M_e	Equilibrium moisture content	kg water/kg dry matter
N	Number of observations	
z	Number of constants in the model	
MR_{exp}	Experimental moisture ratio	
MR_{pre}	Predicted moisture ratio	
D_{eff}	Effective diffusivity	m^2/s
A_o	Area of sample before drying	m^2
A_d	Area of sample after drying	m^2

Peer-review history:
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