

April 29.

17th May.

Research paper

Effect of Blanching and Osmotic Pre-treatment on ^{Convective} 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. ^{The} 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

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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.

68

69 2. MATERIALS AND METHODS

70

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~~^{being} manually ~~into a~~^{sliced}
 74 thickness of 4 ± 1 mm using stainless-steel blade, ~~knife~~^q. 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

gravity drained for how long?
Did the blotting with tissue paper apply to both blanched and osmotic dehydrated samples?

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90 Samples drying was conducted in a convective hot air dryer (Gallenkamp, England) at 65 °C air
91 drying temperature. The drying system was preheated to attain steady conditions (65 ± 1 °C)
92 before samples were loaded. Samples (in triplicate) weighing 50 ± 1g were thinly spread in trays
93 and loaded into the dryer. Changes in weight of samples (in triplicate) were measured with an
94 electronic balance with an accuracy of ± 0.001 (Kern 510, Kern & Sohn, GmbH, Germany) at 30
95 min interval until constant ^{was achieved.} weight ~~loss~~. Final moisture content of the dried samples were also
96 determined (AOAC, 1996).

97

98 2.4 Model fitting and data analysis

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

$$101 \quad MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

102 where MR is the moisture ratio, M_t , M_0 and M_e are moisture content after time t (kg water/kg dry
103 matter), initial moisture content and equilibrium moisture content respectively. However, M_e
104 compared with M_0 and M_t is very small and could be neglected and the MR simplified (Doymaz,
105 2004; Goyal *et al.*, 2007) and expressed as:

$$106 \quad MR = \frac{M_t}{M_0}$$

*You actually measured the M_e .
So why neglect it now? (2)*

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

110 The coefficient of determination (R^2) was the primary criterion for selecting the best model to
111 describe the drying curve. Also, the reduced chi square (χ^2) and the Root Mean Square Error
112 (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 (Akpinar *et al.*, 2003; Gunham *et al.*, 2005; Sobukola, 2009). The X^2 and RMSE were calculated
 115 from the following formulae *equation 3 and 5*

$$116 \quad X^2 = \frac{\sum_{i=1}^N (MR_{exp,i} - MR_{pre,i})^2}{N - z} \quad (3) \quad \text{where is equation 4?}$$

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

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).

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

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 *units?*

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

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

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Did you measure the area before and after drying?

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

$$139 \quad \% \text{ Shrinkage} = \frac{A_0 - A_d}{A_0} \times 100 \quad (8)$$

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

141

142 2.7 Rehydration ratio

143 Samples for rehydration test were obtained after the period of drying. Five grams of dried
144 samples were rehydrated in distilled water (sample:water of 1:40) at room temperature (28.4 °C)
145 in glass beakers by soaking samples in them. Samples were removed at 30 min interval, adhering
146 water carefully blotted with tissue paper, weighed with an electronic balance (Kern 510, Kern &
147 Sohn, GmbH, Germany) and immediately returned to the same soaking water (Doymaz and
148 Ismail, 2011). The test was carried out over a period of 5 hours and the rehydration ratio
149 calculated with the relation: using Eq. 9.

Mass
volume
What?

$$150 \quad \text{Rehydration Ratio} = \frac{\text{Mass of rehydrated sample}}{\text{Mass of dried sample}} \quad (9)$$

151

152 3. RESULTS AND DISCUSSION

153

Equilibrium?

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

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

170

171 3.1 Non-linear regression modeling

172 Although modified Henderson and Pabis, Midilli *et al.* and Logarithmic models adequately
 ✕ 173 described the experimental data ~~generally~~, modified Henderson and Pabis was the best model for
 174 describing the kinetics of drying in the control and brine treated samples while Midilli *et al.* best
 175 fitted the drying data of blanched samples (Tables 2, 3 and 4). Compared to the various models,
 176 modified Henderson and Pabis as well as Midilli *et al.* which are semi-theoretical models derived
 177 from the Ficks 2nd law of diffusion and quite commonly based on the Henderson and Pabis
 178 model (Erbay and Icier, 2009) resulted in the highest R^2 and lowest X^2 and $RMSE$. The R^2 , X^2 and
 179 $RMSE$ for control, brine treated and blanched treated samples were 0.9993, 6.0×10^{-5} , 7.3×10^{-3} ;
 180 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

Needs restructuring.

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

185

186 3.2 Diffusivity

187 The moisture diffusivities for control, brine treated and blanched treated ^{products} were $1.22 \times 10^{-8} \text{ m}^2\text{s}^{-1}$,
188 $1.09 \times 10^{-8} \text{ m}^2\text{s}^{-1}$ and $1.30 \times 10^{-8} \text{ m}^2\text{s}^{-1}$, respectively. Pre-treatment altered the integrity of the
189 internal structure, thereby causing an enhancement as seen for blanched treated or a restriction in
190 internal mass transfer of moisture as in the case of brine treated samples. Once blanched, cell
191 membranes and cell walls lose their ability to resist water flux (Falade and Igbeka, 2007),
192 making moisture diffuse easily and faster out of the tissues. Although some structural changes
193 occur as well during osmotic dehydration, solutes taken up from the osmotic solution, to a
194 significant, extent impede the movement of water out of plant tissues (Wang and Sastry, 2000)
195 resulting in lower effective moisture diffusivity. A similar trend of lowering effective diffusivity
196 between control and brine-treated chayote was observed by Ruiz-Lopez *et al.*, (2010). Generally,
197 the effective moisture diffusivity values obtained are comparable to the range (10^{-13} to 10^{-6}) for
198 drying food materials (Okos *et al.*, 2007, Marinos-Kouris and Maroulis, 2006).

199

200 3.3 Shrinkage

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

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

You did not actually discuss
 Figure 1. You only discussed the
 EMC.

217 3.4 Rehydration

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

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

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

2002? As an
hist

4. CONCLUSION

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

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456

457 Nomenclature

458

a, b, c , Drying coefficient

g, k_o, k, k_l, n Drying constants

MC Moisture content

MR Moisture ratio

K Slope

L Half thickness of slices, units? Is this the Thickness of fresh
slices or dry slices?

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

462

Model name	Model	Reference
Lewis	$MR = \exp (-kt)$	Wang <i>et al.</i> , 2007
Page	$MR = \exp (-kt^n)$	Madamba (2003)
Parabolic	$MR = a+bt+ct^2$	Daghbandan <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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469

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

476

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>	0.9970	0.00030	0.01607

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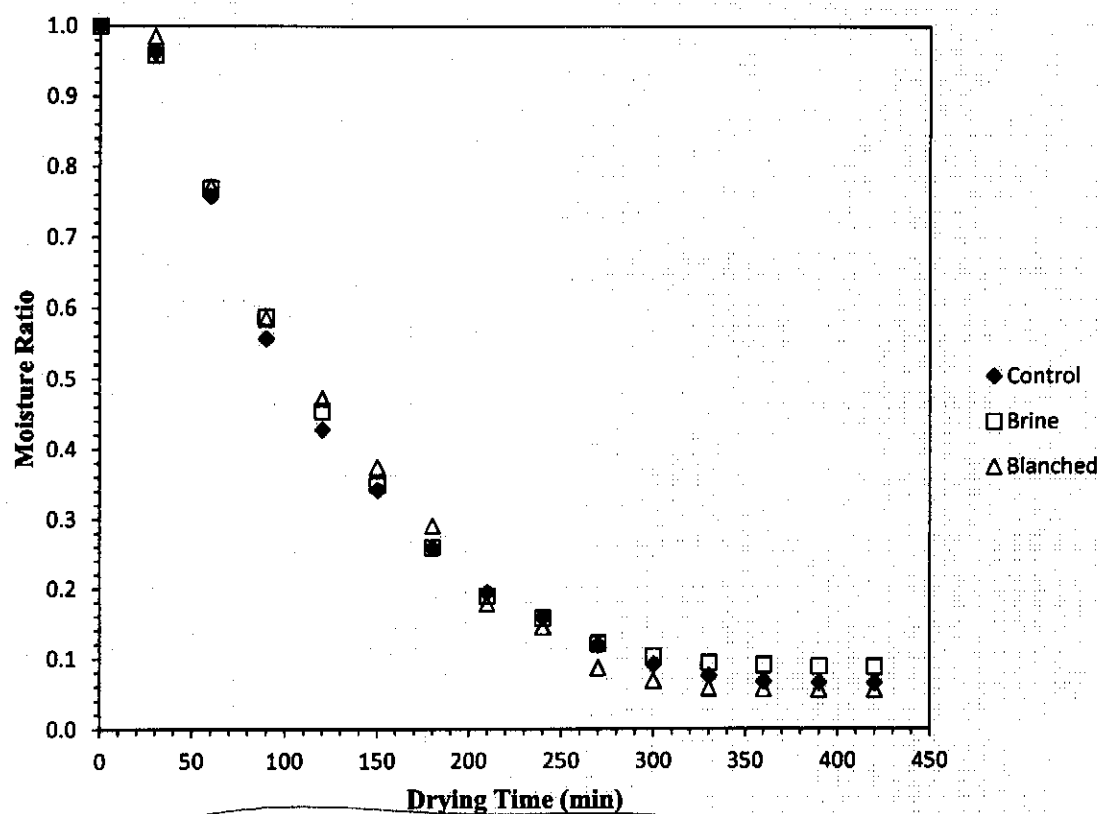


Figure 1: Moisture ratio variation of samples over the period of drying

Full sentence required. Also refer to product, treatment, and method of drying.

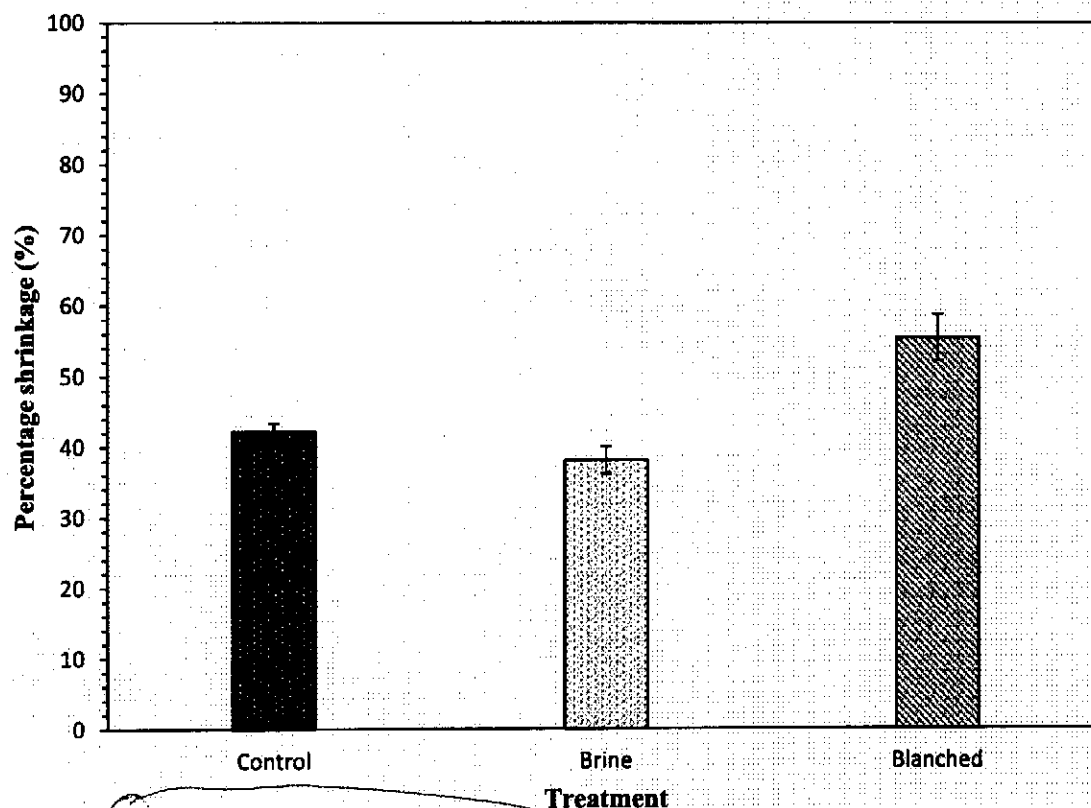
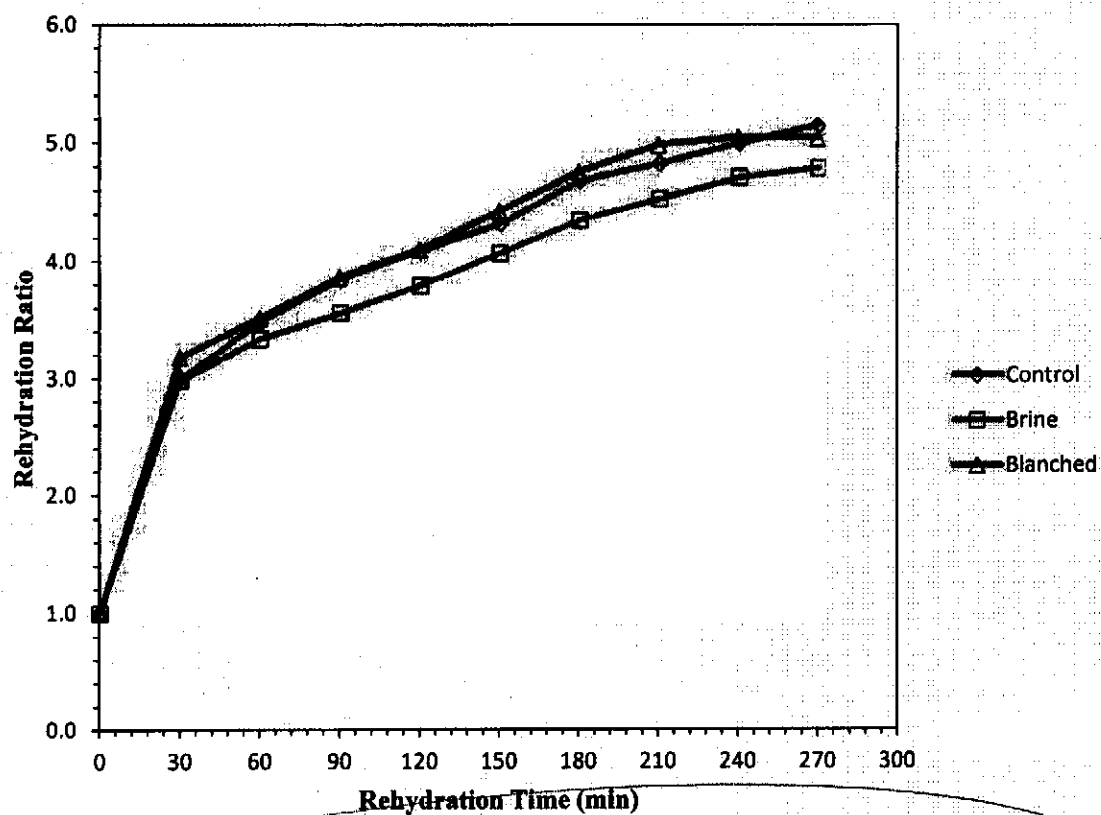


Figure 2. Percentage area shrinkage of dried samples

Full title includes name of product, treatment and method of drying.

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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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See previous comments.