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Modeling of Mass Transfer Parameters of Osmosised Red Bell Pepper

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Abstract

The modeling of mass transfer parameters in terms of water loss and solid gain of osmosised red bell pepper was done. The osmotic dehydration factors considered were osmotic process duration (30 min, 60 min, 90 min and 120 min), osmotic solution concentration (5% (w/w), 10% (w/w), 15% (w/w) and 20% (w/w)) and osmotic solution temperature (30˚C, 40˚C, 50˚C and 60˚C). A 4 X 4 X 4 factorial experiment in a randomized complete block design was used with three replicates and the total runs were 192. The results of analysis of variance showed that all the process conditions were significant on water loss and solid gain at $P \leq 0.05$. However, the values of water loss and solid gain did not drop below 0.11 g/g and 0.344 g/g respectively at all levels of process conditions considered under the Duncan's New Multiple Range Test. Model equations were developed with Essential Regression Software package for water loss and solid gain. The equations were validated numerically and graphically, and were found to reliably describe the behaviour of the process beyond reasonable doubt.
Keywords: *Modeling, water loss, solid gain, osmosised, red bell pepper.*

Introduction

Red bell pepper (*capsicum annuum*) is a vegetable crop that is characterized by glossy external colours.In Nigeria, it is popularly pronounced *tatase* in Yoruba and Hausa languages. It is a widely cultivated bell shaped fruit with three or four lobes (GMF, 2008). The favourable conditions for its growth are: warm soil (21-29˚C), moist soil that is not waterlogged (GardenersGarden.com), moderate salinity at seedling stage and intercrop and inter-row spacing of 18 inches and about 34 inches respectively (FAO, 2013), rainfall condition of 600 to 1250mm; but under irrigation, a better yield of up to 15 ton/ha can be obtained (FAO,2013).

The crop is very rich in some vitamins (especially vitamins C and A), minerals and fibre, but it is very low in calorie (about 1 %) (GMF, 2008). As a result of the high nutritional values, bell peppers have some outstanding nutritional and medicinal values which include defending the body against cancer, arthritis and rheumatism. It also has the potency of curing diabetes, maintaining of cholesterol level in the body, healing of fever, colds (www.fruitsinfo.com), sores and bruises and also aiding the digestion of food (GMF 2008, Vengaiah and Pandey, 2006).

Osmotic dehydration is the process in which water is partially removed from cellular materials when they are placed in hypertonic solution of salt, sugar or mixtures of salt and sugar (Singh *et al.*, 2006). Osmotic dehydration process involves the movement of water out of the product(water loss) into the solution and the corresponding inflow of solute (salt, sugar or their combination) from the solution into the product (solid gain), thereby leading to quality improvement of product. Tiwari (2005) and Karthiayani (2004) gave some reports on the phenomenon of mass transfer during osmotic dehydration. Chavan and Amarowicz (2012) reported some basic advantages of osmotic dehydration; one of it was that the process had the tendency of preserving the wholesomeness of the product. Odewole (2016) worked on the effect of osmotic dehydration pretreatments on the drying rate and quality of red bell pepper; at the end, advantages of osmotic dehydration were confirmed amongst other things done in the research. The kinetics of osmotic dehydration is usually determined by estimating the rate of water loss and solid gain.

It is very important to study the kinetics of osmotic dehydration in terms of water loss and solid gain because they are the performance indices of the osmotic dehydration process. Therefore, the main objective of this study was to develop empirical model equations for mass transfer parameters (water loss and solid gain) of osmisised red bell pepper. The specific objectives were to: (i) investigate the effect of osmotic dehydration pretreatments factors on the water loss and solid gain of red bell pepper (ii) develop model equations for water loss and solid gain, and (iii) validate model equations developed.

Materials and Methods

Sample Procurement and Preparation

The fresh samples of red bell pepper were procured in Ilorin metropolis, Kwara State (North-Central), Nigeria. All the samples were sorted, graded and washed in clean water and were later de-seeded and then cut into pieces along their longitudinal axes with the use of a short stainless steel knife on a stainless steel tray. After these, 50g of each sample was measured on an electronic sensitive weighing balance (OHAUS, 3001) and were soaked in a hypertonic salt (NaCl) solution of four different concentrations (i.e osmotic solution concentrations (B)) (5% (w/w), 10% (w/w), 15% (w/w) and 20% (w/w)). The samples were then placed inside the water baths (SL Shell Lab Model and HH-W420, XMTD-204 Model) at pre-set temperatures (osmotic solution temperature (C)) of 30˚C, 40˚C, 50˚C and 60˚C. The mass ratio of sample to solution used was 1:4.The samples were left inside the water baths for the required osmotic process duration (A) of 60 min, 90 min, 120 min and 150 min respectively. The experiment was done based on a 4 X 4 X 4 factorial experiment in Randomized Complete Block Design (RCBD). Each treatment combination was replicated three times and this made the total experimental runs to 192. The experimental was conducted at the Chemical Engineering Laboratory of University of Ilorin between June and July 2013. The average room temperatures and relative humidity were 30˚C and 60% respectively. At the end of the pretreatment times, the samples were taken out of the water baths, and rinsed with flowing water in order to get rid of adsorbed solute (salt). The output parameter measured were water loss (g/g) and solid gain (g/g).

Estimation of Output Parameters

The two output parameters were measured using equations 1 and 2 given by Fasogbon *et al.*, (2013).

$$WL = \frac{[(M_O - S_O) - (M_{Od} - M_f)]}{M_O - S_O} \quad (1)$$

$$SG = \frac{(M_f - S_O)}{S_O} \quad (2)$$

$WL = water\ loss(g/g)\ SG = solid\ gain\ (g/g),$

$M_0 = sample\ mass\ before\ osmotic\ dehydration(g) M_{0d} =$
$sample\ mass\ after\ osmotic\ deyhration\ (g),$
$M_f = final\ mass\ of\ dried\ sample\ (g) S_0 =$
$initial\ solid\ content\ of\ sample\ (g)$

Statistical Analysis

The data obtained from the experiment were subjected to statistical Analysis of Variance (ANOVA) at $P \leq 0.05$ in SPSS 16.0 statistical computer software package. A further analysis to compare the means of result among different levels of experimental conditions was also carried out with Duncan's New Multiple Range Test(DNMRT).

Model Validation and Development

The general principle governing model development is the formulation of functional relationship between the dependent and the independent variables. The dependent variables in this study were: water loss and solid gain. The independent variables are the three process conditions, namely osmotic process duration (A), osmotic solution concentration (B) and osmotic solution temperature(C).

Seventy five percent of the data obtained were inputted into Essential Regression statistical software package in order to generate relationship between the input variables (osmotic process duration, osmotic solution concentrations and osmotic solution temperatures) and output variables (water loss and solid gain). The rest of the data were used for model validation

Results and Discussion

Results of Analysis of Variance for Water Loss (WL) and Solid Gain (SG)

Table 1 presents the result of the statistical analysis of variance (ANOVA) of data obtained from the experiment. The table shows that all the process conditions and their respective interactions (except the interaction between A and B for water loss) had significant effect on water loss and solid gain of red bell pepper at $P \leq 0.05$. This implied that when carrying out the osmotic dehydration of red bell pepper at $P \leq 0.05$, careful attention must be paid to the significant individual factors and combinations because they would start to impose noticeable effects (positive or negative) on the water loss and solid gain of red bell pepper at $P \leq 0.05$. The results are also in agreement with what was reported by Sunjka and Raghavan (2004) when osmotic dehydration of cranberries was done. Their result revealed that process duration and solution concentration had significant effect on the operation.

Table 1:Analysis of Variance (ANOVA) of the effect of process conditions on the water lossand solid gain of red bell pepper

SV	DF	SS	MS	F	Sig.
Water Loss (g/g)					
A	3	0.011	0.004	4.368	0.006*
B	3	0.379	0.126	155.864	0.001*
C	3	0.051	0.017	21.031	0.001*
A X B	9	0.010	0.001	1.382	0.203
A X C	9	0.019	0.002	2.650	0.008*
B X C	9	0.015	0.002	2.047	0.039*
A X B X C	27	0.050	0.002	2.276	0.001*
Error	128	0.103	0.001		
Total	191	0.638			
Solid Gain (g/g)					
A	3	0.114	0.038	5.381	0.002*
B	3	7.729	2.576	363.602	0.001*
C	3	1.989	0.663	93.560	0.001*
A X B	9	0.261	0.029	4.097	0.001*
A X C	9	1.252	0.139	19.629	0.001*
B X C	9	0.434	0.048	6.811	0.001*
A X B X C	27	0.986	0.037	5.156	0.001*
Error	128	0.900	0.007		
Total	191	13.665			

*** Significant at $P \leq 0.05$**

A-Osmotic Process Duration; B-Osmotic Solution Concentration; C-Osmotic Solution Temperature

Effect of osmotic process duration, osmotic solution temperature and osmotic solution concentration on the water loss of red bell pepper

The effect of process conditions on the water loss of red bell pepper is as presented in Table 2. The table shows that increase in osmotic process duration from 90 min to 150 min caused the mean values of the water loss to reduce from 0.168 g/g to 0.146 g/g, however, change in mean values at 90 min and 120 min were not significantly different from each other. Furthermore, all the mean values were significantly different from each other as the osmotic solution concentration increased from 5% (w/w) to 20% (w/w); this also caused the mean values to progressively increase from 0.110 g/g to 0.266 g/g respectively. Also, water loss increased from 0.15 g/g to 0.182 g/g when osmotic solution temperature increased from 30˚C to 40˚C. However, it reduced from 0.182 g/g to not less than 0.140 g/g when the osmotic solution temperature increased from 40˚C to 60˚C. The reason for the changes could be due to the variety and maturity level of products which could control water loss and solid gain: shape, size and thickness of products; tissue compactness and intercellular spaces, temperature of solution, surface area and so on as reported by Chavan and Amarowicz (2012), Rahaman (1992) and Panagiotu*et al* ., (1998).

Table 2: Effect of process conditions on the water loss of red bell pepper

Osmotic Process Duration (min)	**60**	**90**	**120**	**150**
Water loss (g/g)	0.154[a]	0.168[b]	0.158[b]	0.146[c]
Osmotic Solution Concentration (%(w/w))	**5**	**10**	**15**	**20**
Water loss (g/g)	0.110[a]	0.125[b]	0.166[c]	0.266[d]
Osmotic Solution Temperature (˚C)	**30**	**40**	**50**	**60**
Water Loss (g/g)	0.158[a]	0.182[b]	0.142[c]	0.144[c]

*means with the alphabet are not significantly different from each other at $p \leq 0.05$

Effect of osmotic process duration, osmotic solution temperature and osmotic solution concentration on the solid gain of red bell pepper

Table 2 shows the effect of process conditions on the solid gain of red bell pepper. From the table, it is clearly seen that increase in osmotic process duration led to a gradual reduction in the values of solid gain from 0.635 g/g to 0.571 g/g. The reduction in solid gain could be due to the fact that with time, the concentration of the solution might have reduced as a result of movement of water from the product into the solution. Tiwari and Jalali (2004) conducted a research on osmotic dehydration of mango and pineapple, it was reported that increase in osmotic process duration caused increase in weight loss. The weight loss observed in their research is the same as water loss from the products, which would later dilute the hypertonic solution with time and hence reduced solid to be gained by the products. A direct opposite trend was noticed for osmotic solution concentration, in the sense that, its increase from 5% (w/w) to 20% (w/w) led to gradual increment in the values of solid gain from 0.344 g/g to 0.884 g/g. The reason for this is the higher the concentration of the solution, the faster the rate of mass transfer (Chavan and Amarowicz, 2012), hence, the higher could be the value of solid gain to a particular stage which would be determined from optimization of the process. Lastly, increase in osmotic solution temperature 30˚C to 40˚C did not cause the mean values of solid gain to drop below 0.500 g/g but all the mean values were significantly different from each other.

Table 3: Effect of process conditions on the solid gain of red bell pepper

Osmotic Process Duration (min)	**60**	**90**	**120**	**150**
Solid gain (g/g)	0.635^a	0.583^b	0.574^b	0.571^b
Osmotic Solution Concentration (%(w/w))	**5**	**10**	**15**	**20**
Solid gain (g/g)	0.344^a	0.484^b	0.675^c	0.884^d
Osmotic Solution Temperature (˚C)	**30**	**40**	**50**	**60**
Solid gain (g/g)	0.554^a	0.765^b	0.530^c	0.517^d

*means with the alphabet are not significantly different from each other at $p \leq 0.0$ **Model Equations**

Equations (3) and (4) representing the functional relationships of water loss and solid gain with the input variables respectively were selected from the pool of model equations developed for water loss and solid gain after studying how best they predicted the observed values obtained from the experiment.

$$\boldsymbol{WL} = 5.983\ x\ 10^{-2} + 1.352\ x\ 10^{-3}A - 6.914\ x\ 10^{-6}A^2 + 3.154\ x\ 10^{-4}B^2 - 9.385\ x\ 10^{-6}C^2\left(\boldsymbol{R^2_{adj}} = \mathbf{0.742}\right) \quad (3)$$

$$\boldsymbol{SG} = -2.846 + 3.528\ x\ 10^{-2}A + 1.364\ x\ 10^{-2}B + 1.292\ x10^{-1}C - 1.004\ x\ 10^{-4} - 1.170\ x\ 10^{-3}AC - 1.158\ x\ 10^{-3}C^2 + 2.334\ x\ 10^{-6}A^2C + 4.196\ x\ 10^{-6}AB + 6.441\ x\ 10^{-6}AC^2\left(\boldsymbol{R^2_{adj}} = \mathbf{0.772}\right) \quad (4)$$

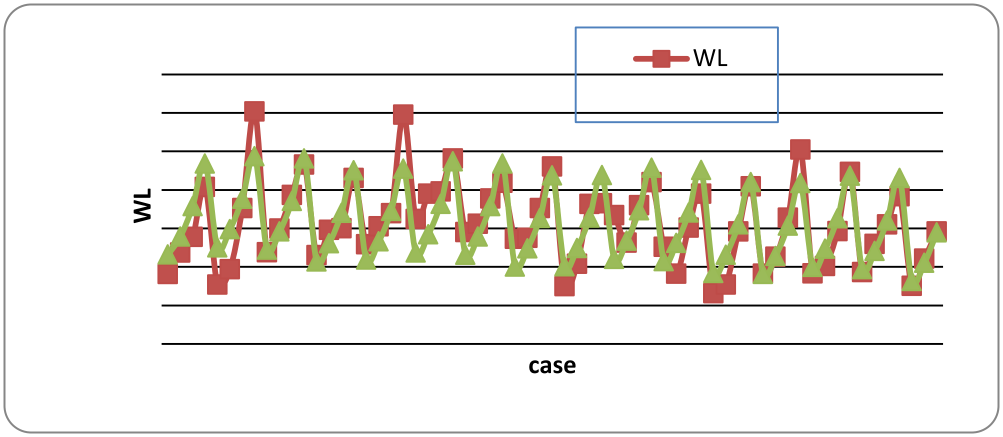
Model Validation

The two models equations developed were validated using numerical and graphical methods. The numerical method made use of some statistics to adjudge the validity of the models, while graphical method made use of plots (graphs). Macal (2005) stated that the main goal of model validation is to ensure that the model is useful in addressing the right problem and provides adequate information about the system under consideration.

For the numerical method, the following statistics were estimated: standard error, mean difference between observed and predicted values, and confidence interval (at 95 %) for water loss were 0.0033, -0.004, and (-0.0071 to 0.0062) respectively. Also, that of solid gain were estimated to be 0.000, 0.010 and (-0.0197 ton 0.0197) respectively. All the low values are indications that the model equations developed have good fit (David *et al.*, 1998) and can be used to relate process inputs(osmotic process duration, osmotic solution concentration and osmotic solution temperature) to output(water loss and solid gain). Darvishi *et al* (2013) got R^2(0.927), X^2(0.2065) and Root Mean Square Error (0.0555) and Taheri-Garavand *et al.* (2011) got R^2(0.99201), X^2(0.00003492) and RMSE (0.00481743) for the validation of drying of bell pepper.

The graphical methods of model validation is as shown in Figures 1- 4

From Figures 1 and 2, the pattern of the observed values (in red) and the predicted values (in green) are almost the same. This is an indication that the



models developed are reliable and hence represent the true behaviour of the process under study.

Figure 1:Observed (red) and predicted (green) water loss (g/g)

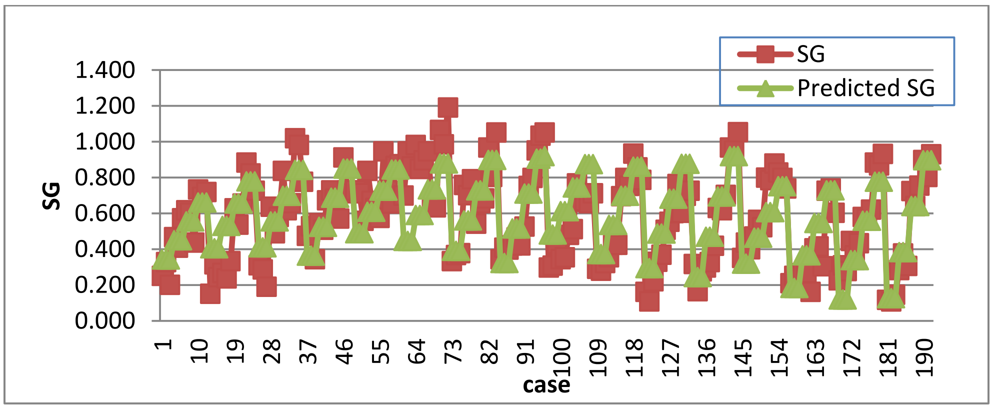


Figure 2: Observed (red) and predicted (green) solid gain (g/g)

Furthermore, normal probability plot of the Expected Normal Values (Rankit) versus the Residuals was also used. The plots examined the error structure to ensure that the residuals behave as expected. In the errors the errors are distributed normally. The graphs clearly showed that the residual plots are not heavy tailed, meaning that they spread about the straight line. For figures 3 and 4 the residuals fell on a straight line for all the process outputs observed. The implication of this is that the assumption of normality of the residuals was not violated. Hence, the models are valid and could be used for their intended purposes of prediction, estimation and so on.

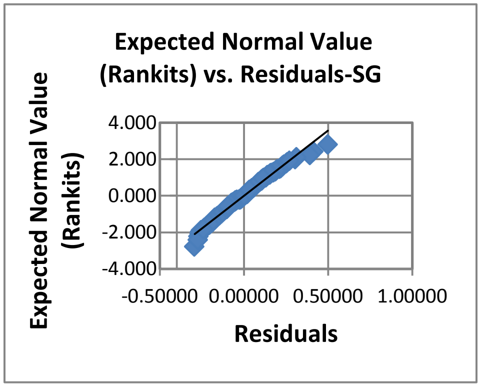


Figure 4: Expected Normal versus Residual for Solid Gain (SG)

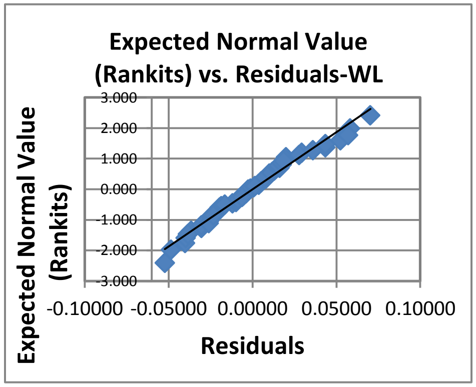


Figure 3: Expected Normal versus Residual for Water Loss (WL)

Conclusions

The effect of osmotic process duration, osmotic solution temperature and osmotic solution temperature were investigated on the water loss and solid gain of red bell pepper. It was discovered that all the process conditions had significance on the water loss and solid gain. However, the values of water loss and solid gain did not drop below 0.11 g/g and 0.344 g/g respectively at all levels of process conditions considered. Furthermore, model equations were developed for water loss and solid gain. The equations were validated numerically and graphically, and were found to reliably describe the behavior of the process beyond reasonable doubt.

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