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Modeling and Optimization of Drying Rate and Quality Parameters of Dried Osmo-Pretreated Green Bell Pepper (*Capsicum annuum*)

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Abstract

A study on modeling and optimization of osmotic dehydration and drying of green bell pepper was carried out. Five levels of osmotic process durations (60 min, 90 min, 120 min, 150 min and 180 min) and five levels of osmotic solution concentrations (5% (w/w), 10% (w/w), 15% (w/w), 20% (w/w) and 25% (w/w) as input parameters were used. Design Expert 8.0.3 version was used to design the experiment in order to get all possible combinations of durations and concentrations. After pretreating all samples of fresh green pepper in hypertonic osmotic solution concentrations of NaCl for the required durations, they were all dried at 50˚C in a fabricated cabinet dryer. The following output parameters were modeled and optimized with Design Expert 8.0.3 version: drying rate, vitamin C, crude protein, crude fibre, fat, ash content, water loss, solid gain, shrinkage and rehydration ratio. Ten (10) model equations, one for each of the output parameters were developed, and checked for adequacy and validity. All developed model equations were found to present functional relationships between input and output parameters. Hence, all developed model equations can be used as reliable tools for estimating, predicting and conducting analysis of the process. Best optimized results were selected based on desirability (0 - 1). Drying rate (maximized), vitamin C (maximized), crude protein (maximized), crude fibre (maximized), fat (maximized), ash content (minimized), water loss (maximized), solid gain (maximized), shrinkage (minimized) and rehydration ratio (maximized) got desirability of 0.889, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 0.85, 0.734 and 0.868 respectively.

Keywords: modeling, optimization, osmotic dehydration, drying, green bell pepper.

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Introduction

Green bell pepper is one of the over 20 species of *capsicum annuum* in the genus of bell pepper (Walsh and Hoot, 2001). All peppers that belong to this specie have the lowest level of capsaicin (a chemical content that is responsible for the pungent smell and flavour of peppers) among all peppers. Some of the nutritional contents of green bell pepper are: vitamin C (highest nutrient), vitamin A, vitamin Bs (B1, B2, B3 and B5), vitamin K, vitamin E, magnesium, manganese, potassium, fibre, calories(lowest nutrient), folate, protein, carbohydrate (Taheri-Garavand, 2011 and GMF, 2008). In terms of health benefits, green bell pepper can cure arthritis, cancer, cataracts, rheumatism, fever, cold, diabetes, sore and bruises. Others benefits are stimulation of stomach secretion for digestion enhancement and regulation of cholesterol level of human body (www.fruitsinfo.com, Vengaiah and Pandey, 2006; and GMF, 2008).

Pretreatment of food materials is done in order to enhance processing operations and for quality retention and improvement. One of the pretreatment methods is osmotic dehydration. Osmotic dehydration is the partial removal of water from food products (cellular materials) by immersing them in hypertonic solution (Singh *et al*., 2006) of salt, sugar or their mixtures. The process is governed by the principle of osmosis (Haynie, 2001). Osmotic dehydration is one of the simple and economical methods of extending the shelf life of perishable products; and it preserves the colour, flavour, and texture of food from heat, thereby improving the nutritional, sensory and functional characteristics of products (Singh *et al.,* 2006; Pokharkar and Prasad, 1998). Tiwari (2005) and Chavan and Amarowicz, (2012) reported the kinetics of osmotic dehydration. Some factors influencing osmotic dehydration are- osmotic solution concentration, osmotic process duration, osmotic solution temperature, type of osmotic agent, ratio of product to osmotic solution, agitation of solution during osmotic dehydration (Chavan and Amarowicz, 2012), physiology of food material to be pretreated in osmotic solution and so on. It has been reported that increase in osmotic solution temperature led to increase in the rate of osmotic dehydration; but higher solution temperature above 60˚C would cause destruction of products cell membrane (Chavan and Amarowicz, 2012). Charles (2010) asserted osmotic solution temperature as one of the important factors controlling the kinetics of mass transfer during osmotic dehydration process. Azoubel and Murr (2004) effectively conducted osmotic dehydration of cherry tomato at room temperature of 25˚C. Odewole and Olaniyan (2016), Odewole *et al*., (2014), Olaniyan and Omoleyomi (2013), Alabi *et al*., (2016) and Fasogbon *et al*., (2013) conducted osmotic dehydration and drying of red bell pepper, mango, okra, onion and pineapple slices respectively. Their results confirmed the principles and advantages osmotic dehydration.

Osmotic dehydration alone cannot make pretreated products to be shelf stable; it is meant to reduce the moisture content of pretreated products to a certain level before further processing. This is because of the presence of substantial amount of moisture in them after pretreatment which might possibly lead to decay and spoilage of products in storage. As a result of this, drying of osmo-pretreated products to safe and shelf stable moisture content is necessary.

Drying is a simultaneous heat and mass transfer process, and it is one of the oldest methods of food preservation which is achieved by the removal of enough or pre-determined moisture from food with the aim of preventing decay and spoilage. Thus, improving eating quality in some cases and extending shelf life of product in most cases. Drying is a means of concentrating the nutrients of food after removal of moisture; as result of this, safe temperature that would reasonably retain the

nutritional qualities of food products must be used for drying, if not the food will be of low quality after drying. Idah *et al., (*2012); Mu'azu *et al.,* (2012); Awogbemi and Ogunleye (2009); and Phisut *et al.,* (2012) suggested that the best temperature range for drying fruits and vegetables should be between 35˚C to 75˚C. Odewole and Olaniyan (2016) used 60˚C for drying of red bell pepper after osmotic dehydration in hypertonic salt solution in a fabricated convective cabinet dryer.

Modeling is the construction of physical, conceptual or mathematical simulation of the real world events (FAO, 2013). It is also the process of developing equations or expressions that show functional relationship between dependent variables (outputs or responses) and independent variables (inputs or conditions of operation). Some examples of model types are: analytical models, statistical models, empirical models, stochastic models, mathematical models, mechanistic models, process model, block models and so on. Model equations are tools for making decision, prediction, estimation, forecasting and analyzing specific systems with the aim of having a better understanding of such systems. Optimization is the process of finding actions that maximize or minimize the value of an object function (www.swlearning.com). Some of the techniques of optimization are differential calculus, linear programming and sequential technique, and simultaneous technique. All these techniques of modeling and optimization are now available in form of software packages for computer systems. Alabi *et al*., (2016), Odewole and Olaniyan (2015), Singh *et al*., (2006) developed models equations and optimize the osmotic dehydration and drying of onion, red bell pepper and carrot slices respectively. Mitra *et al.,* (2011) carried out the optimization of the drying process of onion slices in a vacuum dryer; with temperature range of 50-70˚C, onion slices of 1-5mm thickness, and pretreating in solution. It was discovered that the optimum conditions for the treated samples were 58.66˚C drying temperature and 4.95 mm slice thickness.

Generally, green bell pepper is a highly perishable vegetable. As a result, it is more vulnerable to post-harvest losses. Moody (1985) reported that in refrigerated storage, bell peppers(green bell pepper inclusive) will only be able to maintain their maximum natural nutritional values for a maximum of 10 days. Some developing countries have problems of epileptic power supply; this condition is making it almost impossible for refrigeration of freshly harvested green bell pepper. One of the ways of ensuring the all year round availability of this vegetable with a view to harnessing its excellent nutritional qualities is drying. However, drying alone cannot ensure high quality, hence osmotic dehydration as pretreatment before drying for quality improvement and retention is a viable option. Modeling and optimization of the two processes of osmotic dehydration and drying for the purpose of getting functional relationships between input and output parameters and getting values of input parameters that will either maximize or minimize the output parameters(responses) are necessary. This will ensure better understanding of the process which can be used as tools for further research and industrial production of dried osmo-pretreated green bell pepper. Therefore the objectives of this study were to develop and validate model equations for processing fresh green bell pepper to osmo-pretreated and dried green bell pepper and to carry out optimization of the process with the use of 8.0.3 version of Design Expert Computer Software.

Materials and Methods

Experimental Equipment and Materials

The following equipment and materials were used for the experiment: laboratory oven(GENLAB, Model N53 CF, England) desiccator, a fabricated cabinet dryer, electronic

weighing balance(OHAUS CL Series, Model CL 201, China), stop watch(Nokia X2-01), containers for osmotic dehydration pretreatment, stainless steel tray and knife, foil paper, spatula and hand gloves. Common salt, distil water, fresh green bell pepper.

Experimental Design

To design the experiment, Design Expert 8.0.3 version Computer Software was used. Response Surface Methodology (RSM) under Central Composite Design was used. Five levels of osmotic solution concentrations of common salt (5% (w/w), 10% (w/w), 15% (w/w), 20% (w/w) and 25% (w/w)) and five levels of osmotic process duration (60 min, 90 min, 120 min, 150 min and 180 min) were introduced into the experimental design interface of the software to generate all combinations between the two process conditions.

Experimental Procedure

Fresh green bell peppers were procured from a commodity market in Ilorin, Kwara state, Nigeria. They were graded in order to get better quality for the experiment. Other procedures are in Odewole and Olaniyan (2016). Sliced green bell pepper (100g) was introduced into the osmotic solution for each pretreatment combination at average ambient temperature of 26˚C. At the end of the pretreatment, a non-uniform mass of between 76g - 82g was achieved. 75g for each pretreated samples was introduced into the dryer. A regulated temperature of 50˚C was maintained throughout the period of drying. Hourly loss in mass for each sample was measured with the use of the electronic weighing balance (OHAUS CL Series, Model CL 201, China.) until the end of drying which lasted for about 4 hours. After drying to average moisture content of not greater than 7% (wb), all the dried samples were arranged inside the desiccator and were later taken for nutritional analysis that same day. The experiment was performed at the Processing and Storage Laboratory of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria in June 2016. The average room temperature was around 31˚C and relative humidity of about 65% throughout the period of the experiment.

Output Parameters

Drying rate was estimated using the equation in Odewole and Olaniyan (2016). Quality parameters in terms of vitamin C, crude protein, crude fibre, fat, ash content were determined using AOAC (2002) standard. Water loss and solid gain were estimated with Fasogbon *et al*., (2013) procedures. Shrinkage and rehydration ratio were estimated with Singh *et al*., (2006) procedures.

Data Analysis

All the data for all the 10 outputs (drying rate, vitamin C, crude protein, crude fibre, fat, ash content, water loss, solid gain, shrinkage and rehydration ratio) obtained were introduced into the experiment table earlier designed with Design Expert computer software package. The data were analyzed following the stipulated procedures of the software for RSM in order to get functional reliable relationships that relate the two process conditions with each of the output parameter. Optimization of the process was further done with the software.

Results and discussion

Developed model equations

Below are the 10 developed model equations that gave functional relationship between input variables(osmotic process concentration and osmotic process duration) and output variables (drying rate, vitamin C (Vit.C), crude protein, crude fibre, fat, ash content, water loss (WL), solid gain (SG), shrinkage (Sh) and rehydration ratio (RR)).

$$Drying\ Rate(g/hr) = 28.77021 - 0.042551A - 0.47722B + 2.875 \times 10^{-3}B \quad (R^2_{Adj} = 0.1841) \quad (1)$$

$$Vit.\ C(mg/100g) = 52.21133 - 0.011087A + 0.024794B + 5.41667 \times 10^{-5}AB + 3.93367 \times 10^{-5}A^2 - 7.83877 \times 10^{-4}B^2 \quad (R^2_{Adj} = 0.7240) \quad (2)$$

$$Crude\ Protein(\%) = 20.77144 - 0.055412A + 0.17494B + 8.33333 \times 10^{-5}AB + 2.64257 \times 10^{-4}A^2 - 6.28676 \times 10^{-3}B^2 \quad (R^2_{Adj} = 0.8345) \quad (3)$$

$$Crude\ Fibre(\%) = 3.97369 + 0.014867A + 0.010297B - 2.58333 \times 10^{-4}AB - 5.45959 \times 10^{-5}A^2 + 2.34549 \times 10^{-4}B^2 \quad (R^2_{Adj} = 0.832) \quad (4)$$

$$Fat(\%) = 3.05067 + 0.25116A - 0.53898B - 5.16667 \times 10^{-4}AB - 9.88292 \times 10^{-4}A^2 + 0.0198221B^2 \quad (R^2_{Adj} = 0.5847) \quad (5)$$

$$Ash\ Content(\%) = 3.90983 + 1.85185 \times 10^{-3}A + 2.222 \times 10^{-4}B \quad (R^2_{Adj} = 0.4238) \quad (6)$$

$$WL(g/g) = 0.024658 + 2.59259 \times 10^{-4}A + 0.01033B \quad (R^2_{Adj} = 0.6179) \quad (7)$$

$$SG(g/g) = 0.89338 - 3.8518 \times 10^{-3}A - 0.045B + 2.66667 \times 10^{-4}AB \quad (R^2_{Adj} = 0.3986) \quad (8)$$

$$Sh\ (\%) = 25.9188 + 0.18407A + 0.493333B \quad (R^2_{Adj} = 0.2263) \quad (9)$$

$$RR = 4.14530 - 2.4071 \times 10^{-3}A - 0.078889B \quad (R^2_{Adj} = 0.5282) \quad (10)$$

Model Adequacy Checking

The adequacy of all developed model equations were checked with some specific statistics stated in Table 1. From the table, R^2 and R^2_{Adj} values of outputs were high and some were low. These two statistics are called coefficient of multiple determination and adjust coefficient of multiple determination respectively; it defined the total variability of all models developed. David *et al*., (1998) stated that relatively close values of the statistics is an indication that models developed are good. This statement holds for vitamin C, crude fibre, ash content, water loss and rehydration ratio; and in agreement with the results in Odewole and Olaniyan (2015). In a different statement, Montgomery *et al.,* (1998) wrote that high R^2 values do not always mean that a model is good. Also, low R^2 values do not always mean that a model is bad. Hence, it will be wrong to conclude that model equations with low R^2 values are bad model equations. Therefore, further checking of models was done with other statistics and methods.

Another statistics that guarantee goodness of fit is the so called prediction error sum of squares (PRESS). Models with lower prediction error sum of squares (PRESS) imply good fit. Table 1 also shows the lowest prediction error sum of squares associated with the various models developed, and selected from 10 models equations generated by the software for each of the output.

The coefficient of variation (C.V) which is the unexplained variances in the data given by the standard error of models was also used. Model equations with the lowest values of C.V were selected from the software. For all the models developed, small values of C.V obtained and selected is an indication that the fit is good (David *et al*., 1998).

Furthermore, the probability values of "lack of fit" must not be significant at $P \leq 0.05$. The reason for this is that, it is expected that a fitness of model should be achieved. In a different development, the probability values of models developed must be significant at $P \leq 0.05$ for them to tend towards being accepted as good. From Table 1, the P-values (probability values) of "lack of fit" are not significant for vitamin C (0.9533), fat (0.3955), crude fibre (0.3643), solid gain (0.2299), water loss (0.7283), rehydration ratio (0.4436), shrinkage (0.1144) and drying rate (0.7664). Also, the p-values for models are significant for vitamin C (0.0106), crude protein (0.0019), fat (0.0398), crude fibre (0.002), ash content (0.0255), water loss (0.0033) and rehydration ratio (0.0094).

Lastly, for models to be accepted as good ones and serve their intended purposes, the value of adequate precision must be greater than 4 (Stat-Ease, 2000). All the values of adequate precision in Table 1 are greater than 4. Therefore, it can be concluded that all the models developed are adequate and can be used to relate process input to process output. Hence they can be used for estimation, prediction and analysis of the process.

Table 1: Statistics for Checking of Adequacy of Model Equations

Outputs / Statistics	Drying Rate (g/hr)	Vit.C (mg/100g)	Crude Protein (%)	Crude Fibre (%)	Fat (%)	Ash Content (%)	WL (g/g)	SG (g/g)	Sh (%)	RR
R^2	0.3881	0.8390	0.9035	0.902	0.7577	0.5198	0.6816	0.5490	0.3552	0.6071
R^2_{Adj}	0.1841	0.7240	0.8345	0.832	0.5847	0.4238	0.6179	0.3986	0.2263	0.5282
PRESS	76.63	0.024	5.71	0.27	43.01	0.10	0.048	0.90	1815.18	3.23
P value of "Lack of Fit	0.7664	0.9533	0.0003	0.3643	0.3955	0.0111	0.7283	0.2299	0.1114	0.4436
Model P-Value	0.1997	0.0106	0.0019	0.002	0.0398	0.0255	0.0033	0.0570	0.1114	0.0094
Adequate precision	5.903	9.623	101.66	13.683	6.914	6.585	10.331	8.184	6.085	8.978
Coefficient of Variation (%)	8.58	0.076	0.86	1.54	4.67	1.73	22.73	54.10	19.73	16.19

2.6.3. Models Validity Checking

The ultimate goal of model validation is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the system being modeled and to make sure the model can be actually put to use (Macal, 2005). Tables 2(a)-2(c) are the difference between actual (experimental) values and predicted values for three different treatment combinations. It can be inferred from the tables that there are no much differences(X-Y) between the values of actual and predicted outputs. This is what is expected for models to be called good ones. This result of small differences are also in agreement with what Odewole and Olaniyan (2015) got for osmotic dehydration and drying of red bell pepper. These results also serve as confirmation to the statement earlier mentioned that "high R^2 values do not always mean that a model is good. Also, low R^2 values do not always mean that a model is bad"

Table 2(a): Model Validity Checking for Osmotic Process duration (120 min) and Osmotic Solution Concentration (20 % (w/w))

SN	Outputs	Actual Value(X)	Predicted (Y)	X-Y
1	Drying Rate(g/hr)	22.73	21.02	1.71
2	Vitamin C(mg/100g)	51.77	51.76	0.01
3	Crude Protein (%)	19.20	19.11	0.09
4	Crude Fibre (%)	4.73	4.65	0.08
5	Fat (%)	15.20	14.87	0.33
6	Ash Content (%)	4.18	4.14	0.04
7	Water Loss(g/g)	0.23	0.36	-0.13
8	Solid Gain (g/g)	0.06	0.17	-0.11
9	Shrinkage (%)	61.10	57.87	3.23
10	Rehydration Ratio	2.6	2.28	0.32

Table 2(b): Model Validity Checking for Osmotic Process duration (180 min) and Osmotic Solution Concentration (15 % (w/w))

SN	Outputs	Actual Value(X)	Predicted (Y)	X-Y
1	Drying Rate(g/hr)	20.35	21.31	-0.96
2	Vitamin C(mg/100g)	51.64	51.35	0.29
3	Crude Protein (%)	20.08	20.15	-0.07
4	Crude Fibre (%)	4.70	4.71	0.01
5	Fat (%)	13.40	13.57	-0.17
6	Ash Content (%)	4.28	4.24	0.04
7	Water Loss(g/g)	0.13	0.12	-0.01
8	Solid Gain (g/g)	0.30	0.22	0.08
9	Shrinkage (%)	61.10	61.52	-0.42
10	Rehydration Ratio	3.6	2.32	1.28

Table 2(c): Model Validity Checking for Osmotic Process duration (60 min) and Osmotic Solution Concentration (25 % (w/w))

SN	Outputs	Actual Value(X)	Predicted (Y)	X-Y
1	Drying Rate(g/hr)	18.17	18.60	-0.43
2	Vitamin C(mg/100g)	51.90	51.40	0.50
3	Crude Protein (%)	19.02	18.97	0.05
4	Crude Fibre (%)	4.68	4.69	-0.01
5	Fat (%)	12.82	12.70	0.12
6	Ash Content (%)	4.06	4.03	0.03
7	Water Loss(g/g)	0.31	0.30	0.01
8	Solid Gain (g/g)	0.05	0.06	0.01
9	Shrinkage (%)	40.20	49.30	-9.1
10	Rehydration Ratio	2.3	2.03	0.27

Optimization Results

In simple terms, one of the ways of explaining optimization is that, it is the process of getting the values of input parameters that will either maximize or minimize the output parameters. Table 3 is the result of optimization analysis. Goals were selected based on the importance of those outputs (drying rate, vitamin C (Vit.C), crude protein, crude fibre, fat, ash content, water loss (WL), solid gain (SG), shrinkage (Sh) and rehydration ratio (RR)) in green bell pepper in relation to the study. After the analysis, the software selected one best combinations of inputs(osmotic process duration and osmotic solution concentrations) from 10 different optimization results for each output that best fulfilled the goals of the optimization (maximized or minimized). The 10 optimization combinations for each output were ranked according to desirability (0-1). The closer the desirability to 1, the better the solution (Stat-Ease, 2000), and the solution with desirability of 1 or the closest to 1 were selected. From the table, if drying rate and vitamin C are to be maximized to 24.695 g/hr and 51.9343 mg/100g respectively, osmotic process duration of 60 min and 60.75 min, and

osmotic solution concentration of 5 % (w/w) and 18.44% (w/w) should be used respectively. Similarly, to minimize ash content and shrinkage to 4.02497 % and 39.4299% respectively, osmotic process durations of 61.22 min and 60 min, and osmotic solution concentrations of 7.97% (w/w) and 5% (w/w) should be used respectively. Odewole and Olaniyan (2015) reported maximized values of 4.26g/hr, 152.82 mg/100g, 0.24 g/g and 0.91 g/g respectively for osmotic dehydration and drying red bell pepper with incorporation of different levels of osmotic solution temperatures as part of the inputs; minimized values obtained for ash content was 8.03%. Dhkordi *et al*., (2010) used RSM to optimize the osmo-convective drying of edible mush room and got optimum water loss, solid gain, rehydration ratio and shrinkage of 63.3g/100g, 3.17g/100g, 2.26 and 7.15 %. Singh *et al*., (2006) carried out optimization of osmotic dehydration of carrots and dried at 65˚C in cabinet dryer, the optimum values of 11% osmotic solution concentration, 30˚C of osmotic solution temperature and 120 min osmotic solution temperature were achieved.

Table 3: Results of Optimization Analysis

SN		A:Osmotic process duration(min)	B:Osmotic solution concentration %(w/w)	Optimized Outputs	Goal	Desirability
1	$Drying\ Rate(g/hr)$	60	5	24.695	Maximized	0.889
2	$Vit.C(mg/100g)$	60.75	18.44	51.9343	Maximized	1.00
3	$Crude\ Protein(\%)$	164.25	12.72	20.182	Maximized	1.00
4	$Crude\ Fibre(\%)$	129	7.5	4.8234	Maximized	1.00
5	$Fat(\%)$	126.75	22.31	15.389	Maximized	1.00
6	$Ash\ Cotent(\%)$	61.22	7.97	4.02497	Minimized	1.00
7	$WL(\%)$ -(Water Loss)	120.19	24.69	0.3109	Maximized	1.00
8	$SG(\%)$ - (Solid Gain)	60	5	0.5173	Maximized	0.85
9	$Sh(\%)$ - (Shrinkage)	60	5	39.4299	Minimized	0.734
10	$RR(\%)$-- (Rehydration Ratio)	60	5	3.6064	Maximized	0.868

Conclusions

Ten(10) model equations that gave functional relationships between inputs(osmotic process duration(A) and osmotic solution concentration (B)) and outputs(drying rate, vitamin C, crude protein, crude fibre, fat, ash, water loss, solid gain, shrinkage and rehydration ratio) of dried osmo-pretreated green bell pepper were developed. Adequacy (Table 1) and validity (Tables 2(a)-2(c)) checks on them revealed that they all described the real behaviour of the pretreatment and drying process. Hence, all developed model equations can be used as reliable tools for estimating, predicting and

conducting analysis of the process. Best optimized results were selected based on desirability (0 - 1). Drying rate (maximized), vitamin C (maximized), crude protein (maximized), crude fibre (maximized), fat (maximized), ash content (minimized), water loss (maximized), solid gain (maximized), shrinkage (minimized) and rehydration ratio (maximized) got desirability of 0.889, 1.00, 1.00, 1.00, 1.00, 1.00, 1.00, 0.85, 0.734 and 0.868 respectively.

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