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Process modelling and optimization of osmotic dehydration assisted drying of red bell peppper

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Abstract

Osmotic dehydration (pretreatment) of red bell pepper in hypertonic salt (NaCl) solution and drying was studied. A $4 \times 4 \times 4$ factorial experiment in a Randomized Complete Block Design (RCBD) was used for the pretreatment and pretreated samples were later dried in a fabricated laboratory dryer. Process variables considered were four levels each of osmotic process durations (30, 60, 90 and 120 min), osmotic solution concentrations (5, 10, 15 and 20 % w/w of sodium chloride) and osmotic solution temperatures (30, 40, 50 and 60^{0}C) with each trial conducted in triplicates while a drying temperature of 60^{0}C was used throughout the experiment. Drying rate was estimated for all test runs while vitamin C, vitamin A, ash content, water loss and solid gain were estimated as quality parameters. Model equations were developed with Essential Regression (ESSREG) software package which related output parameters to process variables and validated. Results gave optimum drying rate (maximized), vitamin C (maximized), vitamin A (maximized), water loss (maximized), solid gain (maximized) and ash content (minimized) of 4.26 g/h, 152.82 mg/100g, 1.42 mg/100g, 0.24 g/g, 0.91 g/g and 8.04 % respectively.

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Introduction

Red bell pepper is a common vegetable crop that grows well on wet soil whose temperature is in the range of 21-29 ^{0}C but must not be water logged (GardenersGardening.com). In most cases, the crop is grown under rain fed conditions. In order to obtain high yield, the rainfall of between 600 mm and 1250 mm is needed (FAO, 2013).

The crop is low in calories, but it is rich in fibre and other essential nutrients like vitamins (A, C, E, B and K), potassium, manganese, magnesium and molybdenum (GMF, 2008). Some of its health benefits are: controlling the cholesterol level of the body, curing of diabetes, cancer, rheumatism, cold, fever, bruises and aiding of food digestion (Vengaiah and Pandey, 2006). Moody (1985) reported that red bell pepper would only maintain its maximum natural nutritional values for 10 days in refrigerated storage.

Drying in conjunction with a suitable pre-treatment condition (osmotic dehydration) is a means of achieving the purpose of shelf life extension. Odewole and Olaniyan (2016) had worked on the effect of osmotic dehydration pre-treatments on the drying rate and quality of red bell pepper. It was however recommended that modeling and optimization of the process should be done.

In simplified terms, modeling is 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). Analytical models, statistical models, empirical models, stochastic models, mathematical models, mechanistic models, process model and block models are some examples of models. One of the advantages of modeling is that, checked models in terms of adequacy and validity can be used as reliable tools for decision making; prediction and estimation of output parameters; and also to conduct proper analysis of specific process/system with the aim of having a better understanding of the process/system under study. Optimization is the process of finding values of input parameters that will either maximize or minimize the values of output parameters. Some techniques of optimization are differential calculus, linear programming and sequential technique, and simultaneous technique. All these techniques of modeling and optimization are now embedded in computer software packages for speedy analysis and getting of reliable results. Singh *et. al.*, (2006) and Alabi *et. al.*, (2016) developed empirical model equations and optimize the osmotic dehydration and drying of onion and carrot slices. Mitra *et. al.*, (2011) optimized the drying process of onion slices in a vacuum dryer; with temperature range of 50-

70°C, It was discovered that the optimum conditions for the treated samples were 58.66°C drying temperature and 4.95 mm slice thickness.

There is dire need to make this crop (red bell pepper) in processed form to be available all year round with optimum retention of its nutrients. This will enhance the utilization of its rich nutrients by human beings. This work focused on development of model equations with the use of experimental data obtained by (Odewole and Olaniyan, 2016) and also optimizes the process. Therefore, the objectives of this research were to: (i) develop empirical model equations to estimate the drying rate and quality attributes (water loss, solid gain, ash content, vitamin A and vitamin C) of red bell pepper and; (ii) optimize the process for drying rate and stated qualities.

Materials and methods

Sample preparation and drying operation were as reported in Odewole and Olaniyan (2016). The description of the fabricated convective dryer used for this work is presented in Olaniyan and Omoleyomi (2013). The drying temperature of 60°C was used for the drying operation and it was based on the report of the following authors: Awogbemi and Ogunleye (2009); Idah *et al.*,(2011); Mu'azu *et. al.*, (2012); Nogueura *et al.*, (2005) and Phisut *et. al.*, (2005). A $4 \times 4 \times 4$ factorial experiment in a Randomized Complete Design (RCBD) with three replicates was used for this study. This led to a total of 192 experimental runs. The output parameters measured were drying rate (g/h), solid gain (g/g), water loss (g/g), vitamin A (mg/100g), vitamin C (mg/100g) and ash content (%).

Drying rate has been determined earlier by Odewole and (2016). The post-drying qualities determined were: solid gain (g/g), water loss (g/g), vitamin A (mg/100g), vitamin C (mg/100g) and ash content (%). The procedures used for determining the qualities are as stated in Odewole and Olaniyan (2016).

Parts of the data collected (75%) were introduced into Essential Regression analysis (ESSREG) computer software package in order to generate model equations; the remaining 25% of the data were used to check developed model equations. Model equations developed were used to predict the drying rate and qualities of red bell pepper based on different osmotic solution concentrations, different osmotic process durations and different osmotic solution temperatures. Furthermore, the process was optimized with the software for maximum drying rate and optimum product qualities taken into consideration.

Results and discussion

Model Development

The models were developed taking into consideration a three-factor (osmotic solution concentration, osmotic process duration and osmotic solution temperature) essential regression model. Equations (1-6) were generated from the regression analysis for drying rate, water loss, solid gain, ash content, vitamin C and vitamin A respectively:

$$Y_1 = 5.841 - 1.217 \times 10^{-2}A - 2.681 \times 10^{-2}B - 6.525 \times 10^{-2}C + 5.156 \times 10^{-4}AC + 6.688 \times 10^{-4}C^2 - 5.283 \times 10^{-6}AC^2 \ (R^2_{adj} = 0.890) \quad (1)$$

$$Y_2 = 5.983 \times 10^{-2} + 1.352 \times 10^{-3}A - 6.914 \times 10^{-6}A^2 + 3.154 \times 10^{-4}B^2 - 9.385 \times 10^{-6}C^2 \ (R^2_{adj} = 0.742) \quad (2)$$

$$Y_3 = -2.846 + 3.528 \times 10^{-2}A + 1.364 \times 10^{-2}B + 1.292 \times 10^{-1}C - 1.004 \times 10^{-4}A^2 - 1.170 \times 10^{-3}AC - 1.158 \times 10^{-3}C^2 + 2.334 \times 10^{-6}A^2C + 4.196 \times 10^{-6}ABC + 6.441 \times 10^{-6}AC^2 \ (R^2_{adj} = 0.772) \quad (3)$$

$$Y_4 = 8.318 - 4.357 \times 10^{-3}A + 4.079 \times 10^{-4}AB - 1.455 \times 10^{-3}B^2 + 6.214 \times 10^{-7}A^2C - 1.108 \times 10^{-5}ABC + 3.798 \times 10^{-5}B^2C \ (R^2_{adj} = 0.739) \quad (4)$$

$$Y_5 = 1.301 \times 10^2 - 8.619 \times 10^{-3}C^2 - 1.685 \times 10^{-4}A^2B + 3.362 \times 10^{-5}A^2C - 3.028 \times 10^{-3}AB^2 + 7.498 \times 10^{-4}ABC + 5.345 \times 10^{-3}B^2C + 1.860 \times 10^{-3}C^2B \ (R^2_{adj} = 0.732) \quad (5)$$

$$Y_6 = 1.559 \times 10^2 - 2.807 \times 10^{-2}B - 3.569 \times 10^{-3}C + 1.141 \times 10^{-3}B^2 + 7.065 \times 10^{-4}BC - 2.922 \times 10^{-5}B^2C \ (R^2_{adj} = 0.742) \quad (6)$$

Where Y_1, Y_2, Y_3, Y_4, Y_5 and Y_6 are drying rate, water loss, solid gain, ash content, vitamin A and vitamin C respectively; and A, B and C are osmotic process duration, osmotic solution

concentration and osmotic solution temperature respectively.

Montgomery *et. a.l* (1998) reported that R^2_{adj} (adjusted coefficient of multiple determination) values measure the amount of reduction in variability between the outputs with respect to the input. From model equations developed, drying rate had the highest value of 0.890(89%) for R^2_{adj} and the lowest value of 0.732(73.2%) was obtained for vitamin A. These values were also close to the R^2 (coefficient of multiple determination) which were 0.901, 0.758, 0.787, 0.781, 0.795 and 0.782 for drying rate, water loss, solid gain, ash content, vitamin C and vitamin A respectively. The closeness of values between R^2 and R^2_{adj} is an indication that model equations developed are adequate (David *et al.,* 1998). However, it was also reported in Montgomery *et. al.,* (1998) that high R^2 value should not be used to conclude that a model equation is good or bad for its intended purposes. Therefore a further operation in terms of validation of models was carried out.

Model Validation Checking

The ultimate goal of model validation is to make the model useful, addressing the right problems and ensure it provides accurate information about the system being modelled such that it can actually be put to use (Macal, 2005).

Models validation for this study was done by subjecting both the observed and predicted values of process outputs to paired t-test. The correlation coefficients from the test were 0.9010, 0.7580, 0.7870, 0.7810, 0.7820 and 0.7950 for drying rate, water loss, solid gain, ash content, vitamin A and vitamin C respectively. The high correlation coefficients (above 75 percent) exhibited by all the process model equations is an indication that they were able to well describe the process characteristics with reasonable level of reliability. The mean difference between observed and predicted outputs was also determined, the result showed -0.0004 for water loss and 0.0000 for other outputs. Also, the standard errors obtained for each model equation were 0.0064 for drying rate, 0.0033 for water loss, 0.001 for solid gain, 0.8259 for vitamin C, 0.0027 for vitamin A and 0.0114 for ash content. All these lower values are also reliably used for prediction, estimation and so on. Taheri-Garavand *et al* (2011) and Darvishi *et. al.,* (2013) also worked on the modelling of bell pepper; the approach they used for testing and selecting the best models were the use coefficient of multiple determination(R^2), chi-square values(X^2), Root Mean Square Error (RMSE). Darvishi *et. al.,* (2013) got R^2(0.927), X^2(0.2065) and RMSE (0.0555) and Taheri-Garavand *et. al.,* (2011) got R^2(0.99201), X^2(0.00003492) and RMSE (0.00481743).

Process optimization

The optimized results are as follows: osmotic process duration (A) of 60 minutes, osmotic solution concentration (B) of 5% (w/w) and solution temperature(C) of 30ºC gave a maximum drying rate of 4.26 g/h. The maximum Solid Gain (g/g) value of 0.91 was achieved by combining osmotic process duration (A) of 150 minutes, with osmotic solution concentration (B) of about 20% (w/w) and osmotic solution temperature(C) of 49.0°C. The maximum value of water loss of 0.24(g/g) was achieved with the combination of osmotic process duration (A) of 97.7minutes, osmotic solution concentration (B) of 20%(w/w) and osmotic solution temperature of 30°C. This combination gave the maximum value. The optimum value of Vitamin C was achieved with the combination of 150 minutes osmotic process duration (A), osmotic solution concentration (B) of 20% (w/w) and osmotic solution temperature of 30°C. This combination gave the maximum value of 155.82 mg/100g of Vitamin C.

Furthermore, the optimum value of Vitamin A was achieved with the combination of osmotic solution concentration of 11.7% (w/w) and osmotic solution temperature of 60°C. The combination gave a maximum value of 1.42 mg/100g. Finally, the optimum (minimum) value of ash content (8.04%) was achieved by combining osmotic Process duration of 126.2 minutes, osmotic solution temperature concentration of 19.6% (w/w) and osmotic solution temperature of 60°C.

Conclusions

The empirical model equations developed were found to have described the drying characteristics and qualities of red bell pepper very well and sufficiently predicted all output parameters. Therefore, these models can be applied for industrial drying of red bell pepper

under different process pretreatments. The optimization of the validated models gave optimum drying rate(maximum), solid gain(maximum), water loss(maximum), vitamin C(maximum), vitamin A(maximum) and ash content(minimum) of 4.26 g/h, 0.91 g/g, 0.24 g/g, 152.82 mg/100g, 1.42 mg/100g and 8.04 % respectively. Further studies should also be carried out on the factors that affect the storability of dried osmo-pretreated red bell pepper for long-time preservation and storage under different storage conditions.

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