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Modelling and optimization of the drying process and the quality parameters of dried osmo-pretreated onions (*Allium cepa*)

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ABSTRACT

Modelling and optimization represent an important aspect of drying in food processing, providing a fast and convenient means for quality prediction. The research focuses on modelling and optimization of process parameters such as drying rate, water loss, solid gain, vitamin C, manganese, and iron of dried osmo-pretreated onion slices. Least square regression analysis in the Math-lab computer software was used to model and optimise the process parameters. Six (6) mathematical models were developed for each output from the regression analysis that was carried out. The criteria for adjudging these models were the values of their adjusted coefficient of multiple determinations, prediction error sum of squares (also called deleted residual), R^2 for prediction, coefficient of variation CV, and the Dubin-Watson test for autocorrelation. The models were checked for adequacy using these criteria, and those found to be adequate were selected from among the other possible combinations. Hence, the best-optimized obtained results from the models are 27.50 g/h, 1.61 g/g, 0.15 g/g, 77.52 mg/100 g, 2.79 mg/1000 g, and 2.19 mg/1000 g for drying rate, water loss, solid gain, vitamin C, manganese, and iron, respectively.

Introduction

Onion (*Allium cepa*) is an important underground vegetable, which is rich in micronutrients (i.e., vitamin K, vitamin C, and B6) and macronutrients (i.e., iron, manganese, potassium, and phosphorous) and serves as a spice to other food substances (Lanzotti, 2006). Several studies on the health benefits of onions, including the prevention of heart diseases, natural detoxification, mental alertness, and reversing the oxidative process that is responsible for human cancer, have been reported (Ansar et al., 2013). Onions are susceptible to spoilage after harvest, with about 40 – 50% post-harvest loss (Alabi et al., 2016). Drying offers long time preservation of food materials (Kumar et al., 2012). Onions can be dried from an initial moisture content of about 82% to 8% or less, a moisture

content safe for storage and processing. In addition, drying reduces products' weight and volume significantly and therefore decreases the cost of transportation and storage (Kalse et al., 2017). Convention dryers such as a cabinet tray dryer can be used in drying agricultural products, but major disadvantages of this method include the loss of nutrients and non-uniform drying (Mota et al., 2010). The loss of nutrients is caused by long exposure time to heat and can be checked by reducing the load (i.e., partial removal of moisture present in the food matrix). However, a combination of osmo-dehydration and drying is a better alternative method for drying agricultural products (Alabi et al., 2018). Drying is a complex process that involves heat and mass transfer with changes in physical and chemical properties (Jaiyeoba and Raji, 2012).

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On the other hand, modelling and optimization is an essential tool that provides information on the drying process and demonstrates a fast method for quality prediction. Several techniques have been developed for modelling the food drying process (Arun et al., 2014; Kumar et al., 2012; Taheri-Garavand et al., 2011). Among numerous techniques, the one unique method, which is novel, is the use of least square regression analysis (LSRA). LSRA is simple and accurate and has been used to model the drying process of root vegetables (Dasore et al., 2020) and pepper (Odewole et al., 2016). To the best of our knowledge, this method has not been used for modelling of the drying process of osmo - dehydrated onions. Therefore, the aim of the study was to model and optimise the drying process and some qualities of osmo-dehydrated onions.

Materials and methods

Experimental equipment and materials

The major equipment and materials used for the experiment included a fabricated cabinet dryer, a thermostatic water bath (HH-W420, XMTD-204 Model), a sensitive weighing balance (OHAUS CL Series, Model CL 201, China), a stopwatch, a hand-held thermometer, a desiccator with desiccant, measuring cylinders, a stainless-steel knife and trays, hand gloves and foil paper. Other materials include distilled water, salt, and fresh onions.

Experimental design

A 4³ factorial experiment in a randomized complete block design (RCBD) was used to design the experiment (Alabi et al., 2016). An essential regression in the Math-lab software package (model R2009b) was applied. Four levels of osmotic solution concentrations (OSC) of common salt (5, 10, 15, and 20% w/w), four levels of osmotic solution temperature (OST) (35, 40, 45, and 50 °C), and four levels osmotic process duration (OPD) (30, 60, 90, and 120 minutes) were introduced into the experimental design interface of the software to generate all combinations between the three process conditions.

Experimental procedure

Fresh onions of better grade were procured from Ipata market in Ilorin, Kwara State, Nigeria. They were kept in a ventilated area of the crop processing and storage laboratory, Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin,

Kwara State for 24 hours to attain room temperature. Other procedures demonstrated by Alabi et al., (2016) were used. Onion samples were washed with distilled water and sliced into a uniform thickness of 3 mm with the use of a stainless knife on a stainless-steel tray. Sliced onions (50 g) were introduced into the water bath, continuously stirred to maintain a uniform temperature of not more than ± 1 °C containing the osmotic solution for each pretreatment combination. At the end of the pretreatment, a non-uniform mass of between 42 – 48 g was achieved. During the last stage of sample pretreatment, the power of the cabinet tray dryer was switched on, and the drying temperature (60 °C) was set by a thermocouple device. 40 g of each pretreated sample was then introduced into the dryer. A regulated temperature of 60 °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. This process continued until a crispy texture was felt on the sample, indicating dryness with a moisture content not greater than 7% (db). The drying process lasted for five hours to completion. All the dried samples were arranged inside the desiccator and were checked for nutritional analysis within 24 h. The average room temperature and relative humidity of the study area were 31 °C and 65%, respectively, throughout the period of the experiment.

Output parameters

Drying rate, water loss, and solid gain were estimated using the equation given by Alabi et al. (2016). Quality parameters in terms of vitamin C, manganese, and iron content were determined using the AOAC (2002) standard.

Data analysis and model development

The process modelling technique in the essential regression software package of the Math-Lab computer software was used, the data obtained for vitamin C, manganese, iron, drying rate, water loss, and solid gain were modelled using all the possible relationships between the process conditions via: OSC, OST, and OPD, and the measured outputs (vitamin C, manganese, iron, drying rate, water loss, and solid gain). However, the models that better captured the relationship between the input and output parameters were selected. This was done by exploring the individual relationships among the input parameters, one at a time and keeping others constant to ensure clear interpretations and avoid ambiguity. The best performing functional models were developed from the regression analysis that was

carried out, one for each measured parameter, as seen in equations 1 to 6 for drying rate, water loss, solid gain, vitamin C, manganese, and iron, respectively. The criteria for adjudging these models were the value of their adjusted coefficient of multiple determinations R^2 , prediction error sum of squares PRESS (also called deleted residuals), R^2 for prediction, coefficient of variation CV, and the Durbin-Watson test for autocorrelation. The models were checked for adequacy using these statistics, and those found to be adequate were selected from among the other possible combinations of the models.

Results and discussion

Developed models relating process conditions and process outputs

The empirical model equations, as shown below, proved that the process parameters and their interactions influenced the outcome of the drying rate, water loss, solid gain, and vitamin C, manganese, and iron. The best output parameters are taken at the peak R^2 value. Meanwhile, the results of the effect of the process inputs on the output parameters have been published by Alabi et al. (2016).

Drying rate (g/h) = $9.099732 + 0.646776A + 0.617558B - 0.016117AB - 0.005815AC - 0.004511B^2 + 0.001917BC + 0.000138ABC - 0.000046B^2C$
($R^2 = 0.98$) (1)

Weight loss (g/g) = $-5.423045 + 0.219767A + 0.340183B + 0.036415C - 0.010986AB - 0.004094B^2 - 0.001773BC + 0.000135AB^2 + 0.000021B^2C$
($R^2 = 0.99$) (2)

Solid gain (g/g) = $0.13501092 + 0.06745007A - 0.00305530AB - 0.00004845B^2 - 0.00000407A^2B + 0.00000145A^2C + 0.00003624B^2 - 0.00000014AC^2$
($R^2 = 0.98$) (3)

Vitamin C (mg/100g) = $-2.74.3532 + 10.9884A + 17.0092B + 1.8207C - 0.5493AB - 0.2047B^2 - 0.0886BC + 0.0067AB^2 + 0.0011B^2C$
($R^2 = 0.98$) (4)

Manganese (mg/1000g) = $0.631636 + 0.028076B + 0.008114C + 0.000041A^2B - 0.000010ABC$
($R^2 = 0.98$) (5)

Iron (mg/1000g) = $2.290000 + 0.2028344A - 0.031302C - 0.015081A^2 - 0.005702AB + 0.002513AC + 0.000643BC + 0.000380A^2B$
($R^2 = 0.99$) (6)

Model adequacy checking

Model adequacy was checked using regression statistics and the graphical method. The adjusted coefficient of multiple determinations, which defined the percentage of total variability explained by the model, is high for all process outputs, as shown in Table 1. These high percentages of total variability explained by the models imply good fits. The coefficient of multiple determinations (R), is preferred to R^2 -adjusted, because it takes into account the degrees of freedom in the model. Table 1 shows that the values of the coefficient of multiple determinations (R), R^2 -adjusted, and R^2 for predictions are relatively close and not greater than one for all process parameters. This is an indication that the models developed are good and in agreement with the submission of David *et al.*, (1998).

The prediction error sum of squares (PRESS), another statistics tool, was used to guarantee a good fit, as models with lower PRESS imply good fit, as shown in Table 1. This is also in agreement with the finding of Arun *et al.* (2014). As shown in the Table 1, the models developed for all the output parameters were significant at 5% levels of significance, as shown by their associated probability value (P-value), which implies that the model building process is statistically adequate.

Table 1. Statistics for checking the adequacy of the model equations

Output variables	Vitamin C (mg/100 g)	Manganese (mg/1000 g)	Iron (mg/1000 g)	Drying rate (g/h)	Water loss (g/g)	Solid gain (g/g)
R	0.95	0.90	0.94	0.92	0.93	0.97
R^2	0.98	0.98	0.99	0.98	0.99	0.98
R^2 adjusted	0.90	0.83	0.80	0.87	0.85	0.78
Standard Error	6.85	0.47	0.39	0.81	0.14	0.02
PRESS	53.86	42.46	30.67	31.97	3.82	0.10
R^2 for Prediction	0.88	0.81	0.79	0.84	0.81	0.82
Durbin-Watson Test	1.90	1.82	1.63	1.26	1.90	1.21
First Order Autocorrelation	0.04	0.09	0.18	0.37	0.04	0.40
Model P-Value	0.05	0.01	0.04	0.02	0.05	0.01
Coefficient of Variation	9.24	19.81	20.09	3.07	8.85	29.83

Where: g/g – is a dimensionless unit (g/g)

Model validation

Model validity was done to ensure that the models developed were accurate and useful to predict and provide accurate information on the drying process of osmo-pretreated onion slices. Graphical and statistical approaches in the residual analysis (i.e., normal probability plots of the residuals and plots of the

residuals vs. the predicted response methods) were used for this purpose, as shown in Figures 1 to 12. From the graphical illustrations, the developed models displayed the residual errors approximately distributed with a fixed location and scale, shown outliers, and suggested a better fit; conditions necessary for the model-fitting process (Odewole et al., 2016).

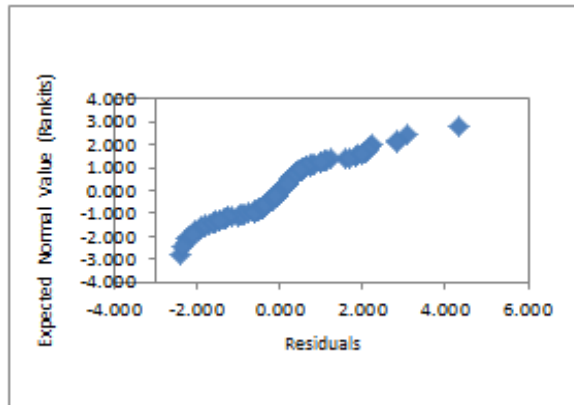


Fig. 1. Expected Normal Value (Rankits) vs. Residuals for Drying Rate (g/h)

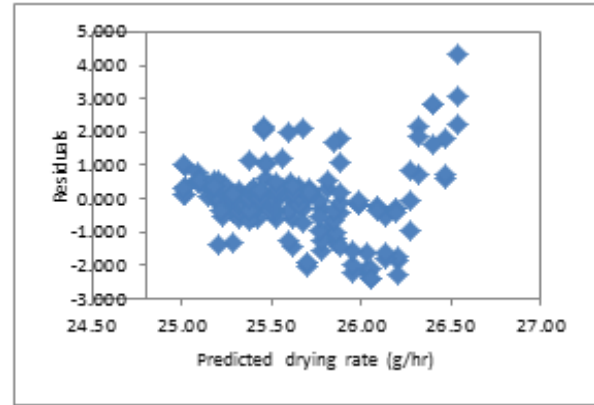


Fig. 2. Residuals vs. Predicted Drying Rate (g/h)

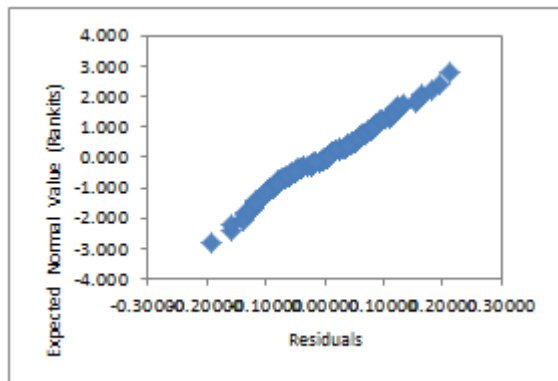


Fig. 3. Expected Normal Value (Rankits) vs. Residuals for Water Loss (g/g)

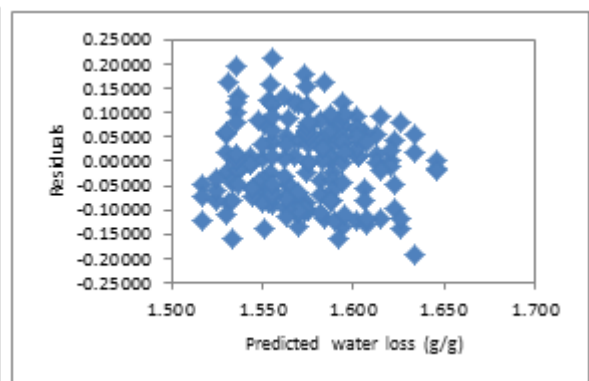


Fig. 4. Residuals vs. Predicted Water Loss (g/g)

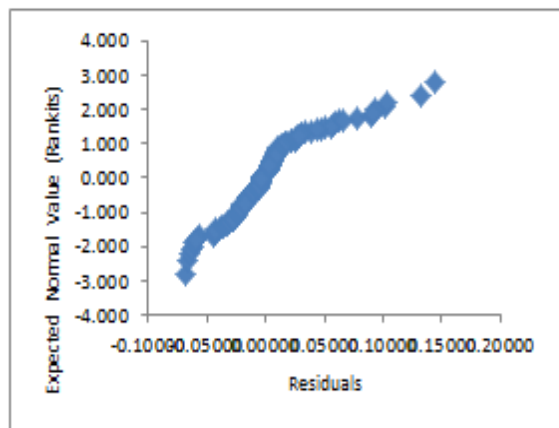


Fig. 5. Expected Normal Value (Rankits) vs. Residuals for Solid Gain (g/g)

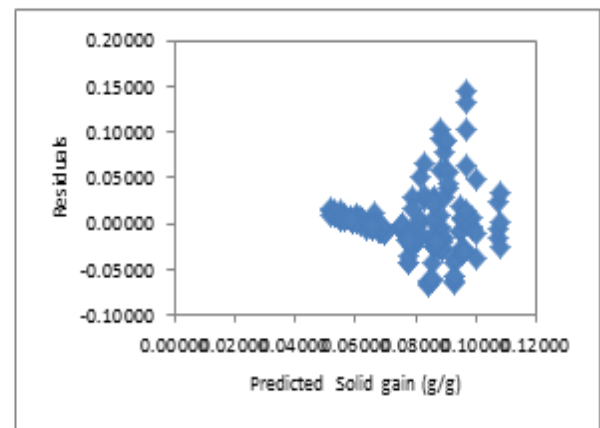


Fig. 6. Residuals vs. Predicted Solid Gain (g/g)

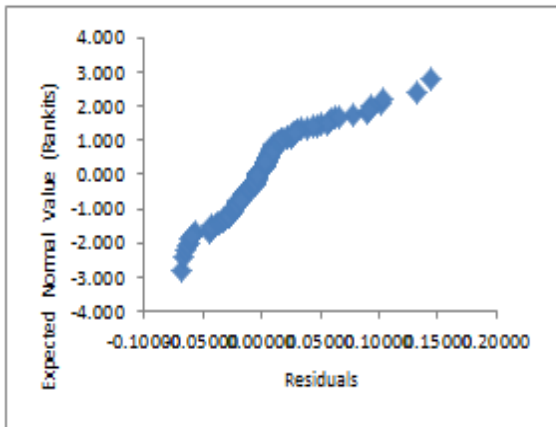


Fig. 5. Expected Normal Value (Rankits) vs. Residuals for Solid Gain (g/g)

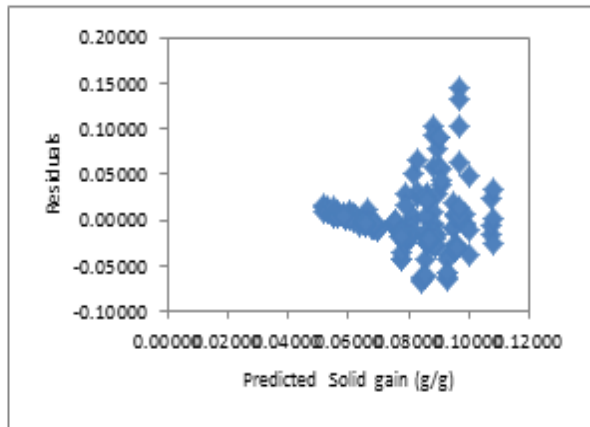


Fig. 6. Residuals vs. Predicted Solid Gain (g/g)

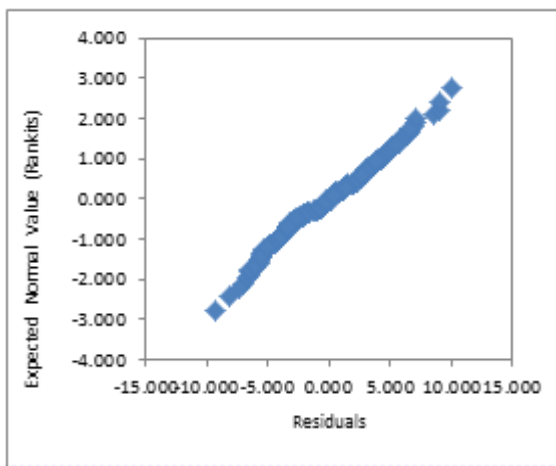


Fig. 7. Expected Normal Value (Rankits) vs. Residuals for Vitamin C (mg/100 g)

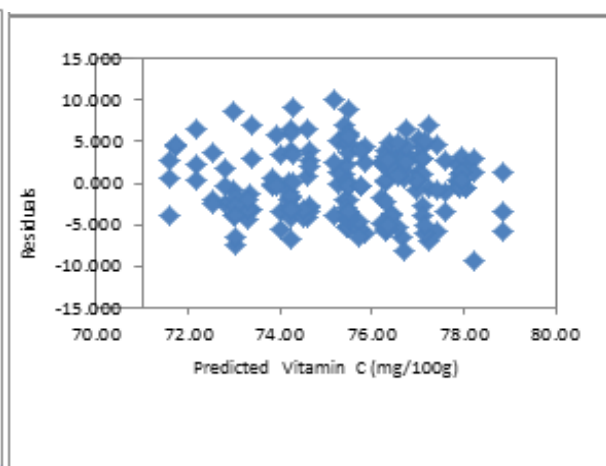


Fig. 8. Residuals vs. Predicted Vitamin C (mg/100 g)

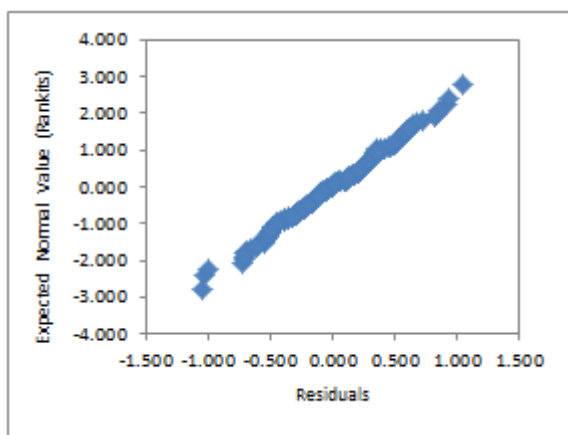


Fig. 9. Expected Normal Value (Rankits) vs. Residuals for Manganese (mg/1000 g)

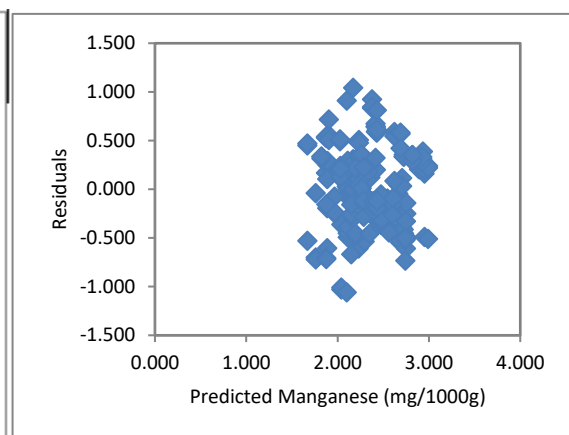


Fig. 10. Residuals vs. Predicted Manganese (mg/1000 g)

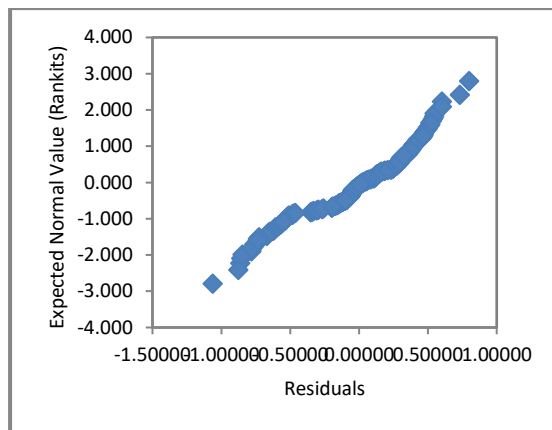


Fig. 11. Expected Normal Value (Rankits) vs. Residuals for Iron (mg/1000 g)

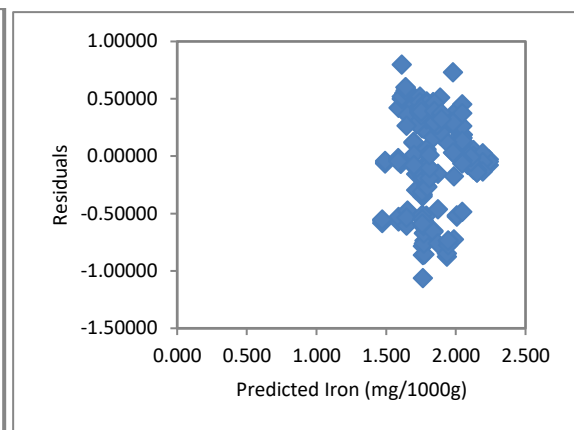


Fig. 12. Residuals vs. Predicted Iron (mg/1000 g)

Table 2. Optimum value for the process parameters and process outputs

Process input parameters	OSC (% w/w)	OST (°C)	OPD (minutes)	Optimized value	Goal	
Output parameters	Vitamin C	5	40	30	77.52	Maximized
	Manganese	20	50	30	2.79	Maximized
	Iron	20	35	120	2.19	Maximized
	Drying rate	5	50	30	27.50	Maximized
	Water loss	5	40	30	1.61	Maximized
	Solid gain	20	35	90	0.15	Maximized

Plots of the residuals vs. the predicted response

Figure 1 shows a typical normal probability plot of the expected normal values (Rankit) vs. the residuals for drying rate, while Figure 2 examines the error structure to ensure that the residual behaves as expected, such that the errors are distributed normally. The graphs clearly show that the residual plots are not heavy-tailed, rather spread about the straight line for all the observed output parameters. This implies that the assumption of normality of the residuals was not violated. Also, the assumption of constant error variance was also checked using the plots of residuals vs. predicted responses. The plots of residuals vs. predicted responses show bands around with constant width for all the observed output parameters. This implies that the error variance is stable with respect to predicted responses. The advantage of using the graphical approach is that it readily illustrates a broad range of complex aspects of the relationship between the model and the data (Macal, 2005). Also, the different types of plots of the residuals from a fitted model provide information on the adequacy and validity of the different aspects of the model.

Optimization results

Optimization basically deals with finding optimum (maximum or minimum) settings of parameters (process conditions) in a mathematical model, in order to obtain a desired output or response value. The

optimized values of process parameters pre-set at their various levels and the optimum values of the process outputs are as presented in Table 2. Water loss, solid gain, drying rate, vitamin C, manganese, and iron were maximally optimized so as to ensure high quality and safe prediction for process design.

From table 2, drying rate, water loss, and solid gain provided maximized values of 27.50 g/h, 1.61 g/g, and 0.15 g/g, respectively, and vitamin C, manganese, and iron provided maximized values of 77.52 mg/100 g, 2.79 mg/1000 g, and 2.19 mg/1000 g, respectively, with the best combinations of process parameters.

Conclusions

Empirical models were successfully developed for process parameters of osmo - dried onion slices in a cabinet tray dryer. Six model equations that showed the relationship between the process parameters and the output parameters were developed. Optimum values of the output parameters were determined with respect to process parameters using the model equations developed. Maximum drying rate, maximum water loss, and maximum solid gain of 27.50 g/h, 1.61 g/g, and 0.15 g/g were obtained, respectively, whereas, maximum vitamin C, maximum manganese, and maximum iron of 77.52 mg/100 g, 2.79 mg/1000 g and 2.19 mg/1000 g respectively, were also obtained. All the model equations are adequate and valid, and are considered

reliable tools for estimating, predicting, and conducting the analysis of the osmo-drying process of onion slices.

Author Contributions: Kehinde Peter Alabi performed the experiment and collected and analysed the results, A. M. Olaniyan analysed the result and did the modelling and optimization, while O. M. Sunmonu wrote the manuscript.

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Appendix

Where:

OSC = Osmotic Solution Concentration (% w/w)

OST = Osmotic Solution Temperature (°C)

OPD = Osmotic Process Duration (minutes)

Vit.C = Vitamin C (mg/100 g)

Mn = Manganese (mg/1000 g)

Fe = Iron (mg/1000 g)

DR = Drying rate (g/h)

WL = Water loss (g/g)

SG = Solid gain (g/g)

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