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ORIGINAL RESEARCH PAPER

EMPIRICAL MODELING OF THE EFFECTS OF MAGNETIC FIELD PRETREATMENT ON THE DRYING RATE OF SWEET PEPPER AND FLUTED PUMPKIN LEAF

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Abstract: Empirical modeling of the effects of magnetic field pretreatment on the drying rate of sweet pepper and fluted pumpkin leaf was done. Static, pulse and alternating magnetic fields were used in conjunction with magnetic field strength (5 - 30 mT) and pretreatment time (5 - 25 min) as the combined pretreatment factors. All samples were dried at 50 °C after pretreatment and the drying rate was estimated. Data obtained were used to produce bar charts that showed statistical effect of magnetic field pretreatment on the drying rate. Same set of data were also used to develop empirical model equations. Results showed that most of the magnetic field pretreatment combinations caused the drying rate of SP (20 - 21 $g\cdot h^{-1}$) and FPL (10 - 12.50 $g\cdot h^{-1}$) to be significantly higher than the drying rate of blanched samples of SP (17 $g\cdot h^{-1}$) and FPL (8 $g\cdot h^{-1}$) at $P \leq 5\%$. Also, there are six (6) empirical model equations that reliably described the characteristics of the process with R^2 (88 - 98 %); R^2_{adj} (83 - 95 %); coefficients of variation (0.88 - 3.80); standard error (0.11 - 1.07); mean of residuals (-0.0008 - 0.0002); standard deviation (0.16 - 1.19); probability values (0.0000 - 0.0007) and adequate precision values (6.80 - 25.46).

Keywords: *emerging technology, functional relationship, non-thermal, thermal, vegetables*

INTRODUCTION

Food drying is the removal of enough or pre-determined moisture from food with the aim of preventing spoilage, improving eating quality, ensuring all year round supply of food, reduction of storage space and transportation cost; and extension of shelf life [1, 2]. It is also a thermo-physical and physico-chemical actions that is governed by simultaneous heat and mass transfer processes [3]. One of the basic principles governing the process of drying is the creation of vapor pressure gradient between the product to be dried and the surrounding air [4]. In order to achieve hot air drying of any product, the vapor pressure of the product and that of the surrounding air must be properly adjusted. Drying will take place when the vapor pressure of the product is greater than that of the surrounding air; with this, moisture will migrate from the product to the surrounding air. The mechanisms governing the movement of moisture and vapor (mass transfer) inside a porous material is due to thermal diffusion, vapor diffusion, hydrodynamic flow, capillary flow, liquid diffusion and surface diffusion [5]. Drying rate is the mass of water removed per unit time [6]; and it is a function of moisture content of the product [7]. Drying rate is one of the important parameters needed in drying kinetics studies [8 – 11]; and substantial information exists on it [12].

A model is a simplified version of reality [13]. Models can be in form of functional equations or expressions that are used as important tools for making prediction and estimation, and for system analyses [14]. It is to be noted that only model equations that reliably described the behavior of a system can be used for analyzing the system. Selection of reliable model equations is through adequacy and validity checking, and this can be done numerically or graphically. The numerical method uses some of the following parameters to adjudge reliable models: R-squared values, R-squared (adjusted) values, T-test values, mean square error, probability value, chi-square, prediction error sum of square, standard error and coefficient of variation. The graphical method uses graphs of observed and predicted values; observed values (Rankit) versus residual; and residual versus predicted values. Computer softwares/applications are now employed for modeling process; this ensures faster execution of task and reduction of human errors of the manual process. Essential regression (ESSREG) computer software package was used to model mass transfer parameters of osmosised red bell pepper [15]; and equations developed were validated numerically and graphically, and were found to reliably describe the behavior of the process. Response surface methodology in Design Expert software package was used to model the drying of osmo-pretreated carrot [16]. Moreso, Microsoft solver was used to model the thin layer drying kinetics of cocoa beans during artificial and natural drying [17].

Sweet pepper (SP) is a fruit vegetable and fluted pumpkin leaf (FPL) is a leafy vegetable. They are botanically referred to as *Capsicum annum* and *Telfairia occidentalis* respectively. They both have medicinal and nutritional properties beneficial to human beings; for example, they contain antioxidants and can regulate the cholesterol level of human body [18]. Specifically, SP cures cataracts, arthritis, lung cancer, diabetes, rheumatism and fever. FPL improves blood level and has anti-inflammatory characteristics. Fruits and vegetables are pretreated with the aim of improving their nutritional, sensory and other qualities as well as to enhance further processing steps. Food pretreatment/processing can be done conventionally or non-conventionally [19]. Blanching, thermal sterilization, thermal pasteurization, salting and manual size and shape adjustment are some typical examples of the conventional method; whereas, Pulse Electric Field (PEF), microwave heating, *sous vide*, ohmic heating and application of magnetic field are some typical examples of the non-conventional method. Magnetic field is a region of space that is capable of inducing surrounding bodies [20]. Magnetic field utilization in the field of food processing is still trying to gain proper recognition. Therefore, it can be considered as an emerging/novel technology of processing food to value added products because it is still gradually evolving. Magnetic fields are classified according to their relative strength as low or high intensity; according to the variation of intensity over space as homogeneous or non-homogeneous; and variation of intensity with time as static or pulse [21]. It has been reported that when living things (foods inclusive) are placed within magnetic field, the magnetic field will interact with them [22]; this will cause modification of the properties of the food just the way other forms of food pretreatment will do. The modification done might lead to better (or otherwise) retention/improvement of sensory, functional and nutritional qualities or other attributes of the food. Although some few literatures exist on the use of magnetic field for food processing [23 - 28]; however, none of the literatures specifically addressed the effect of magnetic field pretreatment on the drying rate of the products used and modeling of the process. Therefore, the objectives of this study were to investigate the effect of three types of magnetic fields-Static Magnetic Field (SMF), Pulse Magnetic Field (PMF) and Alternating Magnetic Field (AMF); magnetic field strength and pretreatment time on the drying rate of sweet pepper and fluted pumpkin leaf; and to develop empirical models in form of equations that reliably described the behavior of the process.

MATERIALS AND METHODS

The following equipment and materials were used for the study: a magnetic field pretreatment device; electronic weighing balance (OHAUS, Model 201, China), fresh samples of sweet pepper and fluted pumpkin leaf; laboratory oven (Model SM9053, England), stainless steel knife and trays. Fresh samples of sweet pepper (SP) and fluted pumpkin leaf (FPL) were procured and prepared for the pretreatment process. Design Expert software (version 6.0.6) was used to design the standard layout of the experiment as shown in Table 1. This was done by incorporating into the experimental design interface of the software the following pretreatment factors: magnetic field type (SMF, PMF and AMF), magnetic field strength (5 - 30 mT) and pretreatment time (5 - 30 min). This made a total of 100 experimental runs with the inclusion blanched and fresh samples as controls. The electronic weighing balance was used to measure uniform experimental quantity per run for SP (100 g) and FPL (10 g). Measured samples were placed in the MF pretreatment device and different combinations of the pretreatment factors were selected according to the experimental layout. After the pretreatment, all samples were immediately dried at 50 °C inside the laboratory oven and drying rate was estimated using standard procedure [29]. The experiment took place at the laboratory of the Department of Food Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin, Nigeria in December 2018. The average temperature and average relative humidity of the laboratory during the drying of all samples were taken with a portable thermo-hygrometer; and the average values obtained were 32 °C and 63 % respectively. All the data obtained from the estimation of drying rate were introduced into Excel 2013 sheet and data analysis interface of the Design Expert software for plotting of bar charts/statistical analysis to investigate the effect of the three pretreatment factors on the drying rate of SP and FPL and for the development of empirical model equations respectively.

Table 1. *Experimental design and layout*

SN	SMF/PMF		AMF	
	SP/FPL		SP/FPL	
	MFS [mT]	PT [min]	MFS [mT]	PT [min]
1	13.5	5	9.5	5
2	19.0	25	5.0	25
3	19.0	25	9.5	25
4	19.0	15	9.5	15
5	19.0	15	5.0	15
6	8.0	15	9.5	15
7	8.0	5	14.0	5
8	19.0	15	9.5	15
9	19.0	15	9.5	15
10	24.5	15	14.0	15
11	30.0	5	5.0	5
12	30.0	15	9.5	15
13	19.0	25	14.0	25

SMF-Static Magnetic Field; **PMF**- Pulse Magnetic Field; **AMF**-Alternating Magnetic Field; **Output-** Drying Rate; **MFS**-Magnetic Field Strength (A); **PT**-Pretreatment Time (B)

RESULTS AND DISCUSSION

Effect of magnetic field (MF) pretreatment on the drying rate of SP and FPL

The effect of MF pre-treatment on the drying rates of SP and FPL are presented in Figures 1 and 2. The drying rates of most MF pretreated SP and FPL are higher than the drying rates of blanched and fresh samples. Higher drying rate implies that the two products will spend less time in the drying medium, this will most likely prevent the loss or over depletion of heat sensitive nutrients, thereby leading to better retention/improvement of nutritional and sensory qualities. Also, it will reduce the cost of energy needed for drying. Specifically, the figures show that the drying rate of MF pretreated SP is about 20 - 21 $g \cdot h^{-1}$ at AMF-2, AMF-4, PMF-5, AMF-5, SMF-6, SMF-7, PMF-8 and PMF-9; and are significantly higher than the drying rate of the blanched sample (17 $g \cdot h^{-1}$) at 5 % probability value. Similarly, the drying rate of MF pretreated FPL is about 10 – 12.50 $g \cdot h^{-1}$ at SMF-1, SMF-2, PMF-2, SMF-3, PMF-3, SMF-5, PMF-5, AMF-5, SMF-6, PMF-6, SMF-6, PMF-7, SMF-9 and PMF-9; this is significantly higher than the drying rate of the blanched sample (8 $g \cdot h^{-1}$) at 5 % probability value. The possible reasons for the higher drying rate of the MF pretreated samples than the blanched samples could be the impact of the distinct characteristics of the types of MF (SMF, PMF and AMF) used with different combinations of magnetic field strength and pretreatment time. That is, static, pulse and alternating magnetic fields have different characteristics on voltage or current-time graph [30]. These characteristics imposed different effects on the pretreated samples. Some of these effects might be softening or rupturing of the structures of the products or creation of more pores or widening of existing pores within the structures of SP and FPL. This situation will lead to faster rate of moisture migration (mass transfer) during drying. Pretreatment of red paprika with High Electric Field Pulses (HELP), High Hydrostatic Pressure (HHP) and water blanching increased its drying rate [31]. Similarly, Osmotic dehydration pretreatment of litchi pulp increased its drying rate [32]. The findings of the two aforementioned literatures are in agreement with those of the magnetic field pretreated SP and FPL of this research.

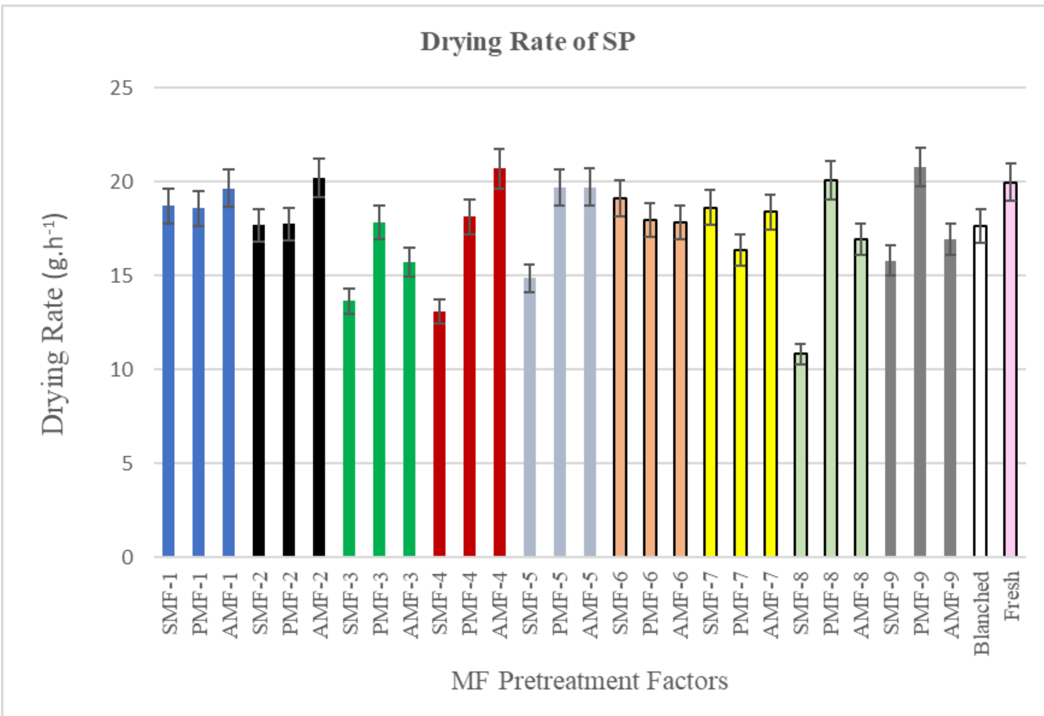

Figure 1. *Drying rate of MF pretreated SP*

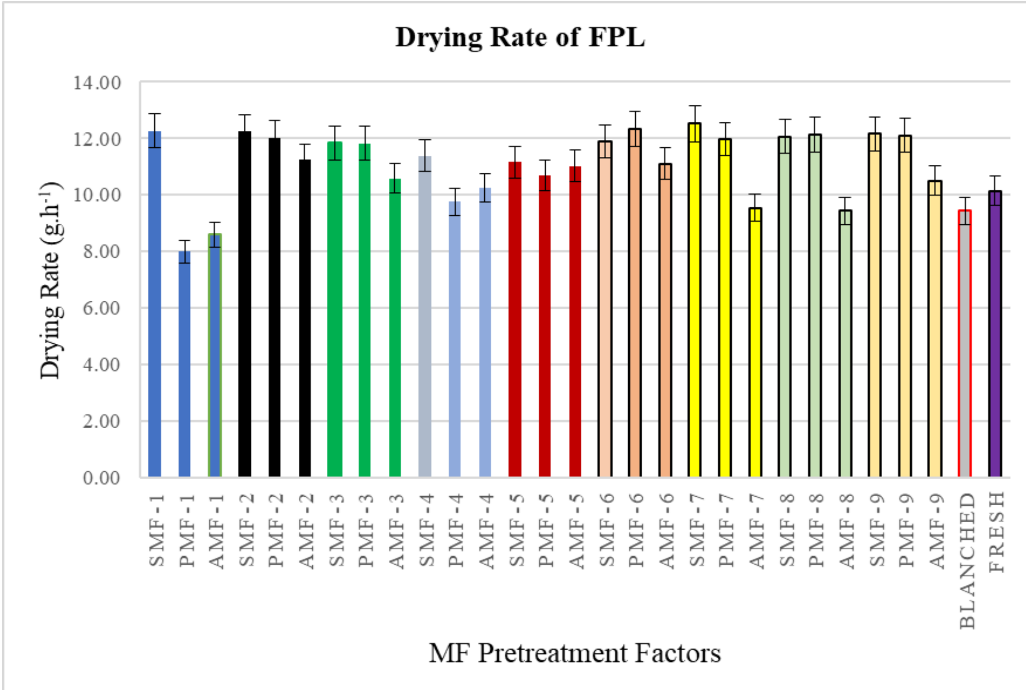

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Figure 2. *Drying rate of MF pretreated FPL*

Developed model equations of the drying rate MF pretreated SP and FPL

The parameters used for selecting all model equations based on adequacy checking and validation process were presented in Tables 2 and 3. R^2 (co-efficient of multiple determination), R^2_{adj} (adjusted coefficient of multiple determination), CV (coefficient of variation), AP (adequate precision), SE (standard error), SD (standard deviation), P-value (probability value) and MR (mean of residuals) are the specific parameters used. For SP, the range of values of R^2, R^2_{adj}, CV, AP, SE, SD, P-value and MR are 93 - 98 %, 89 - 95 %, 0.88 - 3.42, 8.43 - 25.46, 0.25 - 1.07, 0.16 - 1.19, 0.0000 - 0.0006 and -0.0008 - 0.0000 respectively. Similarly, for FPL, the range of values of R^2, R^2_{adj}, CV, AP, SE, SD, P-value and MR are 88 - 96 %, 83 - 92 %, 2.11 - 3.80, 9.67 - 14.57, 0.1 1 - 0.63, 0.28 - 0.64, 0.0001 - 0.0007 and -0.0077 - 0.0002 respectively. This approach is a numerical method of model checking. The main goal of model validation is to ensure that the model is useful in addressing the right problem and provide adequate information about the system under consideration [33]. From the tables, R^2 and R^2_{adj} are relatively close for the drying rates; also, the CV which is the unexplained variances in the data, given by the standard error of regression models was relatively small for all the models developed; this is an indication of goodness of fit and expected of good models [34]. The AP, which is the signal-to-noise ratio (it compares the range of predicted values at the design points to the average prediction error) of all models are greater than four (4), hence, they are all adjudged as good models [35]. Furthermore, P-values of all models are significant at $P \leq 0.05$, the models are good ones. The mean of residuals

(MR), that is, the mean of the difference between the actual values and the predicted values are not much, that means all the models are valid and can be reliably used for prediction, estimation, forecasting and analysis of the process. R^2 of 92.7 % [36] and 99.2 % [37] respectively were obtained for validation of bell pepper drying models. Also, the drying rate of validated models of sweet pepper processed with osmotic solution of salt and drying showed that about 90 % and 89 %, 0.000, 0.0064 were obtained for R^2, R^2_{adj}, MR and SE values [38].

Table 2. *Model equations selection parameters for the drying rate of MF pretreated SP*

	R^2	R^2_{adj}	CV	AP	SE	SD	P-value	MR
SMF	98 %	95 %	0.97	19.25	1.07	1.19	0.0000*	0.0000
PMF	98 %	95 %	0.88	25.46	0.25	0.16	0.0006*	-0.0005
AMF	93 %	89 %	3.42	8.43	0.38	0.65	0.0003*	-0.0008

CV-Coefficient of Variation, AP-Adequate Precision, SE-Standard Error, SD-Standard Deviation, P-Probability (*significant at ≤ 0.05), MR-Mean of Residual, adj-adjusted.

Table 3. *Model equations selection parameters for the drying rate of MF pretreated FPL*

	R^2	R^2_{adj}	CV	AP	SE	SD	P-value	MR
SMF	88 %	83 %	2.39	6.80	0.11	0.28	0.0004*	0.0002
PMF	93 %	88 %	3.80	14.57	0.63	0.43	0.0007*	0.0000
AMF	96 %	92 %	2.11	9.67	0.58	0.64	0.0001*	-0.0077

CV-Coefficient of Variation, AP-Adequate Precision, SE-Standard Error, SD-Standard Deviation, P-Probability (*significant at ≤ 0.05), MR-Mean of Residual, adj-adjusted.

The empirical model equations developed for the drying rates of SP and FPL under SMF, PMF and AMF are shown in Equations 1 to 6.

Developed model equations of the drying rate for MF Pretreated SP

$$-305.04 + 86.87A - 5.92B - 7.40A^2 + 0.20B^2 - 7.25 \times 10^{-2}AB + 0.27A^3 - 3.50 \times 10^{-4}B^3 - 3.55 \times 10^{-3}A^4\ (R^2 = 98\%) - \textbf{SMF} \quad (1)$$

$$14.17 + 1.70A - 0.66B - 0.10A^2 + 0.03B^2 + 2.17 \times 10^{-2}AB + 1.70 \times 10^{-3}A^3 - 4.08 \times 10^{-4}B^3\ (R^2 = 98\%) - \textbf{PMF} \quad (2)$$

$$-3.59 + 4.48A + 1.79B - 0.23A^2 - 0.02B^2 - 0.26AB + 0.01A^2B\ (R^2 = 93\%) - \textbf{AMF} \quad (3)$$

Developed model equations of the drying rate for MF pretreated FPL

$$11.13 + 0.04A + 6.57 \times 10^{-3}B\ (R^2 = 88\%) - \textbf{SMF} \quad (4)$$

$$19.79 - 1.39A - 1.27B + 0.13A^2 + 0.04B^2 - 3.03 \times 10^{-3}A^3\ (R^2 = 93\%) - \textbf{PMF} \quad (5)$$

$$16.65 - 2.50A - 0.55B + 0.16A^2 + 0.02B^2 + 0.26AB - 0.02A^2B - 6.83 \times 10^{-3}AB^2 + 4.73 \times 10^{-4}A^2B^2\ (R^2 = 96\%) - \textbf{AMF} \quad (6)$$

CONCLUSIONS

Most of the magnetic field pretreatment combinations caused the drying rates of SP (20 - 21 $g \cdot h^{-1}$) and FPL (10 - 12.50 $g \cdot h^{-1}$) to be significantly higher than the drying rates of blanched samples of SP (17 $g \cdot h^{-1}$) and FPL (8 $g \cdot h^{-1}$) at $P \leq 5$ %. Six (6) developed empirical model equations adjudged to reliably describe the characteristics of the process were selected on the basis of highest R^2 (88 - 98 %) and R^2_{adj} (83 - 95 %) values; lowest coefficients of variation (0.88 - 3.80), standard error (0.11 - 1.07), mean of residuals (-0.0008 - 0.0002) and standard deviation (0.16 - 1.19); significant probability values (0.0000 - 0.0007) and not less than 4 adequate precision values (6.80 - 25.46). Hence, all the model equations can be used as tools for predicting, estimating, forecasting and analyzing the process. Further research on the optimization of the process is recommended.

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