Drying Process Optimization and Modelling the Drying Kinetics and Quality Attributes of Dried Chili Pepper (*Capsicum frutescens* L.)

Felix Ajuebor[1], Oluwafunmilayo Abiola Aworanti[2], Oluseye Omotoso Agbede[2], Samuel Enahoro Agarry[2,*], Tinuade Jolaade Afolabi[2] and Oladipupo Olaosebikan Ogunleye[2]

[1]*Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria*
[2]*Department of Chemical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria*

(*Corresponding authors e-mail: seagarry@lautech.edu.ng)

Abstract

This study is important in terms of the fact that the production of a dried product with good quality and minimum process drying cost is dependent on individual or combinations of several drying conditions. However, if drying is not properly conducted at favourable drying conditions, it generates product quality-related problems for the consumer and food market. Thus, this study focused on the optimization and evaluation of the main and interactive effects of drying air temperature (DAT), air velocity (DAV), relative humidity (RH), and drying time (DRT) on the cabinet-tray hot air drying and quality attributes of chili pepper using the four-factors-five-level-rotatable central composite experimental design of response surface methodology. The drying kinetics was also modeled using known empirical drying models (Page, Newton, Logarithmic, and Henderson and Pabis). The drying conditions utilized are DAV (0 - 2 m/s), RH (60 - 80 %), DAT (40 - 80 °C), and DRT (180 - 900 min), while the moisture content (MC), carbohydrate content (CHC), total plate count (TPLC), and protein content (PTC) were the considered product quality attributes. The results showed that the most significant drying process conditions that exerted a more pronounced main and interactive effects on the dried chili pepper quality attributes are drying process time and drying air temperature. Second-order quadratic regression model adequately predicted the quality attributes of the dried chili pepper. The optimum process conditions for the production of dried chili pepper with minimum MC (9.93 %) and TPLC (40.10 CFU/g) as well as maximum PTC (7.88 %) and CHC (24.66 %) were obtained to be DAT, 61.59 °C, DAV, 0.70 m/s, RH, 68.39. %, and DRT, 729.63 min. The Page model best describe the drying kinetics. The drying treatments generally retained the protein and carbohydrate contents (nutritional properties) in the dried chili pepper product as well as reduced the microbial load to the acceptable limit allowed for consumption.

Keywords: Chili pepper drying, Drying kinetics, Optimization, Product quality attributes, Quadratic regression models

Introduction

Drying kinetics are often utilized to describe the moisture transport mechanisms that occurs during convective hot air drying of agricultural or food materials [1]. The material drying kinetics or drying rates are generally or oftentimes influenced by the followings [1-4]: 1) drying conditions which include drying temperature, air relative humidity, air velocity or flow rate, sample size, shape, and thickness, 2) types of the dryer and drying method, and 3) type of materials to be dried and material composition. Optimization and modeling the kinetics of drying are important steps required in any thermal process for increasing process efficiency [5]. Accurate determination of drying kinetics or drying rate through application of appropriate drying models play a significant role to obtaining dried products of high quality [6]. Mathematical and empirical models are commonly utilized for the prediction of material drying kinetics and for optimizing the operating parameters and conditions [1]. The determination of these optimal drying conditions can be achieved through the use of 1) classical optimization technique that involves varying one-factor-at-a-time (OFAT) while holding the other factors constant and 2) statistical optimization referred to as response surface methodology (RSM) [7]. One of the drawbacks of OFAT method is that, it

does not provide information on the interactive effects of the operating factors [7]. This shortcoming is overcome by RSM. The RSM provides information on the single or individual effects, interaction effects, and curvilinear/quadratic effects of study variables, as well as generates mathematical and statistical models that defines the relationships between the response and the independent variables and can be represented graphically [7]. The RSM has successfully been applied in various drying operations [3,8-11].

Drying operations such as osmotic dehydration [9], solar drying [12], heat pump drying [13], vacuum drying [14], fixed bed drying [15], spray drying [10], microwave drying [3], infra-red drying [16], fluidized bed drying [17], rotary drying [18], and tray or cabinet drying [19] are examples of several drying technologies that are employed for the drying of agricultural food products. Although fluidized bed and rotary drying produces very good quality product in terms of nutritional composition, colour, texture, and flavour, however, they suffer from the problem of high cost [20]. Nonetheless, majorly for ease of drying operation, faster rate of drying, affordability, and bulk or large-scale economical drying of chili pepper, convective cabinet-tray hot air drying happens to be the most appropriate drying method [20]. Drying operation is a simultaneous coupled heat and mass transfer process as well as a high-cost energy intensive operation that is unsteady, complex, dynamic, and nonlinear [21-23]. Drying could result to varying levels of quality change (textural properties, structural properties, nutritional properties, rehydration properties, sensory properties, and microbiological properties) depending on factors such as fresh-wet material properties, dimensions, shapes, chemical composition, and process conditions [22-23]. That is, during hot air-drying food products undergoes several physical, chemical, organoleptic and nutritional changes that can cause quality loss of the final dried product. Since drying involves heat, the heating process may also induce biochemical reactions like enzymatic browning, caramelization, and maillard reaction which leads to complex changes in food due to the reaction between protein and carbohydrate thereby resulting in nutritional loss [24].

It is therefore of interest to minimize biochemical changes and to maximize nutrient retention, such as macronutrients (proteins, carbohydrates, lipids, fibres, etc.), micronutrients (vitamins and minerals) or bioactive compounds (phenolic compounds, carotenoids, flavonoids, etc). Different food products require different temperatures of drying based on their desired quality attributes and nutrient content. The most frequently applied drying temperatures for preserving food products using convective hot air drying have been reported to be in the range of 50 to 90 °C [22]. It has been reported in the literature that the retention rate of macronutrients such as proteins and carbohydrates in food materials can highly be influenced by drying temperature change [25]. Miranda *et al*. [25], Famurewa and Olumofin [26], and Bikila *et al*. [27] have all reported a decrease in protein content in quinoa seeds, okra, and anchote due to higher drying temperature. The decrease in protein retention has been attributed to denaturation of the protein at relatively high temperature [27]. Melting or denaturation temperature differs for different proteins, however temperatures above 41 °C may results in the denaturation of many proteins [28]. In contrast, Idah *et al*. [29], Olaniyan and Omoleyomi [30], and Ren *et al*. [31] have reported an increase in protein content or retention in tomato, okra, and maize with respect to a higher drying temperature. In addition, Famurewa and Olumofin [26] and Bikila *et al*. [27] have also reported an increase in carbohydrate content or retention in okra and anchote with respect to a higher drying temperature. Takougnadi *et al*. [4] have reported a decrease in the protein content of dried banana when air flow rate or velocity was increased from 20 to 28 dm^3/s at a corresponding relative low temperature of 45 °C as well as at a moderate temperature of 65 °C. Therefore, minimizing fruits and vegetables' quality changes after drying is paramount for quality assurance and final evaluation of the finished dried product.

Chili pepper, being a fruit or crop that belongs to Solanaceae family has several varieties (more than 3,000) worldwide [6]. These varieties can be sub-divided into 5 Capsicum species such as *Capsicum annuum*, *Capsicum frutescens*, *Capsicum baccatum*, *Capsicum pubescens*, and *Capsicum chinense* [6]. The chili pepper has a wide range of medicinal uses as well as being widely used as spices and flavor in a dried and ground form [32]. It is highly nutritive, containing food substances such as vitamins, anti-oxidants, carbohydrates, fats, dietary fiber, and proteins [32]. The other quality characters in chilies are the colour and the pungency [33]. The red colour of chilies is mainly attributed to the presence of carotenoid pigments and the pungency is basically due to the capsaicin compound [33]. The cultivation and availability of chili pepper is seasonal with a 2 to 3 days short shelf life [34]. It is highly perishable with high post-harvest loss (wastage) or deterioration due to high moisture content [6]. Several researchers have in recent times investigated the hot air drying of different variety of chili pepper using a cabinet or tray dryer [33,35,36], rotary dryer [34], and fluidized bed dryer [37]. These several researchers investigated only the effects of pre-treatment, drying methods, and temperature on drying kinetics, capsaicin contents, ascorbic acid (vitamin C), colour retention, and reducing sugar of chili pepper. The drying temperature that was investigated ranges from 35 to 90 °C [33-44] which have led to various

findings as a result of the different chili pepper varieties with different characteristics responding differently to the drying process. Kaleemullah and Kailappan [33] reported that the overall performance of the chilies dried at 55 °C was the best, when the drying time, capsaicin content, and red colour were considered as quality attributes. Mihindukulasuriya and Jayasuriya [34] have reported that the optimal overall drying performance for chili was achieved at a drying temperature of 70 °C while Montoya-Ballesteros *et al*. [35] revealed that a temperature of 35 °C favoured the retention of the bioactive compounds (capsaicin, capsanthin, and ascorbic acid content) in red chilies. To the best of our knowledge, it is only Sigge [42] using a temperature range of 55 - 75 °C and a relative humidity range of 15 - 40 %, as well as Getahun *et al*. [6] utilizing a temperature range of 40 - 60 °C and a relative humidity range of 25 - 45 %, that have investigated the effects of both temperature and relative humidity on the colour of pepper. While Sigge went further to evaluate the effects of both on ascorbic acid. Sigge [42] reported that the maximum colour retention (optimum quality) of green pepper was attained at the drying temperatures of 55 and 60 °C with a relative humidity that ranged from 15 - 40 %, as well as maximum L-ascorbic acid retention at the drying temperatures of 65 and 70 °C with a relative humidity of 15 %. Getahun *et al*. [6] also reported that the highest or maximum colour retention in chili pepper of different maturity stage was obtained at a drying temperature of 50 °C and relative humidity of 35 % within the shortest drying time. Thus, 2 of the measures that can be taken to maximize nutrient retention and reduce losses are to utilize low to moderate drying temperature and to minimize drying time.

Although most of the above workers have only studied the effect of temperature at constant air velocity and very few at different relative humidity on the colour and pungency as well as on the ascorbic acid (vitamin C) as nutritional quality index) of chili pepper, but the quality of dried food products can generally also be evaluated by its safety based on the degree of microbial load (microbiological quality) and nutritional quality using protein and carbohydrate as index or marker. This is because proteins and carbohydrates are relatively present in greater amounts than other macronutrients, micronutrients, and bioactive compounds in chili pepper as obtained from the literature [32,39,45]. Hence, protein content and carbohydrate content can be used as nutritional quality index since they play a vital biochemical role in human growth and health. To this end, there is a dearth of information on the effects or impacts of drying temperature at different levels of air velocity and relative humidity on the nutritional (i.e. protein and carbohydrate content) quality attributes of the dried chili pepper. More also, the levels of relative humidity that have been investigated as a drying process condition in food product's drying as obtained from literature ranges from 10 to 80 % [46-50]. However, higher levels of relative humidity have not been investigated for the drying of chili pepper. In this study, the authors would evaluate the effect of higher range of relative humidity (60 - 80 %) which have seldom been studied.

Moreover, few number of studies as obtained from the literature have been conducted to investigate the effects of pretreatment, temperature, and methods of drying on the microbial load of dried green onions, tomato, carrots, and apple [51-53]. However, to the best of our knowledge, the effects of drying temperature at varying levels of air velocity and relative humidity on the microbiological (microbial load) quality attributes of the dried chili pepper have not been investigated. In addition, there is a paucity of information on the interactive effect of these drying process conditions on the convective hot air drying process of chili pepper and its post-quality attributes as well as on the optimization of the drying conditions and the quality attributes of the dried product. The inadequate drying information connected to the dried chili pepper product's qualities elicits quality problems for the consumer and food market. Hence, due to these available research gaps, there is the need to evolve specific drying strategies that simultaneously minimize the quality degradation of red chili pepper, while maximizing the production efficiency under optimum operating process conditions.

The main purposes of this present study are therefore to: 1) evaluate the independent and interactive effects of drying temperature (40 - 80 °C), drying time (180 - 900 °C), relative humidity (60 - 80 %), and air velocity (0 - 2 m/s) on the drying and nutritional (protein and carbohydrate) and microbiological (microbial load) quality attributes of dried chili pepper, 2) optimize the drying process conditions that would maximize the dried product quality attributes with minimum moisture content and minimum microbial load (total plate count), as well as maximum protein and carbohydrate contents using RSM, and 3) model the drying kinetics using known literature empirical thin-layer drying models (Page, Newton, Logarithmic, and Henderson and Pabis). The novelty of this study is in the fact that nutritional value and the microbiological load of cabinet tray-dried chili pepper were evaluated using the response surface methodology to determine the practical application of cabinet tray-hot air-drying technique with the appropriate drying conditions in addressing food quality as well as provide scientific evidence for the development and implementation of good drying practices for dried chili pepper. The results of this study have explicitly demonstrated that the cabinet-tray-hot air-drying technique with the appropriate drying

conditions can be utilized effectively to preserve/retain or improve the nutritional benefits and reduce microbiological load as well as increased acceptance of dried chili pepper product.

Materials and methods

Sample

The fresh Nigerian red chili pepper samples were purchased from a local market at Lagos (6.5219°N, 3.3565°E), Nigeria. The purchased chilies were mostly at the commercial matured ripe stage. The chilies were physically and properly handled with care. This is because rough handling can cause mechanical injuries which can affect the quality and shelf life [54]. Those that have suffered from rottenness, mechanical injuries and damage were sorted out and discarded. The red chilies were thereafter graded and washed with tap water and then precooled by dipping into cold clean water (hydrocooling). The precooled red chilies were cleaned with tissue paper and kept in a polyethylene bag (good packaging container) that will prevent bruising and puncturing of the chilies. The polyethylene-package red chilies were then subjected to refrigeration storage (i.e. stored in the refrigerator at 4 °C and relative humidity of 80 - 90 %) prior to usage. It is to be noted that the steps taken above are the ways of controlling the initial qualities of the raw material [54]. Before the use of the red chilies, the samples were brought out from the refrigerator and kept for some hours to achieve equilibrium temperature (28 °C) with the environment.

Preliminary drying procedure

The chili pepper samples were sliced into a size thickness of 2 mm and 1 kg of the samples were weighed using a digital precision balance (Sartorius Secura1103-1Sar, Germany). The weighed samples were loaded into cabinet-tray dryer (**Figure 1**) of dimension 65×55×90 cm³.
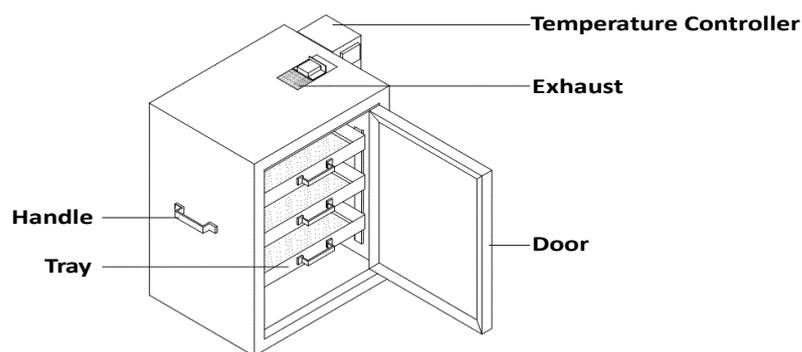

Figure 1 A cabinet-tray dryer for the drying of red chili pepper.

The description of the dryer has been presented elsewhere [55]. The chili pepper drying was carried out at different temperatures (40 - 70 °C), air velocities (0.5 - 2.0 m/s), and levels of relative humidity (65 - 80 %) using one-factor-at-a-time (OFAT) procedure. The air entering into the drying chamber was manually humidified using a water aerosol (i.e. 1 L water trigger sprayer (Sprayon Model SO-075)) [42] until the desired relative air humidity was attained. The water aerosol was operated behind the air-blower. A dual-testing instrument (PCE-555 Model, Southampton, United Kingdom) that measures both relative humidity and temperature was used for both the relative humidity and temperature measurement. An air-blower delivers the hot air into the drying chamber and the velocity in meters per second (m/s) was measured with a hot-wire anemometer (PCE-009 Model, Southampton, United Kingdom) linked to the air-blower. At intervals of 30 min, the samples were withdrawn to measure the weight until the chili pepper weight obtained was constant. The experimental tests were repeated in triplicate (n = 3) and the mean values were utilized.

Design of drying experiment using rotatable central composite design (RCCD)

Four-factor-five-level-rotatable central composite experimental design of RSM in Design-Expert 6.0.8 (State Ease, USA) software was utilized to evaluate the influence of drying process conditions (drying temperature, air velocity, relative humidity, and drying time) on the quality attributes (product moisture content, protein content, carbohydrate content, and total plate count) of dried chili pepper slices.

The independent drying process variables are air velocity, relative humidity, drying temperature, and drying time. Each of the independent variables was coded at 5 levels between −1 and +1 including the center point (0) and 2 axial points, −2 and +2 (**Table 1**) [9]. The low and high values of these independent variables utilized for this experimental design were obtained from a preliminary drying experiment and these values are air velocity (X_1), 0.5 and 1.5 m/s, relative humidity (X_2), 65 and 75 %, drying temperature (X_3), 50 and 70 °C, and drying time (X_4), 360 and 720 min. The actual (uncoded) and coded values of factors and levels used in this drying experimental design are presented in **Table 1**. The RCCD generated 30 experimental runs that corresponded to sixteen factorial points, 8 axial points, and 6 replicates of the center point (**Table 1**) which were performed in triplicate. There are 4 dependent response variables, which are product moisture content (MC) (Y_{MC}), protein content (PTC) (Y_{PTC}), carbohydrate content (CHC) (Y_{CHC}), and total plate count (TPLC) (Y_{TPLC}), respectively. Mean values of the determined response variables were utilized.

Table 1 Experimental range and levels of the variables with the experimental design using rotatable central composite design for chilli pepper drying.

Dependable variable	−2	−1	0	+1	+2
Air Velocity (X_1) (m/s)	0.0	0.5	1.0	1.5	2.0
Relative Humidity (X_2) (%)	60	65	70	75	80
Drying Temperature (X_3) °C	40	50	60	70	80
Drying Time (X_4) (min)	180	360	540	720	900

Run	Air velocity (m/s) X_1	Relative humidity (%) X_2	Drying temperature (°C) X_3	Drying time (min) X_4
1	0.5 (−1)	65 (−1)	50 (−1)	360 (−1)
2	1.5 (+1)	65 (−1)	50 (−1)	360 (−1)
3	0.5 (−1)	75 (+1)	50 (−1)	360 (−1)
4	1.5 (+1)	75 (+1)	50 (−1)	360 (−1)
5	0.5 (−1)	65 (−1)	70 (+1)	360 (−1)
6	1.5 (+1)	65 (−1)	70 (+1)	360 (−1)
7	0.5 (−1)	75 (+1)	70 (+1)	360 (−1)
8	1.5 (+1)	75 (+1)	70 (+1)	360 (−1)
9	0.5 (−1)	65 (−1)	50 (−1)	720 (+1)
10	1.5 (+1)	65 (−1)	50 (−1)	720 (+1)
11	0.5 (−1)	75 (+1)	50 (−1)	720 (+1)
12	1.5 (+1)	75 (+1)	50 (−1)	720 (+1)
13	0.5 (−1)	65 (−1)	70 (+1)	720 (+1)
14	1.5 (+1)	65 (−1)	70 (+1)	720 (+1)
15	0.5 (−1)	75 (+1)	70 (+1)	720 (+1)
16	1.5 (+1)	75 (+1)	70 (+1)	720 (+1)
17	0.0 (−2)	70 (0)	60 (0)	540 (0)
18	2.0 (+2)	70 (0)	60 (0)	540 (0)
19	1.0 (0)	60 (0)	60 (0)	540 (0)

Run	Air velocity (m/s) X_1	Relative humidity (%) X_2	Drying temperature (°C) X_3	Drying time (min) X_4
20	1.0 (0)	80 (+2)	60 (0)	540 (0)
21	1.0 (0)	70 (0)	40 (−2)	540 (0)
22	1.0 (0)	70 (0)	80 (+2)	540 (0)
23	1.0 (0)	70 (0)	60 (0)	180 (−2)
24	1.0 (0)	70 (0)	60 (0)	900 (+2)
25	1.0 (0)	70 (0)	60 (0)	540 (0)
26	1.0 (0)	70 (0)	60 (0)	540 (0)
27	1.0 (0)	70 (0)	60 (0)	540 (0)
28	1.0 (0)	70 (0)	60 (0)	540 (0)
29	1.0 (0)	70 (0)	60 (0)	540 (0)
30	1.0 (0)	70 (0)	60 (0)	540 (0)

From **Table 1** the air velocity of 0.0 m/s indicates that there is no air flow from the air blower. With no air flow from the air blower, the chili pepper received indirect heat by conduction from heated trays and/or heated shelves on which the trays lie or by radiation from heated surfaces [56].

Product quality analysis

The parameters analyzed as quality indices are MC, PTC, CHC, and TPLC. The MC of chili pepper samples was gravimetrically determined using the oven method of drying in which the samples were dried to constant weight at 105 °C [57]. Kjeldahl nitrogen standard method [57] and the phenol-sulphuric acid method [58] were utilized for the respective PTC and CHC determination. The TPLC was performed using standard pour plate method [59]. The initial values of MC, PTC, CHC, and TPLC in the fresh chili pepper are 84.98 % (wet basis), 3.09, 5.56 %, and 5.70×10^5 CFU/g, respectively.

Statistical analysis

The Design-Expert 6.08 software (State-Ease, Inc., Minneapolis MN, USA) was applied for carrying out analysis of the chili pepper drying data. The prediction of the response variables based on multiple linear regression analysis was performed using a quadratic polynomial model equation provided in Eq. (1).

$$Y = \beta_o + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_{ij}$$

(1)

where Y = predicted response, β_o = offset term (i.e. fixed constant of the response at the experiment center point), β_i = linear or main coefficient, β_{ii} = quadratic coefficient, and β_{ij} = interaction coefficient. X_i (i = 1, 2, 3) and X_j (j = 1, 2, 3) ($i \neq j$) are the drying process independent variables. The quadratic polynomial model adequacy to fit the chili pepper drying experimental data was assessed using the variance (ANOVA) and regression analyses having such components as: coefficient of determination (R^2), Adjusted R^2, Predicted R^2, and Adequate Precision, lack of fit, and coefficient of variation (CV). The model terms were evaluated for each response using the probability value (i.e. *p*-value).

Optimization of drying process conditions and dried product quality attributes

In optimizing the drying process conditions for chili pepper, the desirability function in the numerical optimization tool of RSM was applied, using the Design-Expert 6.08 statistical software (State-Ease, Inc., Minneapolis MN, USA). In carrying out the optimization process, the target objective, was set as a maximum value for the PTC and CHC, and minimum values for the MC and TPLC, while the values of the 4 independent variables were set at the ranges being studied. The predicted experimental drying process conditions with the highest desirability were selected and recorded. The predicted and observed experimental results of the responses obtained at optimum drying process conditions were recorded.

Verification of predicted optimum process conditions

For verification of the predicted optimum drying process conditions as obtained, using the numerical optimization tool, laboratory chili pepper drying experiments were conducted in triplicate under the obtained predicted optimum drying process conditions. The experimentally observed values of the response variables (PTC, CHC, MC, and TPLC) were recorded and then compared with the predicted values to check the validity of the models. The percentage error (%E) between the experimental value and the predicted value was calculated as provided in Eq. (2) [60];

$$\%E = \frac{Z_j - Z_i}{Z_j} \times 100 \tag{2}$$

Where Z_i is the predicted value and Z_j is the experimental value.

Empirical modeling of the kinetics of chili pepper drying

The empirical drying models that were fitted to the chili pepper kinetics data include, the Page model (Eq. (3)), Newton model (Eq. (4)), Logarithmic model (Eq. (5)), and Henderson and Pabis model (Eq. (6)) [61,62];

Page model:

$$MR = \exp(-kt^n) \tag{3}$$

Newton model:

$$MR = \exp(-kt) \tag{4}$$

Logarithmic model:

$$MR = a * \exp(-kt) + c \tag{5}$$

Henderson and Pabis model:

$$MR = a * \exp(-kt) \tag{6}$$

where, $\qquad MR = \dfrac{M_t - M_e}{M_o - M_e} \tag{7}$

and a, c, n, are empirical constants; k, drying constant; t, drying time; MR, moisture ratio. The model that best fit the data was selected according to statistical criteria. The best of fit was determined using 3 parameters, the highest values for the R^2, the smallest values for the root mean square error (RMSE) and chi-square (χ^2), respectively [62-63].

Results and discussion

Evaluation of the effect of drying process conditions on product quality attributes

The results for the MC, TPLC, PTC, and CHC of the dried chili pepper product after the drying process are depicted in **Table 2**.

Table 2 Values of the MC, PTC, CHC, and TPLC of the dried red chili pepper.

Run	Factors				Response							
					MC (%)		PTC (%)		CHC (%)		TPLC (CFU/g)	
	DAV (m/s)	RH (%)	DAT (°C)	DRT (min)	Expt	Pred	Expt	Pred	Expt	Pred	Expt	Pred
1	0.5	65	50	360	30.65	31.67	5.75	5.64	20.44	20.18	80.77	82.81
2	1.5	65	50	360	24.40	26.03	6.37	6.21	21.68	21.31	68.27	71.53
3	0.5	75	50	360	36.57	36.43	5.15	5.17	19.00	19.10	92.61	92.33
4	1.5	75	50	360	28.98	29.98	5.95	5.83	20.82	20.54	77.43	79.44
5	0.5	65	70	360	23.88	24.55	6.45	6.37	21.78	21.62	67.23	68.57
6	1.5	65	70	360	22.76	22.14	6.55	6.59	22.02	22.09	64.99	63.75
7	0.5	75	70	360	26.55	26.64	6.17	6.16	21.26	21.15	72.57	72.75
8	1.5	75	70	360	23.55	23.42	6.47	6.48	21.94	21.92	66.57	66.32
9	0.5	65	50	720	21.65	21.75	6.66	6.65	22.28	22.27	62.77	62.97
10	1.5	65	50	720	18.52	18.82	7.00	6.95	22.74	22.73	56.51	57.10
11	0.5	75	50	720	22.48	23.49	6.55	6.45	22.00	21.81	64.43	66.45
12	1.5	75	50	720	20.44	19.75	6.77	6.85	22.44	22.57	60.35	58.97
13	0.5	65	70	720	11.33	10.71	7.68	7.74	24.24	24.49	42.13	40.90
14	1.5	65	70	720	10.89	11.01	7.72	7.70	24.32	24.20	41.25	41.49
15	0.5	75	70	720	11.44	9.79	7.66	7.81	24.20	24.55	42.35	39.04
16	1.5	75	70	720	9.91	9.27	7.81	7.86	24.50	24.64	39.29	38.02
17	0.0	70	60	540	24.86	24.80	6.34	6.35	21.60	21.59	69.17	69.05
18	2.0	70	60	540	18.95	18.65	6.92	8.97	22.66	22.82	57.37	56.75
19	1.0	60	60	540	20.83	19.71	6.71	6.84	22.32	22.60	61.13	58.89
20	1.0	80	60	540	21.98	22.73	6.60	6.53	22.10	21.97	63.43	64.94
21	1.0	70	40	540	31.0	29.07	5.72	5.92	20.38	20.75	81.47	77.60
22	1.0	70	80	540	9.90	11.47	7.80	7.66	24.49	24.26	39.28	42.41
23	1.0	70	60	180	36.77	35.19	5.12	5.29	18.94	19.38	93.01	89.85
24	1.0	70	60	900	9.90	11.12	7.80	7.68	24.49	24.19	39.28	41.71
25	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
26	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
27	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
28	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
29	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
30	1.0	70	60	540	12.12	12.12	7.62	7.62	24.12	24.12	43.71	43.71
Fresh Chili Pepper	-	-	-	-	84.98	-	3.09	-	5.56	-	$> 10^5$	-

Note: Expt. = Experimental; Pred. = Predicted

Product moisture content and total plate count

From **Table 2**, it was observed that run numbers 1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10, 11 and 12, 13 and 14, and 15 and 16 were carried out at the same drying conditions of RH, DAT, and DRT but at varying DAVs and the results show that both the MC and TPLC decreases while the PTC and CHC increases as the DAV gradually increased from a low level of 0 m/s (i.e. no air from the air blower) to a high level of 2 m/s (i.e. air flow from the air blower). In tray dryers, the food is spread out, generally quite thinly, on trays in which the drying takes place. This observation indicates that a rise in air velocity (from no air flow to when there was air flow) results in an increased moisture removal from the fresh sample and thus a decrease in the amount of MC retained in the dried product. The reduction in the moisture content led to the observed drastic reduction in the TPLC. Also, the increase in PTC and CHC may probably be because of an increased moisture removal leading to a concentrated PTC and CHC in the dried product [64]. Over the range of 0.0 - 2.0 m/s of air velocity, the MC, TPLC, PTC, and CHC did not change over a wide range.

Run numbers 1 and 3, 2 and 4, 5 and 7, 6 and 8, 9 and 11, 10 and 12, 13 and 15, 14 and 16, and 19 and 20 were performed at the same drying conditions of DAV, DAT, and DRT but at different levels of RH, and the results revealed that the MC and TPLC increases while the PTC and CHC as the RH gradually increased from a low level of 60 % to a high level of 80 %. This observation showed that an increase in the RH (i.e. increase in the water or moisture saturation of the air) led to a decrease in moisture removal from the fresh samples and hence an increase in the amount of MC retained in the dried product. The reason for this observation is attributed to increased water vapour pressure of the air as a result of the increased RH which diminishes its saturation deficit, thereby resulting in a decreased mass transfer driving force (mass transfer coefficient) in the fresh sample as well as reducing the capacity to absorb water or moisture from the sample surface and as a result moisture removal decreases, resulting in an increased MC in the dried product. The increase in the MC led to the observed rise in the TPLC. This observation of an increased MC, due to an increase in RH has similarly been reported for the tray drying of green bell pepper [42] and apple [65], respectively. The observed decrease in the PTC and CHC may be because there is a decrease in the moisture removal from the fresh samples which led to less concentration of the PTC and CHC, respectively.

Drying temperature effect was studied at a similar condition of DRT, RH, and DAV (run numbers 1 and 5, 2 and 6, 3 and 7, 4 and 8, 9 and 13, 10 and 14, 11 and 15, 12 and 16, and 21 and 22) and the results obtained indicate that an increasing DAT from 40 to 80 °C resulted in the respectively observed decrease in the MC and TPLC as well as an increased PTC and CHC. It could be seen that over the temperature range of 40 to 80 °C, the respective MC, TPLC (microbial load), PTC, and CHC change over a wide range which implies the high impact of temperature. These observed results indicate that an increase in the DAT increased the moisture quantity removal from the fresh chili pepper, hence the chili pepper MC reduction. The increase in moisture removal due to increasing DAT is due to the fact that increase in DAT invariably implies an increase in heat energy which increases the moisture diffusion rate from the interior to the surface of the material and subsequently an increased moisture evaporation from the surface to the drying air stream. This MC reduction led to the observed TPLC reduction and the observed respective increase in the amount of PTC and CHC. A similar observed result of a decreased MC due to an increasing DAT has been reported for the hot air drying of savory leaves [48], spray drying of pink guava [10], and convective tray hot air drying of apple [65]. Also, a decreased microbial load due to a rising DAT has been observed for the drying of tomatoes [52] as well as for green onions [53]. The PTC and CHC values obtained at the temperature range of 40 to 80 °C are above the obtained value for the fresh chili pepper (**Table 2**). The reason for the higher PTC and CHC in the dried product within the temperature range of 40 to 80 °C as compared to the fresh chili pepper may be due to the fact that at higher temperature greater moisture is being evaporated from the solid-liquid material (chili pepper) leading to a concentrated solute (PTC and CHC) in the dried product. In addition, this observed result may probably be as a result of the chili pepper's variety [64] as well as the type of drying method [66]. On the other hand, Bikila *et al.* [27] have reported for anchote (*Coccinia abyssinica* (Lam.) Cogn.) drying an increased CHC and a decreased PTC due to a steady rise in the temperature of drying.

The effect of drying time on the chili pepper drying and its quality attributes was investigated at similar conditions of drying (DAT, RH, and DAV) as seen in the experimental run 23 and 25, 23 and 24, 8 and 16, 7 and 15, 6 and 14, 5 and 13, 4 and 12, 3 and 11, 2 and 10, and 1 and 9. The achieved results show that there is a decrease in both the MC and TPLC as well as an increase in both the PTC and CHC as the time of drying increased from 180 to 900 min. Furthermore, the results obtained also indicate that over the drying time range of 180 to 900 min, the respective MC, TPLC, PTC, and CHC changed over a wide range proving the high impact of drying time. Therefore, these observed results demonstrated that

the removal of water or moisture from fresh samples of chili pepper increases due to increased DRT, thereby leading to MC and TPLC reductions with the dried product having a more concentrated PTC and CHC. Senadeera *et al*. [67], Zhao *et al*. [11], Idah *et al*. [29] have respectively observed and reported an MC reduction for the drying of fruits and vegetables as a result of an increased time of drying.

As generally observed from **Table 2**, the TPLC values of the dried chili pepper ranged from 39.28 - 93.01 CFU/g at the DAV range of 0 to 2 m/s; RH range of 60 to 80 %; DAT range of 40 to 80 °C; and DRT range of 180 to 900 min. These values were observed to be lower than the TPLC value of 5.70×10^5 CFU/g obtained for the fresh samples of chili pepper. The observed difference between the TPLC value obtained for the fresh chili pepper and the dried chili pepper could be deduced to the synergistic effects of thermal and dehydration inactivation that is based on the intensity of drying temperature, drying time, and characteristic of the drying environment (such as relative humidity, pressure, air velocity, etc.) [29,67]. The high MC, which invariably implies high water activity of the fresh chili pepper may have been responsible for the high TPLC. This is because microbial species viability increases more in such kind of a favorable moisture environment. The TPLC values obtained for the dried chili pepper product were found to be within the accepted range of $< 10^5$ CFU/g [68] and therefore implies that the dried products are within the acceptable limit required for consumption.

The results in **Table 2** generally revealed that the PTC and CHC values of the dried chili pepper respectively range from 5.12 to 7.81 % and 18.94 to 24.50 % at a DAT range of 40 to 80 °C, a DAV range of 0 to 2.0 m/s, a RH range of 60 to 80 %, and a DRT range of 180 to 900 min. These PTC and CHC values are relatively greater than 3.09 % of the PTC and 5.56 % of the CHC values obtained for the fresh chili pepper. This indicates that the different drying conditions range utilized in this study generally led to either the retention or preservation/improvement of the PTC and CHC in the dried chili pepper.

Statistical modelling and ANOVA

The drying experimental data was fitted to the quadratic regression model (Eq. (1)) and the coefficients of the model were obtained using the Design Expert (6.08) software. To test the fit of the model, ANOVA where the Fischer test (F-value), *p*-value, and R^2 were determined and evaluated are presented in **Table 3**.

Table 3 ANOVA for response of MC, PTC, CHC, and TPLC of dried chili pepper.

Source	Product moisture content				Protein content			
	C. Estimate	MS	F-value	*p*-value	C. Estimate	MS	F-value	*p*-value
Model (β_0)	12.12	135.23	139.5	< 0.0001	7.62	1.35	88.5	< 0.0001
X_1 (β_1)	−1.54	56.80	70.3	< 0.0001	0.16	0.58	51.5	< 0.0001
X_2 ((β_2)	0.76	13.71	36.6	0.089	−0.078	0.15	23.2	0.0081
X_3 (β_3)	−4.40	464.46	402.7	< 0.0001	0.44	4.57	310.5	< 0.0001
X_4 (β_4)	−6.02	869.05	1162	< 0.0001	0.60	8.58	671.9	< 0.0001
X_1^2 (β_{11})	2.40	158.07	84.2	< 0.0001	−0.24	1.58	32.0	< 0.0001
X_2^2 (β_{22})	2.28	142.04	4.82	< 0.0001	−0.23	1.50	5.85	< 0.0001
X_3^2 (β_{33})	2.04	113.80	20.0	< 0.0001	−0.21	1.18	34.3	< 0.0001
X_4^2 (β_{44})	2.76	208.66	6.75	< 0.0001	−0.28	2.19	7.63	< 0.0001
$X_1 X_2$ (β_{12})	−0.20	0.65	5.77	0.5239	0.023	0.009	4.69	0.4710
$X_1 X_3$ (β_{13})	0.81	10.43	4.83	0.0194	−0.087	0.12	6.88	0.0141
$X_1 X_4$ (β_{14})	0.68	7.32	18.0	0.0445	−0.067	0.072	10.3	0.0493

Source	C. Estimate	MS	F-value	p-value	C. Estimate	MS	F-value	p-value
X_2X_3 (β_{23})	−0.67	7.10	1.38	0.0473	0.067	0.072	0.017	0.0493
X_2X_4 (β_{24})	−0.76	9.12	8.48	0.0271	0.069	0.077	5.89	0.0424
X_3X_4 (β_{34})	−0.98	15.33	107.6	0.0063	0.092	0.14	64	0.0102

$R^2 = 0.9881$; Adj. $R^2 = 0.9770$; Pred. $R^2 = 0.9314$; Adeq. Pre =31.1; C.V = 5.10 $R^2 = 0.9877$; Adj. $R^2 = 0.9763$; Pred. $R^2 = 0.9264$; Adeq. Pre = 30.5; C.V = 2.20

Source	Carbohydrate content				Total plate count			
	C. Estimate	MS	F-value	p-value	C. Estimate	MS	F-value	p-value
Model (β_0)	24.12	5.48	146.9	< 0.0001	43.71	540.85	74.5	< 0.0001
X_1 (β_1)	0.31	2.27	101.1	< 0.0001	−3.07	226.93	40.5	< 0.0001
X_2 ((β_2)	−0.16	0.60	32.1	0.0141	1.51	54.84	27.5	0.0089
X_3 (β_3)	0.88	18.52	408.5	< 0.0001	−8.80	1857.50	471.0	< 0.0001
X_4 (β_4)	1.20	34.75	1175	< 0.0001	−12.0	3475.71	866.9	< 0.0001
X_1^2 (β_{11})	−0.48	6.31	109.5	< 0.0001	4.80	631.63	57.9	< 0.0001
X_2^2 (β_{22})	−0.46	5.80	8.14	< 0.0001	4.55	568.15	6.07	< 0.0001
X_3^2 (β_{33})	−0.40	4.47	14.8	< 0.0001	4.07	455.47	27.5	< 0.0001
X_4^2 (β_{44})	−0.58	9.34	4.80	< 0.0001	5.52	835.00	14.2	< 0.0001
X_1X_2 (β_{12})	0.076	0.093	4.59	0.2896	−0.40	2.59	4.65	0.5237
X_1X_3 (β_{13})	−0.17	0.44	11.0	0.0302	1.61	41.73	4.94	0.0193
X_1X_4 (β_{14})	−0.17	0.46	28.5	0.0281	1.35	29.27	12.1	0.0444
X_2X_3 (β_{23})	0.15	0.37	0.030	0.0458	−1.33	28.41	0.44	0.0472
X_2X_4 (β_{24})	0.15	0.38	8.41	0.0428	−1.51	36.48	5.03	0.0271
X_3X_4 (β_{34})	0.17	0.47	125.9	0.0262	−1.96	61.31	158.9	0.0063

$R^2 = 0.9851$; Adj. $R^2 = 0.9713$; Pred. $R^2 = 0.9143$; Adeq. Pre = 28.2; C.V = 0.10 $R^2 = 0.9881$; Adj. $R^2 = 0.9770$; Pred. $R^2 = 0.9314$; Adeq. Pre =31.1; C.V = 2.26

Note: C. Estimate = Coefficient Estimate; MS = Mean Square; Adj. = Adjusted; Pred. = Predicted; Adeq. Pre. = Adequate Precision; * Significant at p < 0.05.

The R^2 and the Adjusted R^2 values are high (> 0.95) for all the models representing the responses (**Table 3**). The relatively high values of R^2 obtained shows that the degree of concordance between the observed experimental value and predicted values is relatively high. The respective "Predicted R^2 values are high (> 0.90) and are in a reasonable agreement with their corresponding Adjusted R^2 and thus the models are adequate. "Adequate Precision" measures the S/N (signal/noise) ratio and a ratio that is above the value of 4 is adequate and desirable. The respective Adequate Precisions for all the response models are high (> 25) which indicates that the noise to signal ratio for all the respective models are adequate. The ANOVA for all the response quadratic regression models revealed that the models are highly significant, as evident from the very low p-value (< 0.0001) of the F-test. Also, p-values less than 0.05 reveal that the terms of the model are significant and values above 0.1000 show that the terms of the model are insignificant.

Table 3 results reveal that RH, DRT, DAV, and the DAT had a significant effect ($p \leq 0.05$) on the MC, TPLC, PTC, and CHC with DRT and DAT wielding more pronounced main effects as depicted by higher R^2 values. The quadratic polynomial regression model equations for the MC, TPLC, PTC, and CHC as connected to the coded levels of drying parameters were obtained as Eqs. (8) - (11), respectively;

$$Y_{MC} = 12.12 - 1.54X_1 + 0.76X_2 - 4.40X_3 - 6.02X_4 + 2.40X_1^2 + 2.28X_2^2 + 2.04X_3^2 + 2.76X_4^2 - 0.20X_1X_2 \quad (8)$$
$$+ 0.81X_1X_3 + 0.68X_1X_4 - 0.67X_2X_3 - 0.76X_2X_4 - 0.98X_3X_4$$

$$Y_{TPLC} = 43.71 - 3.07X_1 + 1.51X_2 - 8.80X_3 - 12.03X_4 + 4.80X_1^2 + 4.55X_2^2 + 4.07X_3^2 + 5.52X_4^2 - 0.40X_1X_2 \quad (9)$$
$$+ 1.61X_1X_3 + 1.35X_1X_4 - 1.33X_2X_3 - 1.51X_2X_4 - 1.96X_3X_4$$

$$Y_{PTC} = 7.62 + 0.16X_1 - 0.078X_2 + 0.44X_3 + 0.60X_4 - 0.24X_1^2 - 0.23X_2^2 - 0.21X_3^2 - 0.28X_4^2 + 0.023X_1X_2 \quad (10)$$
$$- 0.087X_1X_3 - 0.067X_1X_4 + 0.067X_2X_3 + 0.069X_2X_4 + 0.092X_3X_4$$

$$Y_{CHC} = 24.12 + 0.31X_1 - 0.16X_2 + 0.88X_3 + 1.20X_4 - 0.48X_1^2 - 0.46X_2^2 - 0.40X_3^2 - 0.58X_4^2 + 0.076X_1X_2 \quad (11)$$
$$- 0.17X_1X_3 - 0.17X_1X_4 + 0.15X_2X_3 + 0.15X_2X_4 + 0.17X_3X_4$$

The R^2 values that were respectively obtained for MC, TPLC, PTC, and CHC response model equations are 0.9881, 0.9881, 0.9877, and 0.9851. This reveals a good degree of model fit. The effect of the drying process variable's interaction on the MC, TPLC, PTC, and CHC are illustrated in the 3D (3 - dimensional) response surface plots (**Figures 1 - 6**). The interaction effects between DAV and RH on the MC, TPLC, PTC, and CHC of dried chili pepper is illustrated as 3D response surface plots in **Figure 1(A) - 1(D)**.
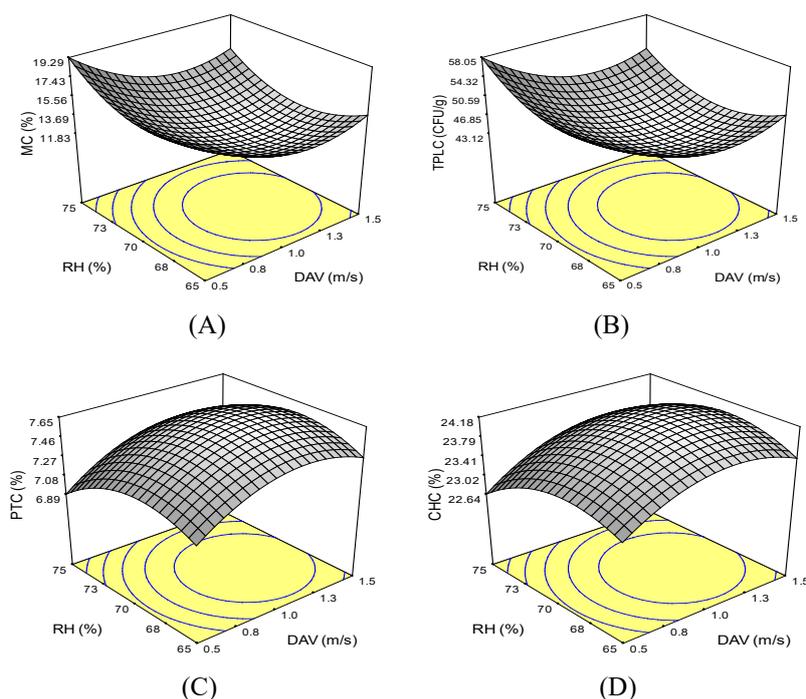

(A) (B)

(C) (D)

Figure 2 3-dimensional (3D) response surface plot indicating interaction effect of (A) RH and DAV on MC (B) RH and DAV on TPLC (C) RH and DAV on PTC (D) RH and DAV on CHC during the chili pepper drying process.

It is observed that the interaction effect of DAV and RH on the MC, TPC, PTC, and CHC is respectively insignificant (**Table 3**). Nevertheless, **Figures 2(A) - 2(D)** revealed that during chili pepper drying at a fixed DAT and DRT, there is a respective marginal increase in MC and TPC as well as a

marginal decrease in PTC and CHC when the DAV and RH were mutually increased. **Figure 3(A) - 3(D)** shows that there is a significant ($p \leq 0.05$) and positive interaction impact between DAV and DAT on both the MC and TPLC while the interaction is also significant ($p \leq 0.05$) but negative on PTC and CHC.
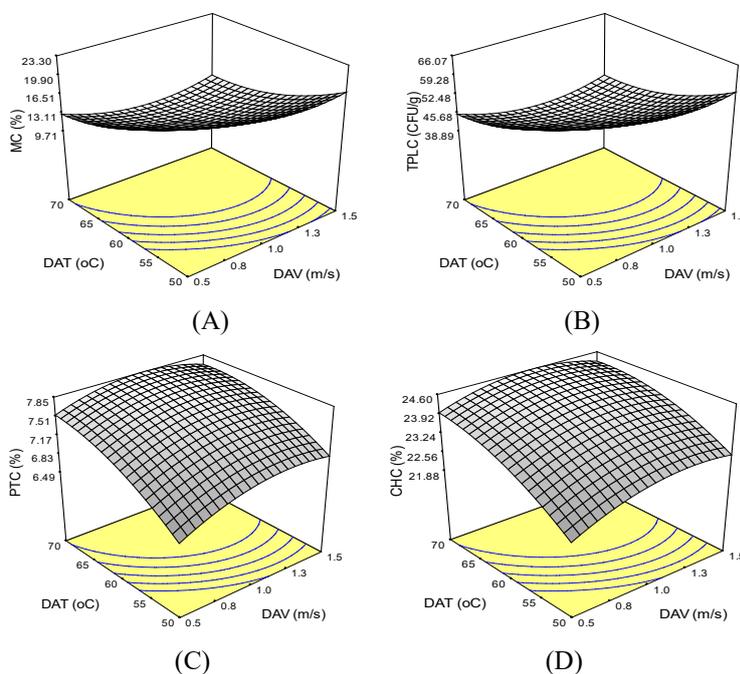

| (A) | (B) |

| (C) | (D) |

Figure 3 3-dimensional (3D) response surface plot indicating interaction effect of (A) DAV and DAT on MC (B) DAV and DAT on TPLC, (C) DAV and DAT on PTC, (D) DAV and DAT on CHC during the chili pepper drying process.

The 3D plots illustrate that at a fixed RH and DRT, the MC and TPLC decreased while the respective PTC and CHC increased due to the increasing DAV and DAT. Thus, **Figures 3(A) - 3(D)** suggest that at a fixed RH and DRT, the DAV and DAT has to be stepped up for a dried chili pepper product that possesses lower MC, TPLC, and higher PTC and CHC to be obtained.

Figures 4(A) - 4(D) illustrate the DAV and DRT interaction impact on MC, TPLC, PTC, and CHC.
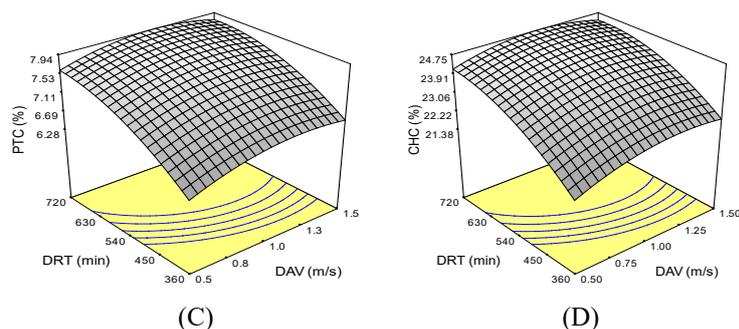

| (A) | (B) |

(C)

(D)
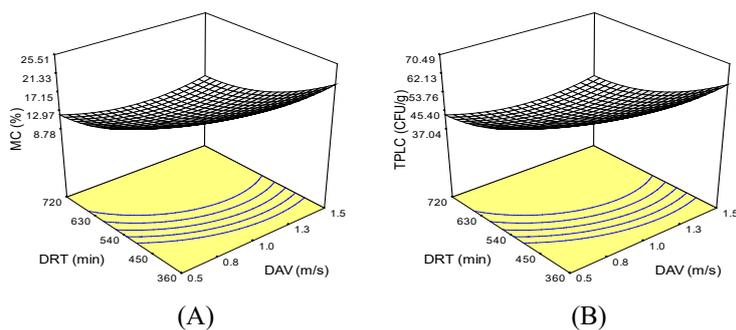
Figure 4 3 dimensional (3D) response surface plot indicating interaction effect of (A) DRT and DAV on MC, (B) DRT and DAV on TPLC, (C) DRT and DAV on PTC, (D) DRT and DAV on CHC during the chili pepper drying process.

From the 3D plots, it is observed that DAV and DRT interaction on the MC and TPLC is positive and mutual while its interactive impact on the PTC and CHC is respectively negative. **Figures 4(A) - 4(D)** demonstrates that at a fixed RH and DAT, the MC and TPLC declined while the PTC and CHC respectively increased as the DAV and the DRT simultaneously increased. This means that to obtain a dried chili pepper product that will possess a low MC and TPLC, as well as a high PTC and CHC, a higher DAV and longer DRT will be utilized at a fixed RH and DAT. **Figures 5(A) - 5(D)** shows the effect of RH and DAT interaction on MC, TPLC, PTC, and CHC, respectively.
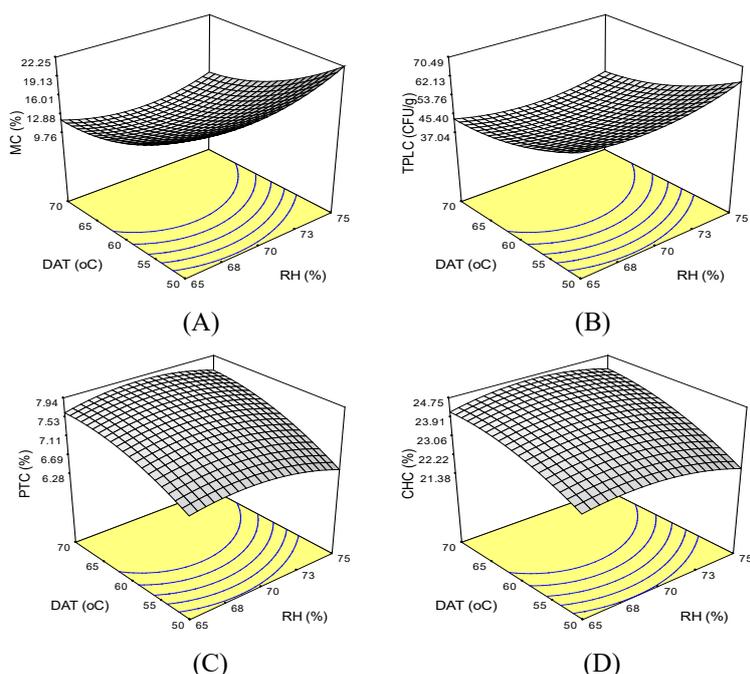

(A)

(B)

(C)

(D)

Figure 5 3 dimensional (3D) response surface plot indicating interaction effect of (A) DAT and RH on MC, (B) DAT and RH on TPLC, (C) DAT and RH on PTC, and (D) DAT and RH on CHC during the chili pepper drying process.

Both the MC and TPLC have been significantly ($p \leq 0.05$) and negatively impacted by the RH and DAT interaction while the PTC and CHC are significantly ($p \leq 0.05$) and positively affected by the interaction. **Figures 5(A) - 5(D)** illustrates that at a fixed DAV and DRT, a decrease in RH with a concomitant increase in the DAT resulted in both the MC and TPLC reduction as well increase in both the PTC and CHC. This observation indicates that high DAT and low RH will bring about a dried chili pepper that has a low MC and TPLC as well as a high PTC and CHC.

The RH and DRT interaction effect on MC and TPLC is negative while on the PTC and CHC, the interaction effect is positive which is illustrated in **Figures 6(A) - 6(D)**.
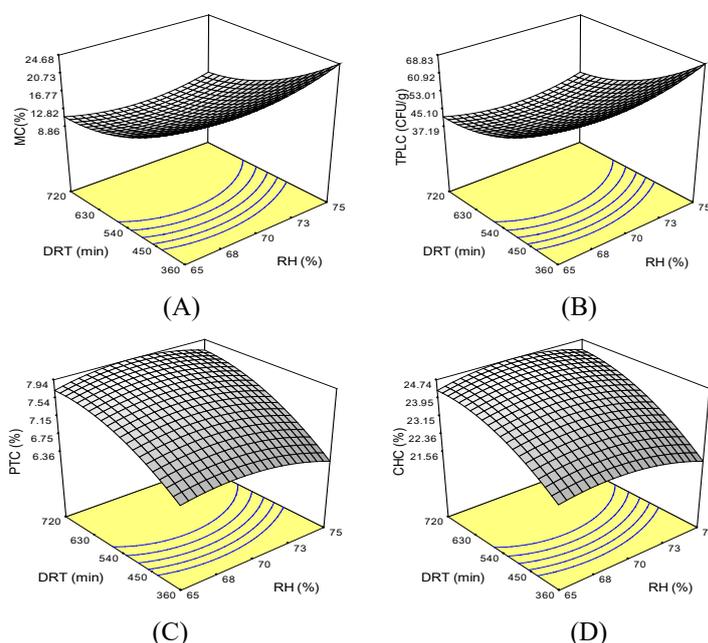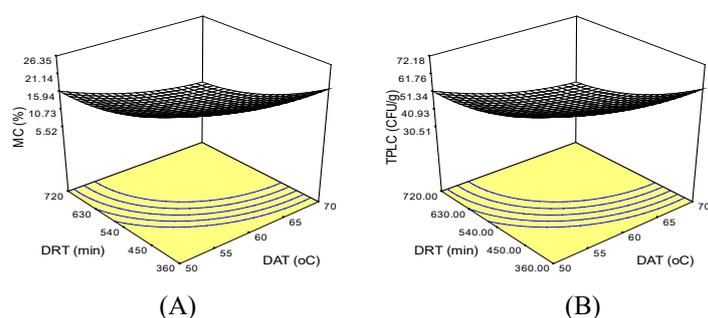

(A) (B)

(C) (D)

Figure 6 3-dimensional (3D) response surface plot indicating the interaction effects of (A) DRT and RH on MC, (B) DRT and RH on TPLC, (C) DRT and RH on PTC (D) DRT and RH on CHC during the chili pepper drying process.

The surface plots show that at a fixed DAV and DAT, the dried chili pepper MC and TPLC reduce while both the amount of PTC and CHC increases as result of the decrease in the RH and an increase in the DRT. Hence, **Figure 6(A) - 6(D)** tends to suggest that at a fixed DAV and DAT, the RH has to be reduced and the DRT to be increased to obtain some dried chili pepper products that possess a lower MC and TPC as well as a higher PTC and CHC.

The 3D response surface plots that illustrates interaction effect between DAT and DRT on the MC, TPLC, PTC, and CHC of dried chili pepper are provided in **Figures 7(A) - 7(D)**.
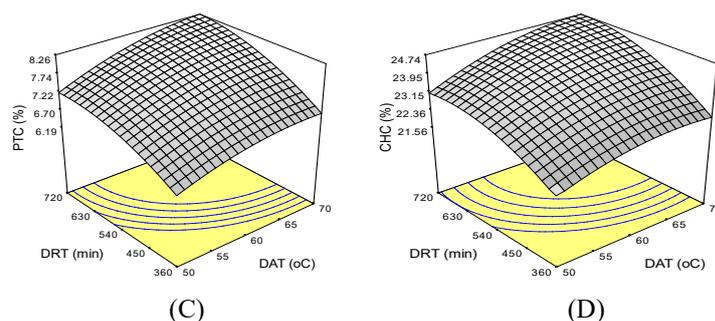

(A) (B)

(C)   (D)

Figure 7 3-dimensional (3D) response surface plot indicating the interaction effects of (A) DRT and DAT on MC (B) DRT and DAT on TPLC (C) DRT and DAT on PTC and (D) DRT and DAT on CHC during the chili pepper drying process.

The interaction impact of DAT and DRT on the MC and TPLC is significantly ($p \leq 0.05$) negative and mutual while its interactive effect on both the PTC and CHC is positive and significant. **Figures 7(A) - 7(D)** shows that drying at a fixed DAV and RH, both the MC and TPLC of the dried chili pepper product reduces to lower levels while both the PTC and CHC increases when the DAT and DRT are simultaneously increased. That is, a dried chili pepper product with a lower MC, lower TPLC, higher PTC, and higher CHC will be obtained at a higher DAT and DRT. Zhao *et al*. [11] and Idah *et al*. [29] have similarly and respectively reported an observation of a decreased MC for the drying of squid-laver snack and tomato when both DAT and DRT were increased.

Optimum chili pepper drying conditions and validation
A desirability function value of 1.000 was obtained in the course of predicting the chili pepper drying optimum conditions (**Figure 8**).
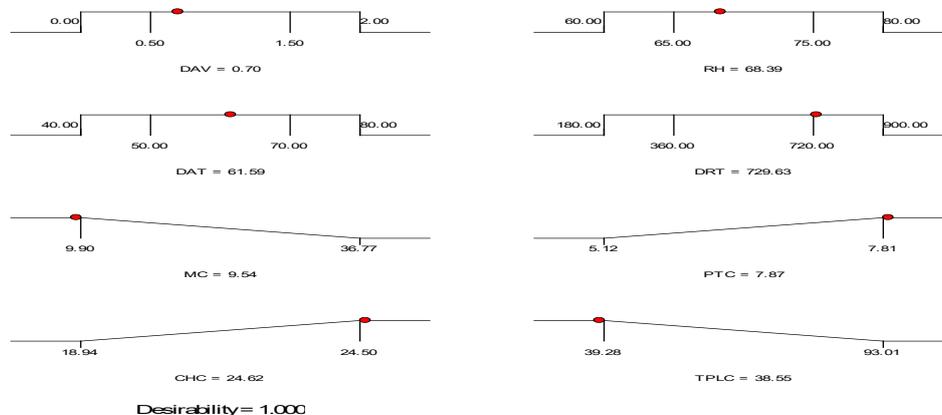

Figure 8 Ramps (desirability plot) showing predicted optimum values for the drying process conditions and predicted optimum values for the corresponding responses (quality attributes).

The optimum (uncoded) values of 0.70 m/s, 68.39 %, 61.59 °C, and 729.63 min were respectively predicted for DAV, RH, DAT, and DRT to obtain a dried chili pepper product that respectively has a minimum MC value of 9.54 %, a minimum TPLC value of 38.55 CFU/g, a maximum PTC value of 7.87 %, and a maximum CHC value of 24.62 %. The validation experiment was carried out at these predicted optimum drying conditions to respectively validate the minimum MC, minimum TPLC, maximum PTC, and maximum CHC. The validation experiment results for the dried chili pepper are 9.93 %, 40.10 CFU/g, 7.88 and 24.66 % for the minimum MC, minimum TPLC, maximum PTC and the maximum CHC, respectively. Percent errors of −4.09, −4.02, −0.127, and −0.162 % were found between the predicted and validated experimental values calculated utilizing Eq. (2). These values explicitly implied that there are no significant differences between the predicted and validated values.

Modeling the thin layer drying kinetics

The preliminary experimental results of MC variation with DRT at the different DAV, RH, and DAT were fitted to the 4 different drying model (Newton, Page, Logarithm, and Handerson and Pabis) equations given in Eqs. (3) - (6) using the non-linear regression (NLR) tool of MATLAB 6.5 version computer software. The model that had the highest R^2 and the lowest RMSE was selected [36]. The values of R^2, RMSE, and χ^2 obtained by the NLR analysis are presented in **Table 4**.

Table 4 Statistical validation and the drying constant of the tested drying models at different drying conditions.

Drying conditions	Page model					Handerson and pabis model				
	k	n	R^2	RMSE	χ^2	a	k	R^2	RMSE	χ^2
Air velocity (m/s)										
0.5 (at 70 °C and 60 %RH)	1.0E-4	1.62	0.976	0.027	0.0015	1.39	0.0050	0.956	0.074	0.0110
1.0 (at 70 °C and 60 %RH)	2.1E-4	1.51	0.978	0.030	0.0018	1.24	0.0051	0.967	0.068	0.0092
1.5 (at 70 °C and 60 %RH)	2.4E-4	1.48	0.984	0.037	0.0027	1.10	0.0057	0.953	0.064	0.0082
2.0 (at 70 °C and 60 %RH)	3.1E-4	1.39	0.981	0.034	0.0023	1.07	0.0075	0.949	0.055	0.0061
Relative humidity (%)										
65 (at 70 °C and 2 m/s)	1.78E-4	1.40	0.996	0.017	0.0006	1.08	0.0081	0.957	0.057	0.0065
70 (at 70 °C and 2 m/s)	1.77E-4	1.50	0.995	0.020	0.0008	1.09	0.0076	0.965	0.053	0.0056
75 (at 70 °C and 2 m/s)	1.76E-4	1.52	0.998	0.013	0.0003	1.10	0.0066	0.942	0.072	0.0104
80 (at 70 °C and 2 m/s)	1.62E-4	1.60	0.989	0.032	0.0020	1.10	0.0061	0.959	0.063	0.0079
Temperature (°C)										
40 (at 2 m/s and 60 %RH)	4.0E-4	1.64	0.982	0.027	0.0015	1.45	0.0035	0.941	0.074	0.0110
50 (at 2 m/s and 60 %RH)	4.3E-4	1.60	0.984	0.030	0.0018	1.43	0.0043	0.954	0.068	0.0092
60 (at 2 m/s and 60 %RH)	6.3E-4	1.53	0.979	0.037	0.0027	1.08	0.0054	0.945	0.064	0.0082
70 (at 2 m/s and 60 %RH)	8.3E-4	1.26	0.994	0.016	0.0005	1.08	0.0056	0.954	0.058	0.0067

Drying conditions	Logarithmic model						Newton model			
	a	c	k	R^2	RMSE	χ^2	k	R^2	RMSE	χ^2
Air velocity (m/s)										
0.5 (at 70 °C and 60%RH)	1.10	1E-06	0.0005	0.955	0.078	0.0122	0.0036	0.924	0.097	0.0188
1.0 (at 70 °C and 60 %RH)	1.09	1E-06	0.0030	0.946	0.065	0.0085	0.0037	0.948	0.079	0.0125
1.5 (at 70 °C and 60 %RH)	1.08	1E-06	0.0050	0.953	0.064	0.0082	0.0046	0.944	0.069	0.0095
2.0 (at 70 °C and 60 %RH)	1.02	1E-06	0.0075	0.949	0.055	0.0061	0.0070	0.941	0.059	0.0070
Relative humidity (%)										
65 (at 70 °C and 2 m/s)	1.03	1E-06	0.0076	0.947	0.064	0.0082	0.0734	0.944	0.065	0.0085
70 (at 70 °C and 2 m/s)	1.08	1E-06	0.0072	0.965	0.053	0.0056	0.0069	0.951	0.062	0.0077
75 (at 70 °C and 2 m/s)	1.09	1E-06	0.0066	0.945	0.072	0.0104	0.0059	0.924	0.083	0.0138
80 (at 70 °C and 2 m/s)	1.09	1E-06	0.0061	0.959	0.062	0.0077	0.0056	0.949	0.069	0.0095
Temperature (°C)										
40 (at 2 m/s and 60 %RH)	1.09	1E-05	0.0056	0.954	0.078	0.0122	0.0041	0.925	0.097	0.0188
50 (at 2 m/s and 60 %RH)	1.08	1E-05	0.0059	0.936	0.065	0.0085	0.0046	0.935	0.079	0.0125
60 (at 2 m/s and 60 %RH)	1.09	1E-05	0.0068	0.947	0.064	0.0082	0.0047	0.935	0.069	0.0095
70 (at 2 m/s and 60 %RH)	1.09	1E-05	0.0068	0.953	0.058	0.0067	0.0056	0.932	0.067	0.0090

Table 4 results show that at different DAV, RH, and DAT, the value of R^2 (0.924 - 0.998) was above 0.90, indicating a good model fit [61]. However, for the Page model, the obtained R^2 values at the different DAV, RH, and DAT were comparatively the highest among the remaining 3 tested drying models and the model also had the lowest RMSE values at these different DAV, RH, and DAT. Therefore, based on the highest R^2 and lowest RMSE and χ^2, the Page model was proposed to be the best and adequate model to describe chili pepper drying kinetics at the different process conditions. A similar observation of the Page model best describing the drying kinetics of the hot air drying of persimmon slices, thyme leaves, red pepper and bitter leaf has respectively been reported by Senadeera *et al*. [67], Turan and Fıratlıgil [63], and Agarry [62]. The Page model parameters for the cabinet-tray hot air drying of chili pepper indicate that k (drying constant) increased with increasing DAV and increasing DAT, while n (empirical constant) generally decreased with increasing DAV and increasing DAT. However, k decreased with increasing RH and n increased with increasing RH. Agarry [62] has similarly observed and reported for the drying of red pepper and bitter leaf an increased k when DAT was increased in the drying of red pepper and bitter leaf.

Conclusions

From the investigation of the response surface methodology of optimizing red chili pepper convective hot-air drying process conditions and the dried product quality attributes as well as modelling the thin-layer drying kinetics carried out using a cabinet-tray drying equipment, the following conclusions can be made. Firstly, DRT and DAT are the most significant drying process conditions that exerted a more pronounced main (individual) and interactive effects on the dried chili pepper quality attributes (MC, PTC, CHC, and TPLC) while DAV and RH exerted the least significant effect in the course of convective hot air drying. Secondly, the second-order quadratic regression models can predict adequately the quality attributes of dried chili pepper with respect to the drying conditions (DAV, RH, DAT, and DRT). Thirdly, the drying treatments generally improved or retained/preserved the PTC and CHC (nutritional properties) in the dried chili pepper product as well as reduced the microbial load to the acceptable limit allowed for consumption. Fourthly, the kinetics of chili pepper drying can most suitably be described by Page's empirical drying model. Lastly, the optimum drying process conditions required for red chili pepper drying using a cabinet-tray drying equipment to obtain a dried chili pepper with optimum quality attributes of a minimum MC and TPLC as well as maximum PTC and CHC are a drying temperature of 61.59 °C, an air velocity of 0.70 m/s, a relative humidity of 68.39 %, and a drying time of 729.63 min. This can be utilized as a standard or baseline information for varieties of dried red chili pepper industrial production. Further studies will be performed in our laboratory to evaluate the effects of physical and chemical pretreatments, temperature, step-down relative humidity strategy, and drying time on the nutritional (protein, carbohydrate, and ascorbic acid) and microbial qualities as well as colour quality and shrinkage of different varieties of chili pepper using intermittent microwave-convective air drying.

Acknowledgements

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