Optimization of Foam-Mat Drying Process of Watermelon Pulp Using Response Surface Methodology

J Isa[1*] and A. P. Olalusi[2]
[1,2]Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria
E-mail: jisa@futa.edu.ng; apolalusi@futa.edu.ng

ABSTRACT

Introduction: Foam mat drying involves the change of agricultural material from a high moisture content level to a stable foam which is achieved by moisture reduction mechanism.

Aim: In this study, foam-mat drying process of watermelon was optimized using response surface methodology. Foaming conditions (Carboxyl methyl cellulose and egg albumen) and the drying system parameters (air velocity and air temperature) were optimized using response surface methodology.

Methodology: To evaluate the drying behaviour, the drying experiment was designed using design expert software using a central composite design setting variable of drying temperature (60 °C – 80 °C), air velocity (0.5 m/s – 2 m/s), carboxyl methyl cellulose (0.5 % - 2.5 %), egg albumen (5 % - 15 %). Twenty-two runs of the experiment were performed using different levels of variables combinations. Based on the statistical tests performed, the best model that described each response was selected using a polynomial analysis.

Results: The optimum values for the drying conditions were: 77.42^{O}C, 0.5m/s, 0.5% and 5% for temperature, air velocity, carboxyl methylcellulose and egg albumen respectively and the optimum values for the drying characteristics were: 25.07 KJ/mol, 1.7345E-10 m^2/s, 29.019 % (wet-basis). 0.742 g/cm^3 and 540 minutes (approximately 9hrs) for activation energy, effective diffusivity, moisture content, foam density and the drying time respectively.

Conclusion: The study of the foam-mat drying of watermelon pulp revealed that the inlet temperature, air velocity, CMC and egg albumen has a significant effect on its drying characteristics.

Keywords: Watermelon pulp, foam-mat drying, optimization, response surface methodology, activation energy

1 Introduction

Foam mat drying involves the transformation of biological material from a liquid to a stable foam which is accomplished by air drying [1]. Azizpour et al. [2] reported that foam mat drying dates back to 1917. Foam mat drying which is an example of a novel drying technique [3] has received attention by its characterization through faster drying, and drying of material that contain high moisture content [2]. Foam mat drying can be used in the removal of moisture in juice, milk, fruits, beverages, jams [4]. Application of foam mat drying can be extended to the large-scale production of fruit powders

Watermelon *(Citrullus lanatus*) belongs to the family Cucurbitaceae and in the same family with cucumber and pumpkin. There are more than 100 varieties of watermelon ranging in weight from less than 1.4 kg to more than 32 kg and may be round or oblong in shape. It has smooth skin and may vary in color from light green to dark green [5]. Watermelon contains 91% water and 7% of carbohydrates. It is rich in lycopene a very powerful antioxidant, and also in citrulline [6]. [7] made a report that watermelon is a valued source of natural antioxidants with special reference to lycopene, ascorbic acid, and citrulline and these functional ingredients act as protection against chronic health problems like cancer insurgence and cardiovascular disorders. Many research works agreed with that fact that watermelon contains two health benefit component that cannot be ignored. Fruits have been said to be a major source of concentrated natural components that help in maintaining human health; Lycopene, a red pigment of the carotenoid class found in only a few fruits and vegetables, is a powerful oxygen radical scavenger and highly effective antioxidant. A high dietary intake of tomatoes, rich in lycopene content, is associated with a lower risk of certain cancers, primarily of the prostate [8]

Citrulline is described by [8] as a non-essential amino acid, its medication through oral method to children and adolescents with sickle cell disease resulted in improvement in symptoms and raised plasma arginine levels. It was concluded that watermelon rind is a rich source of amino acid and also might produce a good product from agricultural waste.

Drying is a heat treatment method of food processing technology (Jayas and Singh, 2011). The method most time reduces water activities in the material. Drying is applied to lower the moisture content of fruit to a level that can prevent the growth of mold and fungi and thus minimize microbial degradation [2]. In drying, two processes occur simultaneously which involve the transfer of heat and removal of a water molecule [1]. Recent techniques of drying include; vacuum drying, freeze drying, supercritical CO2 drying, centrifugal drying/dewatering, ultrasonic drying, heat pump drying, superheated steam drying, spray drying, hybrid drying/combination drying [9]. Another method of drying which is most economical than any other drying technique is foam mat drying [1].

This research work is focused on optimization of the drying characteristics of foam dried watermelon as a function of drying system parameters (temperature and air velocity) and structural parameters (foaming and stabilizing agent). Response surface methodology (RSM); a collection of mathematical and statistical technique that are useful for modeling and analysis of problems in which the response is influenced by several variables. The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process [10].

2 Materials and methods

The experiment to accomplish the desired objectives was performed in the Department of Agricultural and Environmental Engineering of Federal University of Technology, Akure.

2.1 Selection and sample preparation

The watermelon fruit used for this study were purchased in local retail store around the south gate of the Federal University of Technology, Akure. The fruits were wash and store until use. The watermelon rind was removed, sliced into cubes and the seeds were removed. The fruits were blended into juice using Binatone blending machine.

2.1.1 Foam treatment

The foamed watermelon concentrate was prepared by giving foaming treatment to the prepared concentrated juice by adding different levels of foaming agents, foaming stabilizer. The foaming agent and foaming stabilizer was added to watermelon concentrate at room temperature. The formation of foam was formed by whipping with a mixer. The foaming agent: Egg albumen (5-15 %), foaming stabilizer: carboxyl methylcellulose (0.5-2.5 %) and whipping time: 3-15 minutes. The foamed watermelon concentrates were prepared by varying the levels of foaming agent and the foaming stabilizer.

2.2 Experimental design for optimization of foamed watermelon pulp

The central composite experimental design was selected for the optimization of process variables i.e. egg albumen, carboxyl methylcellulose, air velocity, and drying temperature using Response surface methodology. Response surface methodology or RSM; a collection of mathematical and statistical technique that are useful for modeling and analysis of problems in which the response is influenced by several variables. The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process [10]. The design experiment runs were generated by using a central composite design using a variable of air velocity, temperature, egg albumen as a foaming agent and carboxyl methyl cellulose as the stabilizing agent and giving a response variable of Activation Energy, Moisture Diffusivity, foam density, drying time and Final moisture

2.2.1 Determination of foam density

The density of the foamed watermelon pulp was determined in terms of mass per volume (g/cm^3). The density was determined by measuring the foam volume in a cylindrical beaker and measuring the mass with the use of weighing balance.

$$\text{Foam density } \rho = \frac{\text{mass}}{\text{volume}} \text{ g/cm}^3 \qquad (2.1)$$

2.2.2 Determination of the drying parameter

The experiment sample was spread on an aluminum foil and placed in a mechanical dryer. The weight of the sample weight of each sample was checked every half an hour to determined drying rate and other drying parameters.

Table 2.1: Nomenclature of drying parameters

Abbreviations	Full form
x^2	Reduced chi-square
a, b, c, n	Empirical constants in drying models
CMC	Carboxyl Methyl Cellulose
D_{eff}	Effective moisture diffusivity, m^2/s
K	Drying constant

L	The thickness of foam mat, m
M_i	Initial moisture content
M_t	Moisture content at time t, kg moisture
M_e	Equilibrium moisture content, kg moisture
M_o	Initial moisture content, kg moisture
MR	Dimensionless moisture ratio
N	Number of observations
R^2	Coefficient of determination
$RMSE$	Root mean square error
MBE	Mean biased error
t	Drying time, h
Z	Number of drying constant
EA	Egg Albumen

2.2.3 Determination of drying rate (DR)

The drying rate is one of the important parameters that help in the understanding of drying characteristics of a material. The drying rate is calculated using expression described by Salahi et al. [11]

$$DR = \frac{M_t - M_{t+\Delta t}}{\Delta t} \qquad (2.2)$$

where $M_{t+\Delta t}$ is moisture content at t + Δt (kg water/kg dry solid), t is the time (min) and Δt is time difference (min).

2.2.4 Determination of moisture ratio

The moisture content of the samples was expressed in term of moisture ratio (MR) using the expression described by salahi et al. [11]

$$MR = \frac{M_t - M_e}{M_i - M_e} \qquad (2.3)$$

2.2.5 Determination of moisture diffusivity

Fick's diffusion equation was used for calculation of effective diffusivity as described by Wilson *et al.* [12]

$$MR = 8/\pi^2 \exp\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \qquad (2.4)$$

Which can be rewritten as

$$D_{eff} = \frac{\ln MR - \ln\frac{8}{\pi^2}}{\frac{\pi^2 t}{4L^2}} \qquad (2.5)$$

The slope (K_o) is calculated by plotting ln(MR) against time to determine the effective diffusivity for different temperatures.

$$K_o = \left(\frac{\pi^2 D_{eff}}{4L^2}\right) \qquad (2.6)$$

2.2.6 Determination of activation energy

The relationship between the diffusion coefficient with the temperature can often be described by the Arrhenius-type relationship Equation as described by Azizpour et al. [13] in equation 2.7

$$D_{eff} = D_o \, exp\left(-\frac{E_a}{RT}\right) \qquad (2.7)$$

where D_0 is the constant in Arrhenius equation ($m^2 \, s^{-1}$); Ea is the activation energy (KJ mol^{-1}); R is the universal gas constant (kJ mol^{-1} K^{-1}). It can be rearranged in the form of:

$$\ln(D_{eff}) = \ln(D_o)\frac{-E_a}{RT} \qquad (2.8)$$

The activation energy was calculated by plotting the $\ln(D_{eff})$ against the reciprocal of absolute temperature (1/T)

3 Results and Discussions

3.1 Model fitting

The central composite design (CCD) data were analyzed using multiple regression analysis and the correlation between the independent variables of foam mat drying *viz*., Temperature (60-80 °C), air velocity (0.5-2.5 m/s) carboxyl methylcellulose (0.5-2.5 %) and egg albumen (5-15 %) and dependent variables such as activation energy, effective diffusivity, moisture content, foam density and drying time. After the analysis, a polynomial relationship was developed between the dependent and independent variable.

3.1.1 Model equations

From equation 3.1, the coefficients of the first order terms variables indicated that the activation energy increased with the increased in inlet air temperature, decreased in air velocity, increased in CMC, decreased in egg albumen and increased in combination of both CMC and egg albumen concentration.

From equation 3.2, the coefficients of the first order terms variables indicated that the effective diffusivity increased with increased in temperature, decreased in air velocity, decreased in CMC, decreased in egg albumen.

From equation 3.3, the coefficients of the quadratic equation variables indicated that the moisture content increased with decreased in temperature, increased in air velocity, increased in CMC, increased in egg albumen and decreased with combination of CMC and egg albumen.

From equation 3.5, the coefficients of the linear equation indicated that the drying time increased with increase in temperature, increase in air velocity, decrease in CMC and egg albumen concentration.

$$Activation\ energy = 22.15 + 1.17A - 0.8808B + 0.4647C - 0.3717D - 1.43AB + 0.9196CD \quad (3.1)$$

$$Effective\ diffusivity = 9.6267E - 11 + 2.636E - 11A - 1.442E - 11B - 1.17E - 11C - 1.899E - 11D + 1.657E - 11AB + 1.395E - 11CD \quad (3.2)$$

$$Moisture\ content = 40.52 - 9.86A + 1.15B + 2.44C + 8.40D + 1.35AB - 2.90CD \quad (3.3)$$

$$Foam\ density = 0.7425 \quad (3.4)$$

$$Drying\ time = 684 - 36.12A + 47.8B - 32.98C - 2.86D + 51.77AB + 2.77CD \quad (3.5)$$

Where

A = Temperature

B = Air velocity

C = Carboxyl methylcellulose concentration

D = Egg albumen

3.2 Optimization of drying characteristics of watermelon pulp

Numeric optimizations were carried out for the drying system parameters and the structural parameters of foam dried watermelon pulp. The desirability of the independent variables and the dependent variables was summarized in the table 3.1. The goal was to put the dependent factors; temperature, air velocity, CMC and egg albumen in range. The independent factors; effective diffusivity and foam density to be maximized. Activation energy, moisture content and drying time to be minimized. The optimum conditions for the independent variables were found to be temperature 77.42 °C, air velocity 0.5 m/s, carboxyl methylcellulose of 0.5 %, Egg albumen 5 % for achieving minimized activation energy of 25.07 KJ/mol, maximized effective diffusivity of 1.74345 X 10^{-10} $m^{2/}s$, minimized moisture content to be 29.19% wet-basis, maximized foam density of 0.742 g/cm^3, minimized drying time of 9hrs with a desirability of 70.2%. The effective diffusivity of the foam-mat dried watermelon increases with temperature as shown on the model plot. This behavior is also observed in foam mat drying of watermelon pulp by Wilson et al. [12]. The moisture content of foam dried watermelon reduces with increasing temperature and at a range of air velocity of 1.1 – 1.4 m/s. keeping the carboxyl methyl cellulose and egg albumen at 1.5% and 10% respectively. This may be due to the generation of high hot air during drying, which might have trapped the moist air that was found in the fed product and it might have reduced the moisture content to a greater extent which was also reported by Jaya and Das [14]. The drying time of the foam dried watermelon reduces with increasing temperature and reducing air velocity. The drying time 600 minutes (10hrs) was recorded between a temperature of 74 °C – 80 °C and an air velocity of 0.5 m/s and 8 m/s. moisture content reduces with a decrease in egg albumen concentration but increases with increases in carboxyl methylcellulose concentration. Maciel *et al*. [14] also reported that moisture loss was faster in samples containing higher albumen concentration.

Table 3.1: Optimization Goal Table

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Temperature	is in range	60	80	1	1	3
B: Air Velocity	is in range	0.5	2	1	1	3
C: CMC	is in range	0.5	2.5	1	1	3
D: Egg Albumen	is in range	5	15	1	1	3
Activation Energy	minimize	20.4608	31.6752	1	1	3
Effective Diffusivity	maximize	1.47943E-11	1.80896E-10	1	1	3
Moisture content	minimize	20.8998	79.6584	1	1	3
Foam Density	maximize	0.512	1.1866	1	1	3
Drying Time	minimize	540	720	1	1	3

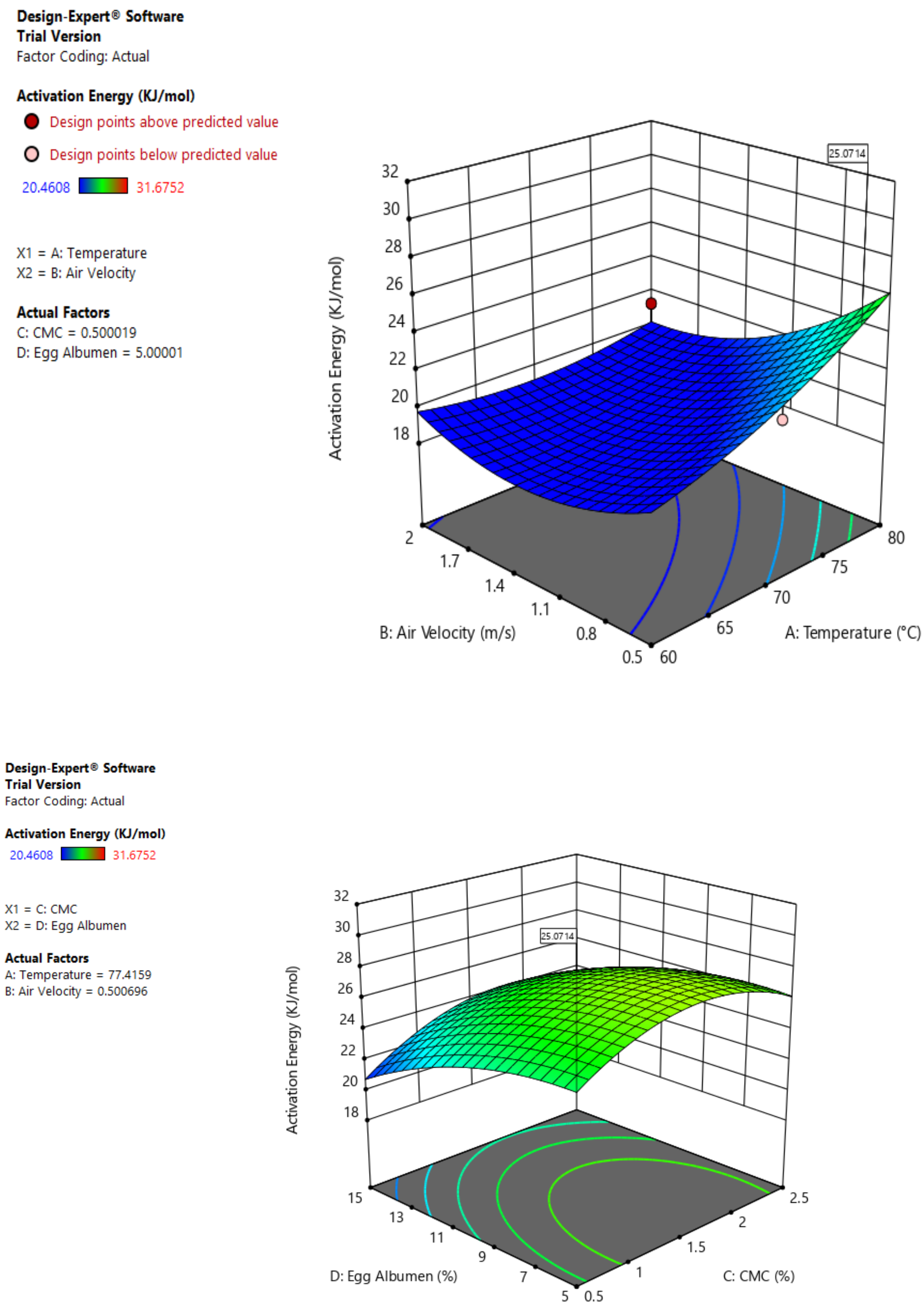


Figure 3.1: Optimized graph of activation energy

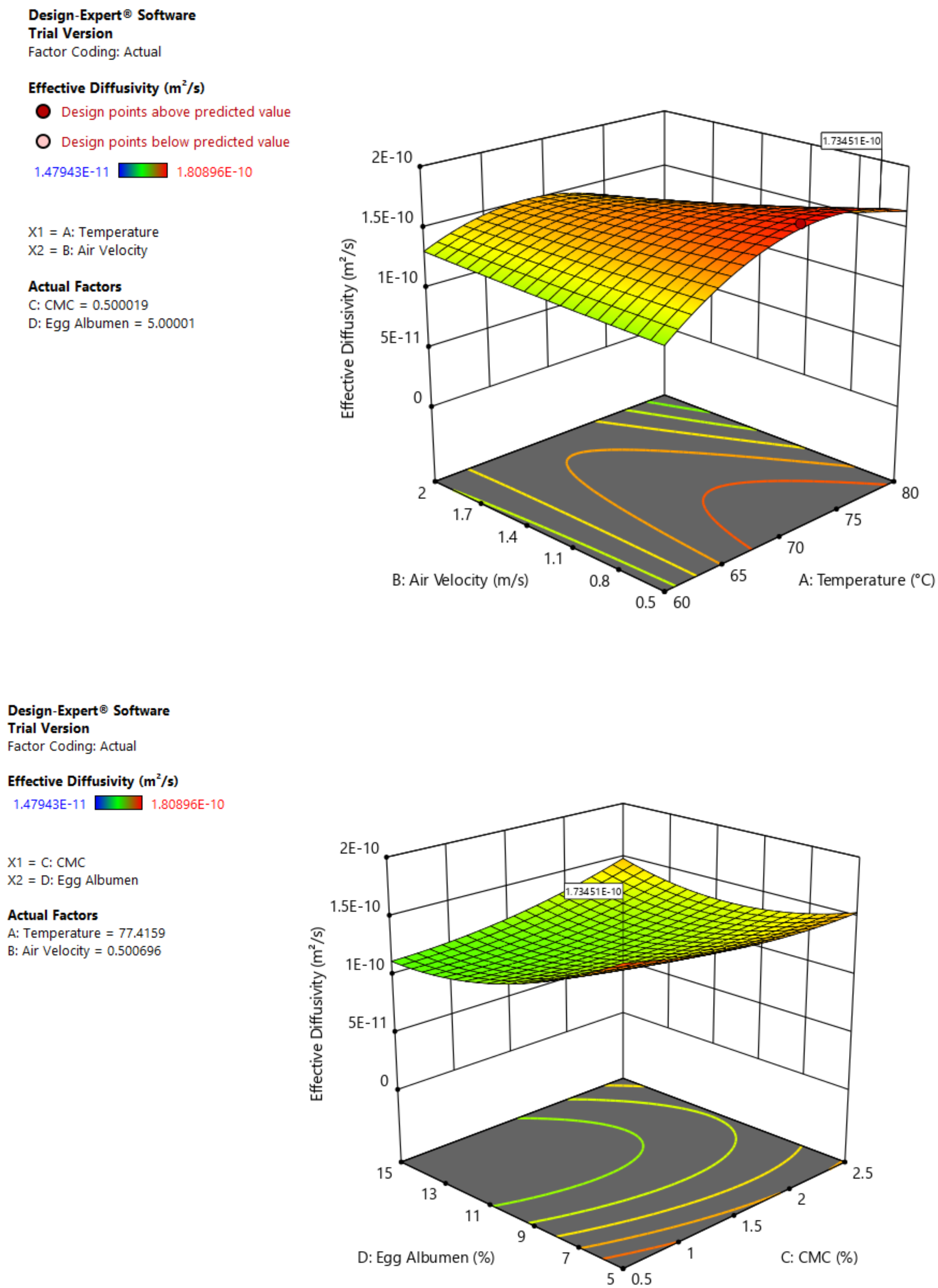
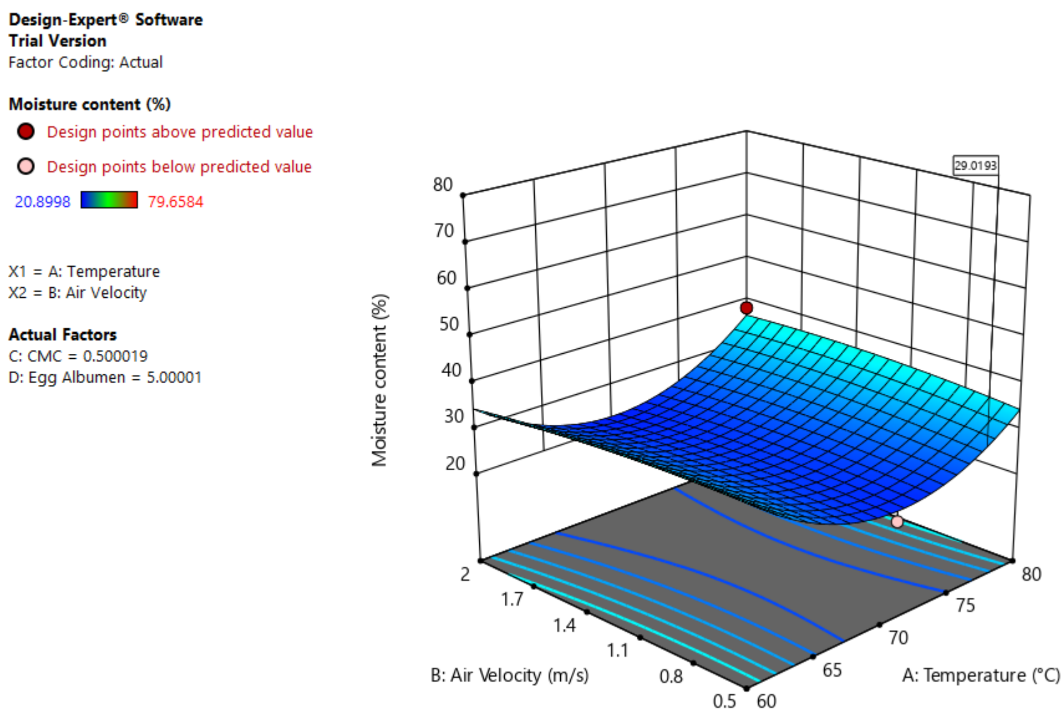


Figure 3.2: Optimized graph of effective diffusivity



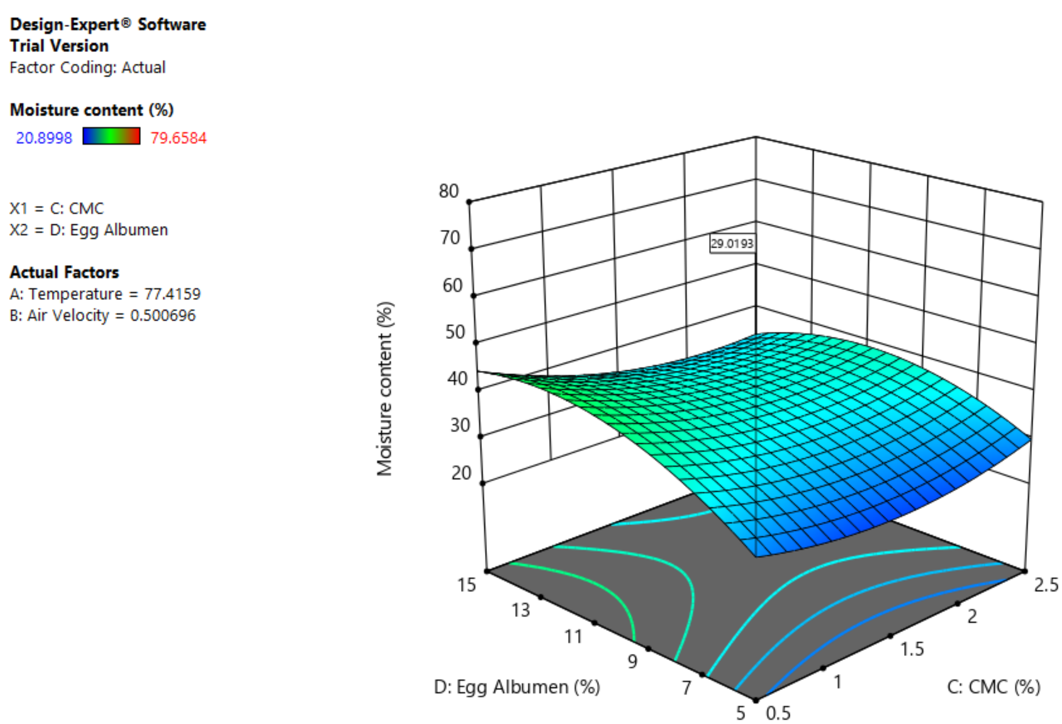
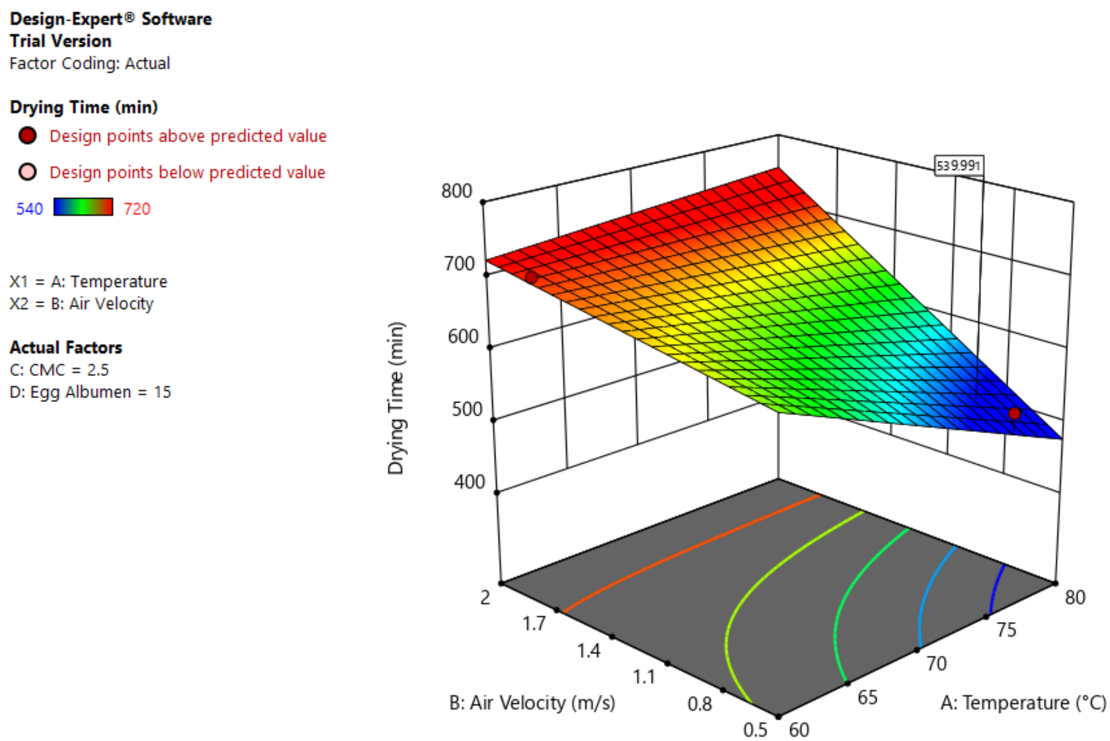


Figure 3.3: Optimized graph of moisture content



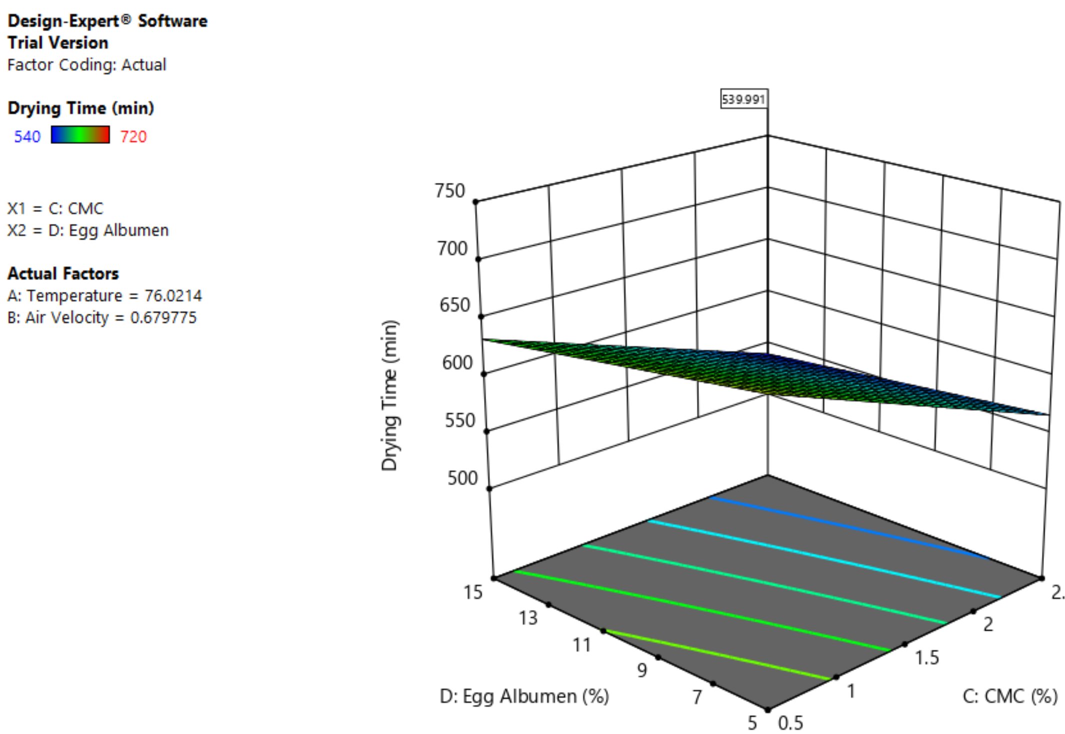


Figure 3.4: Optimized graph of drying time

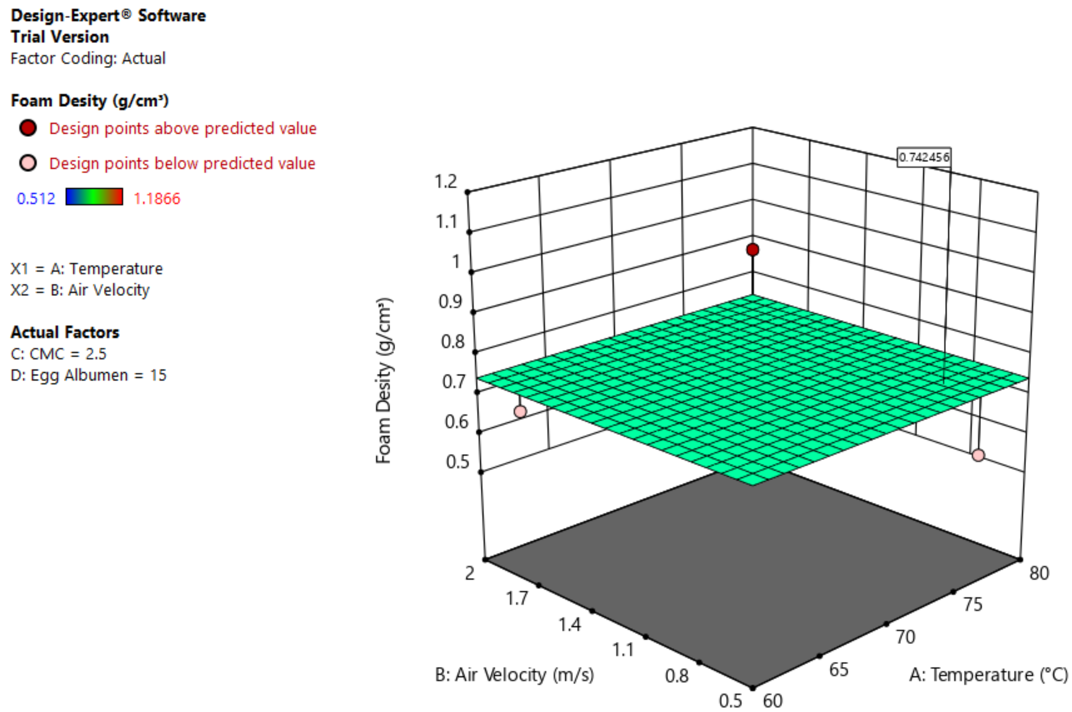


Figure 3.5: Optimized graph of foam density

4 Conclusion

The foam-mat drying of watermelon pulp was successfully carried out using a central composite design followed by response surface methodology. The optimum process conditions of foam-mat drying of watermelon pulp were activation energy of 25.07 KJ/mol, effective diffusivity of 1.73 X 10^{-10} m^2/s, the moisture content of 29.02 % (wet basis), a foam density of 0.74 g/cm^3, drying time of 540 minutes. A polynomial analysis was carried out, were quadratic model best described the activation energy, effective diffusivity, moisture content. mean model best described the foam density, whilst linear and 2FI model described the drying time. The study of the foam-mat drying of watermelon pulp revealed that the inlet temperature, air velocity, CMC and egg albumen concentration has a significant effect on the drying characteristics of the process.

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