ZIBELINE INTERNATIONAL™
PUBLISHING

ISSN: 2616-4302 (Online)
CODEN: AMMCFL

Acta Mechanica Malaysia (AMM)

DOI: http://doi.org/10.26480/amm.02.2024.139.163

RESEARCH ARTICLE

ENVIRONMENT-CONTROLLED DRYING OF CUT-ROSELLE: ANALYSIS OF DRYING-PARAMETERS & VALIDATION OF MODIFIED-PAGE II

I.E. Saeed*, Zulkhairi Zainol Abidin

Dept of Mech. & Manufacturing Eng., Faculty of Eng. & Built Environ., National University of Malaysia, 43600 Bangi, S.D.E., Malaysia.
****Corresponding author: ismt5@yahoo.com***

ARTICLE DETAILS

Article History:

Received 20 May 2024
Revised 18 June 2024
Accepted 25 July 2024
Available online 27 July 2024

ABSTRACT

This Part II, of the research on the controlled-environment drying of Cut-Roselle, aimed to inspect the effects of varying drying-conditions on the drying-rate and drying-constant, and to assess, evaluate, and verify the Modified-Page II model's performance. The study is carried-out in a chamber with controlled humidity, airspeed, and temperature. Where, different relative-humidity and temperatures are applied. The analysis of thin-layer drying-models revealed that the Modified-Page II model provided the most accurate fit, out of the 12 models. The average values obtained for the drying-constant (k), the model-coefficients (n) and (L) are, respectively, 0.00343, 0.99219, and -0.87306. The precision of the developed model is validated through two approaches: comparing the predicted-moisture contents with the actual moisture-data and examining the residuals in relation to the predicted-moisture contents. The findings indicated that the Modified-Page II model successfully, characterized the drying-performance of the Cut-Roselle.

KEYWORDS

Modified-PageII; model-validation; drying-constant; drying-rate; drying-parameters; Roselle

1. INTRODUCTION

Roselle or Karkade, is a perennial herb referenced in (Thuy et al., 2023). Which is grown for medicinal purposes across various nations (Shruthi et al., 2016). Its vibrant red-hue and unique-flavour make it a favoured ingredient in jam, beverage, jelly and productions. The petals, abundant in anthocyanins, act as a natural-dye and are a potential antioxidant source (Lema et al., 2021; Pi-Jen et al., 2002). A calyx-derived infusion, known as Sudan-tea, is traditionally consumed in East-Africa, for coughs alleviation (Morton, 1987). For further details on Roselle's cultivation, bio-composite applications, and its uses in medicinal, domestic, and industrial sectors can be refer in (Ahiduzzaman et al., 2021; Mariod et al., 2021; Sapuan et al., 2021).

Hot-air drying, is commonly used in the food-industry to dehydrate the products, with temperature settings tailored to the heat-sensitivity of the food and the desired-quality of the final-product (Buzrul 2022; Lewicki, 2006). The wide variety of dehydrated foods available, along with the emphasis on quality (considering nutritional-content, textures, colors, forms/shapes), and energy-efficiency, highlight the needs for comprehensive consideration of the drying-processes (Górnicki et al., 2007). Due to the complex nature of food, drying may involves multiple mechanisms simultaneously. Thus, modelling the drying-process and predicting outcomes, in various conditions, is essential to understand the drying-mechanisms. The drying-rate during the falling-rate phases is influenced by the concentration-gradient within the food and is dependent on the drying-temperature (Nguyen and Price, 2007).

Mathematical-modelling of thin-layer drying, is crucial for managing operational-parameters effectively and estimating the performance of drying-systems (Jain and Pathare, 2004), designing and optimization of the equipment (Buzrul, 2022), as well as for comprehending the drying-process itself (Górnicki et al., 2007). Precise drying-models are needed for drying-curves simulation in varying-conditions (Simal et al., 2005). While theoretical-models focus on moisture-movement being mainly, driven by internal-resistances mechanisms, the semi-theoretical and empirical models merely, consider external-resistances (Babalis et al., 2006). Models with fewer parameters are preferred for establishing clear-relations between parameter-values and drying-conditions applied (Chen, 2002). Nonetheless, accurately describing and predicting kinetics of the drying-material, poses a significant challenge in the field of drying process-modelling.

Reliable and consistent models are crucial for the precise assessment and prediction of drying durations and rates (Coumans, 2000). The kinetics of the drying are heavily affected by factors such as the temperature of the air and the physical-dimensions of the substances (Kiranoudis et al., 1997; Krokida et al., 2003). The drying-rate constants are calculable independently of the food material's shape or its varying dimensions during the drying-process (Simal et al., 2005; Rapusas and Driscoll, 1995). It investigates the mechanisms of transferring heat and mass, and examines the effects of various process-parameters on the dehydration-process. The quantification of this constant is achieved through experimental studies that monitor the reduction in moisture-levels over time, under different drying-environments (Krokida et al., 2004).

The rate at which drying occurs is governed by factors that control the transfer-mechanisms. These include the vapour-pressure within the material and the surrounding-air, the speed and temperature of the air, the rate at which water moves within the material, and the material's thickness and drying surface-area (El-Aouar et al., 2003). Moreover, different product types have their unique drying-characteristics (Belghit et al., 2000). The drying-curves refers to charts that illustrate how the average moisture-contents change with times, or how the drying-rates vary with the average moisture-contents (Jannot, 2004). Various drying techniques and systems, such as solar, traditional hot-air, or hybrid methods, are employed to dehydrate agricultural and food products.

Quick Response Code	Access this article online	
	Website: www.actamechanicamalaysia.com	**DOI:** 10.26480/amm.02.2024.139.163

Cite the Article: I.E. Saeed*, Zulkhairi Zainol **Abidin** (2024). Environment-Controlled Drying Of Cut-Roselle: Analysis Of Drying-Parameters & Validation Of Modified-Page Ii: Research Article. *Acta Mechanica Malaysia, 7(2): 139-163.*

Numerous thin-layer drying models exist to characterize the drying-behavior of these materials. Reseachers in a study introduced 34 thin-layer drying mathematical-models, commonly applied to fit the performance of foods and agricultural products (Inyang, et al., 2018). Two-term-Gaussian-model is found the best to fit the two-phase olive-pomace greenhouse-drying (Mellalou et al., 2023). Mugi and Chandramohan, used solar-dryers to dry guava-slices, and found that Page models are the best models to describe the drying-curves (Mugi and Chandramohan, 2022). Midilli-kucuk model is found the best fitted to thin-layer drying of the Rosemary-leaves, red-chilli solar-drying, and groundnut drying (Mghazli et al., 2017; Ekka and Palanisamy, 2020; Shimpy et al., 2022). The drying-curves of the mangoes are well described by the Approximation-of-diffusion and Two-term drying models (Dissa et al., 2011). Orange-slices drying-curves are fitted by Modified-Henderson and Pabis models (Atalay, 2019). Weibull, and Two-term exponential-models best fitted the Stevia-leaves drying (Téllez, et al.,2018). Page model represented apple-drying (Yuan et al., 2019, Lingayat et al., 2020), and apple-slices microwave-vacuum drying (Polat et al., 2019), while Midilli et al. model performed well for watermelon-drying (Lingayat e al., 2020). Modified Henderson model explained the drying characteristics of tomato-pieces, under mixed solar-dryer, while Pabis model explained the indirect-solar-dryer behavior (César et al., 2020). Page & Modified-Page, models described the drying-kinetics of garlic-slices (Engin and Tulek, 2014). The logarithmic model is the best drying-model for open-sun drying of gooseberry-slices (Patel et al., 2023).

To prove the reliability of established drying-models, the calculated moisture-content values (predicted by the model), are compared with measured (experimental) values (Simal et al., 2005; Midilli et al., 2002; Togrul and Pehlivan, 2003). As well, the residuals are analysed against the model's predicted values (Imad, 2010b; Keller, 2001; Spatz, 2001). In the first part of this study, statistical-analysis demonstrated that the Modified-Page II model performed better than other models. Hence, the goals of this work are to evaluate and validate the developed Modified-Page II model, for thin-layer drying of Cut-Roselle (*Hibiscus sabdariffa* L.), and to examine the impacts of the drying-conditions on the drying-rates, drying-constant, and model-parameters.

2. MATHEMATICAL-MODELLING

Experiments on thin-layer drying of Cut-Roselle are conducted in a Constant-Temperature and Humidity-Chamber. The experiments and the utilized equipment are detailed in first part of the study. Additionally, mathematical-modelling for the drying-experiments is provided. Twelve thin-layer drying models are fitted to the experimental-data using the non-linear regression-method with the least-squares Levenberg-Marquardt procedure (Doymaz, 2007; Saeed et al., 2008a; Suherman et al., 2012; Taskin et al., 2021). And compared using goodness-of-fit statistical-measures (Imad, 2010b; Inyang et al., 2018; Zhang et al., 2023). The results showed the power of the Modified-Page II model to best describe the drying-performance of the Cut-Roselle. The basic formulae that describe the moisture-contents, drying-rate, statistical-parameters, and thin-layer drying-model, are given by:

Moisture-content, dry-basis (MC_{db}) (Mugi and Chandramohan, 2022; Joshy et al., 2021, Kipcak and Doymaz, 2020):

$$MC_{db} = \frac{W_w}{W_d}.100 \tag{1}$$

Moisture-ratio (*MR*) (Kipcak and Doymaz, 2020; Izli et al., 2018; Jayasuriya et al., 2023):

$$MR = (M - M_e)/(M_o - M_e) \tag{2}$$

Drying-rate (*DR*) (Engin and Tulek, 2014; Jayasuriya et al., 2023; Saeed et al., 2012):

$$DR = \left(M_{(t+dt)} - M_t\right)/dt \tag{3}$$

Residual MR (MR_{Resid}) (Saeed et al.,2008b; Tahir, 2008; Imad, 2010b):

$$MR_{residual} = MR_{observed} - MR_{predicted} \tag{4}$$

Coefficient-of-determination (R^2) (Joshy et al., 2021; Jayasuriyaet al., 2023; Ismail and Kocabay, 2018):

$$R^2 = SSR/SST = 1 - SSE/SST \tag{5}$$

Adjusted-R^2 (AR^2) (Spatz, 2001; Tahir, 2008; Keller,2001):

$$AR^2 = 1 - [SSE/(df_{error})]/[SST/(df_{total})] \tag{6}$$

Error (residual) sum of squares (SSE) (Saeed et al.,2008a; Tahir, 2008; Imad,2010a):

$$SSE = \sum_{i=1}^{N} \left(MR_{exp,i} - MR_{cal,i}\right)^2 \tag{7}$$

Standard-error of estimate (*SEE*) (Saeed, et al.2008a; Tahir, 2008; Imad, 2010a):

$$SEE = \sqrt{\sum_{i=1}^{N} \left(MR_{exp,i} - MR_{cal,i}\right)^2 \quad (N - n_p)} \tag{8}$$

Reduced-sum sq.-error (*RSSE*) (Engin and Tulek, 2014; Imad, 2010a; Tahir, 2008):

$$RSSE = \sum_{i=1}^{N} \left(MR_{exp,i} - MR_{cal,i}\right)^2/(N) \tag{9}$$

Root-mean sq.-error (*RMSE*) (Joshy et al., 2021; Jayasuriyaet al., 2023; Ingle et al., 2022):

$$RMSE = \sqrt{\sum_{i=1}^{N} \left(MR_{exp,i} - MR_{cal,i}\right)^2 \Big/ (N)} \tag{10}$$

Mean-sum of sq.-errors (*MSE*) (Kingsly and Singh,2007; Imad, 2010a; Tahir, 2008), or reduced chi-square (χ^2) (Joshy et al., 2021; Jayasuriyaet al., 2023; Ingle et al., 2022):

$$MSE = \sum_{i=1}^{N} \left(MR_{exp,i} - MR_{cal,i}\right)^2 \quad (N - n_p) \tag{11}$$

Arrhenius-equations: *Eq.*12 (Gupta et al.,2002; Sogi et al., 2003; Tahir, 2008) and Equation 13 (Tarigan, 2007; Azzouz et al., 2002; Shivhare et al., 2000):

$$k = k_o \, Exp(-E_o/R\,T) \tag{12}$$

$$k = A_o \, Exp(-B/T) \tag{13}$$

Modified-Page II is given as (Buzrul, 2022; Imad, 2010a; Dasore et al., 2019):

$$MR = \exp(-k(t/L^2)^n) \tag{14}$$

3. RESULTS & DISCUSSIONS

As shown in Part-I of this study, the drying-temperature is the primary factor influenced the drying-kinetics of Cut-Roselle, with increased temperature significantly reduced the drying-time. This effect is also shown by many studies (Soysal et al., 2006; Wang et al., 2007; Therdthai, and Zhou, 2009). Conversely, air-humidity had a lesser effect on the drying-process. A statistical-analysis is performed, and a comparison among twelve drying-models is conducted to select the most-accurate model for the drying-curves. Dimensionless moisture-ratio (MR) is used to quantify the moisture-content (Thuy et al. 2023; Inyang, et al., 2018; Saeed, et al., 2008a; Imad, 2010a). The predicted (or theoretical) MR by the Modified-Page II model and the observed (experimental) MR are plotted against drying-time, and shown in Figure 1 to Figure 4 (Chabane and Adouane, 2018). It is obvious that the model predicted-well the drying-curves of Cut-Roselle, as the data-points of the observed-moisture and predicted-moisture are frequently, matching. Furthermore, the statistical-measures, i.e., R^2, AR^2, SSE, SEE, RSSE, RMSE, and MSE, are shown in Tables 1 to 4. These values are better than or agreed well with data found in the literature. For instance, gooseberry-slices drying (open-sun process) yielded an R^2 of 0.9976 and an RMSE of 0.01255 (Patel et al., 2023). While solar drying of Amelie and Brooks varieties of mangoes resulted in R^2 values of 0.989 and 0.992, respectively, with an RMSE of less than or equal to 0.0283 (Dissa et al., 2011). Researcher found values for R^2=0.9993, RMSE=0.0114, MSE=0.0001, RSSE=0.00014, in the hot-air-drying, and values for R^2=0.9992, RMSE=0.0104, RSSE=.00011, MSE=0.00012, in solar-drying of Roselle (Tahir, 2008). The mixed solar-drying of tomato-slices showed an R^2 of 0.9888, and RMSE= 0.0027, while, indirect solar-drying showed an R^2 of 0.9996, with an RMSE of 0.008 (César et al., 2020). A study in 2023 found an R^2 of 0.998 and an RMSE of 0.00023, for Roselle-seeds dried at 70°C, and an R^2 of 0.996 for drying at 55°C (Thuy et al., 2023). In the study by researchers in 2021, on drying of scent-leaf and lemon-basil leaf, they found values for R as 0.9998 and 0.9961, and for SSE as 0.0002 and 0.0034, and for RMSE of 0.0081 and 0.0222, respectively (Mbegbu et al., 2021).

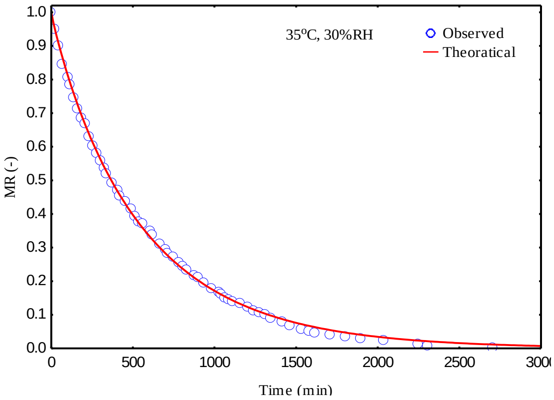

Figure 1a: MR vs. time (35°C, 30%RH)

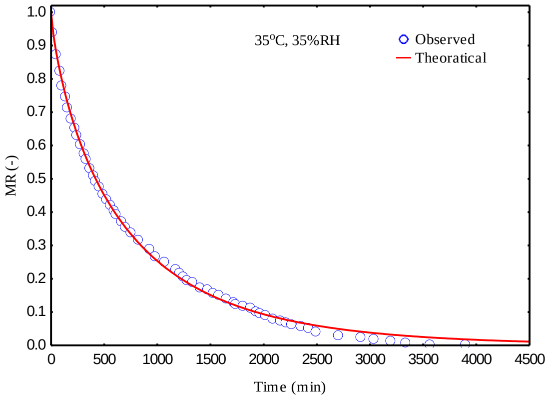

Figure 1b: MR vs. time (35°C, 35%RH)

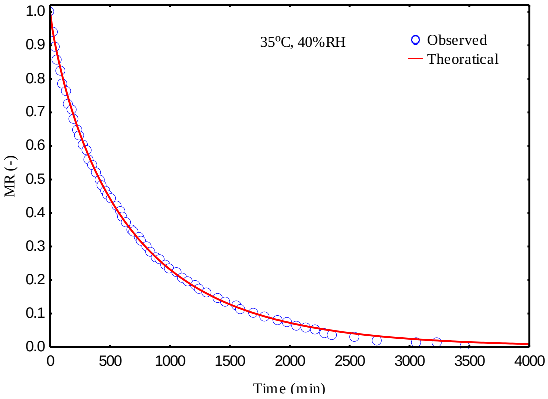

Figure 1c: MR vs. time (35°C,40%RH)

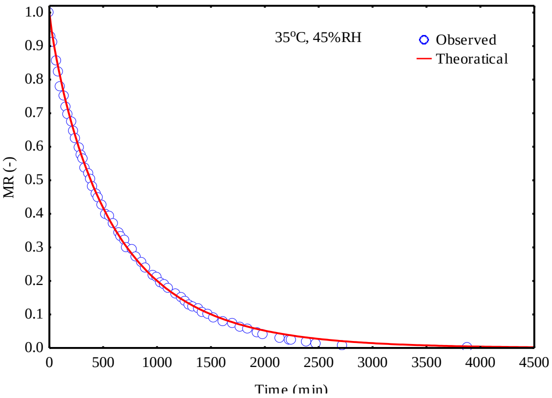

Figure 1d: MR vs. time (35°C,45%RH)

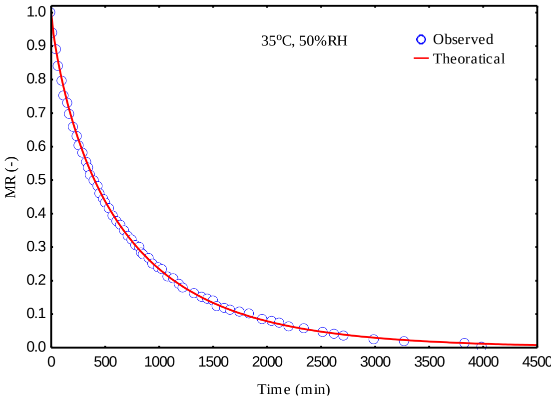

Figure 1e: MR vs. time (35°C,50%RH)

Table 1: Statistical – Measures at 35°C

RH	R^2	SSE	SEE	RSSE	RMSE	MSE
30	0.9996	0.0047	0.0091	0.00008	0.0089	0.0001
35	0.9994	0.0064	0.0106	0.00011	0.0103	0.0001
40	0.9998	0.0022	0.0063	0.00004	0.0061	0.0000
45	0.9997	0.0035	0.0078	0.00006	0.0076	0.0001
50	0.9999	0.0007	0.0035	0.00001	0.0035	0.0000

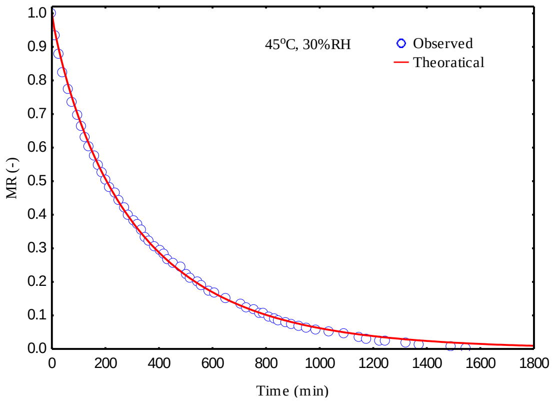

Figure 2a: MR vs. time (45°C,30%RH)

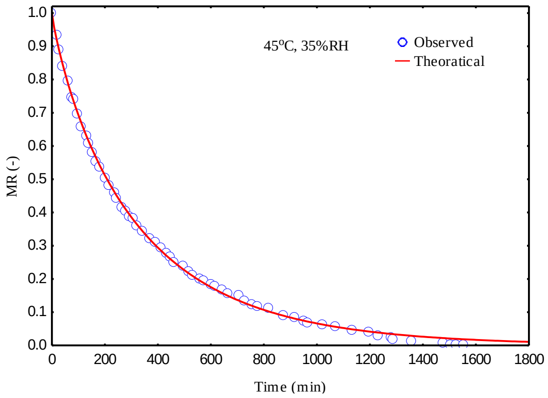

Figure 2b: MR vs. time (45°C,35%RH)

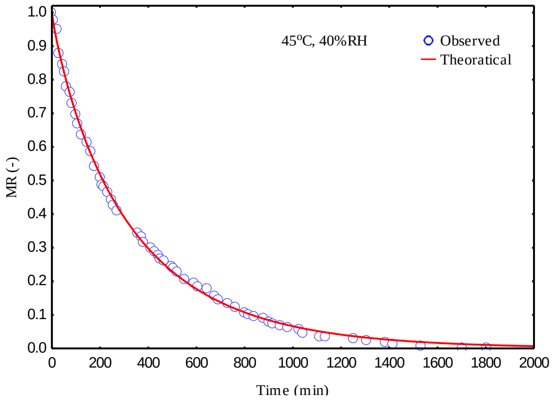

Figure 2c: MR vs. time (45°C,40%RH)

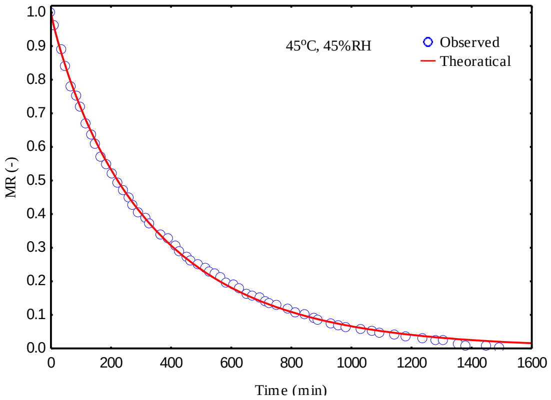

Figure 2d: MR vs. time (45°C,45%RH)

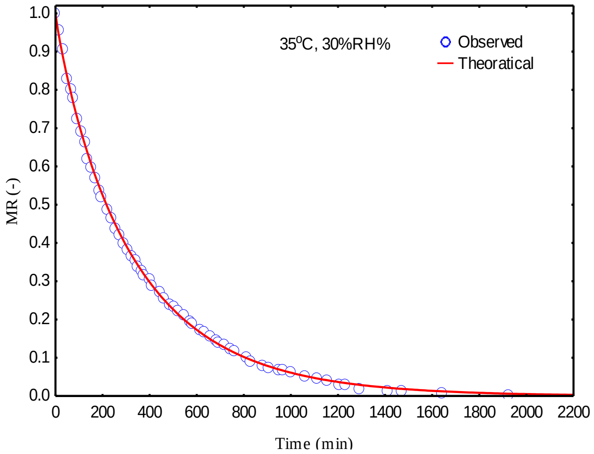

Figure 2e: MR vs. time (45°C,50%RH)

Table 2: Statistical- Measures at 45 °C

RH	R^2	SSE	SEE	RSSE	RMSE	MSE
30	0.9996	0.0037	0.0081	0.00006	0.0079	0.0001
35	0.9996	0.0044	0.0088	0.00007	0.0085	0.0001
40	0.9994	0.0073	0.0113	0.00012	0.0110	0.0001
45	0.9996	0.0041	0.0085	0.00007	0.0082	0.0001
50	0.9997	0.0030	0.0072	0.00005	0.0071	0.0001

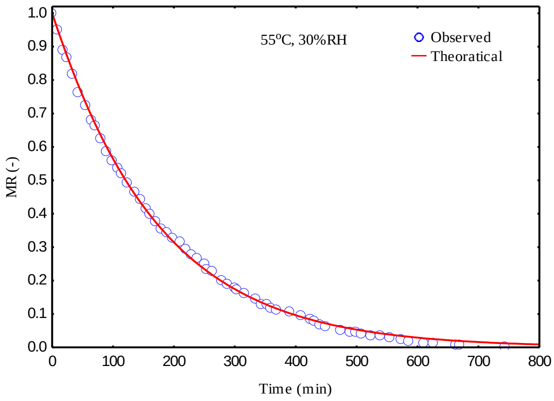

Figure 3a: MR vs. time (55°C,30%RH)

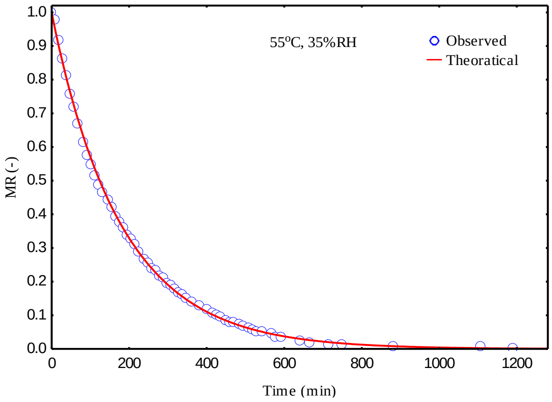

Figure 3b: MR vs. time (55°C,35%RH)

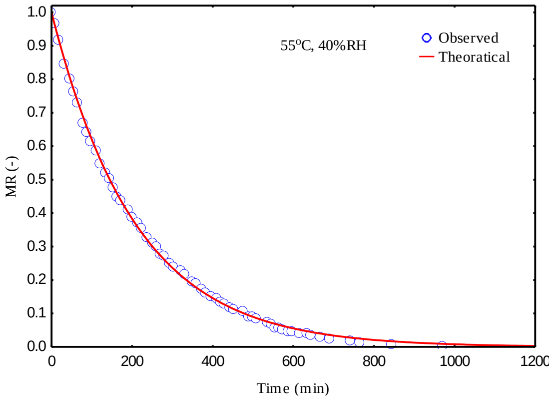

Figure 3c: MR vs. time (55°C,40%RH)

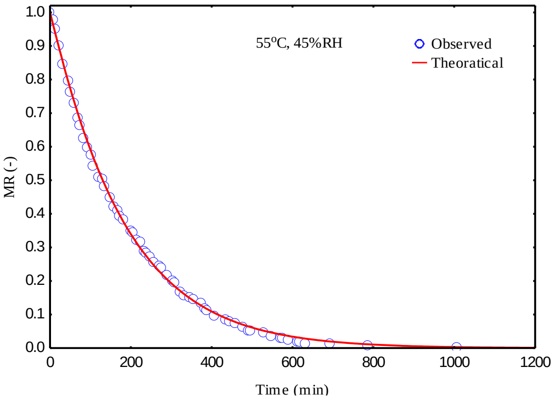

Figure 3d: MR vs. time (55°C,45%RH)

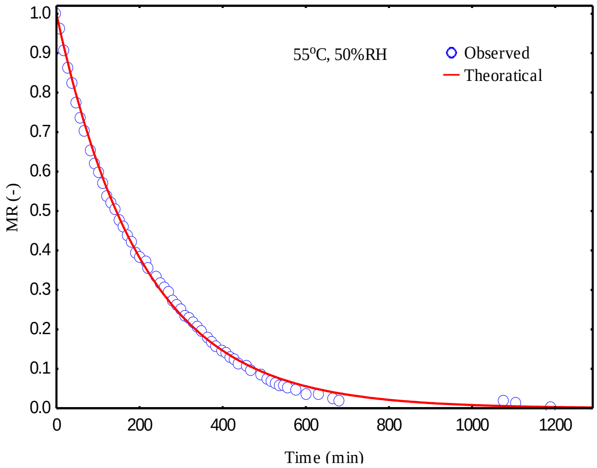

Figure 3e: MR vs. time (55°C,50%RH)

Table 3: Statistical-Measures at 55 °C

RH	R^2	SSE	SEE	RSSE	RMSE	MSE
30	0.9995	0.0049	0.0092	0.00008	0.0090	0.0001
35	0.9996	0.0035	0.0079	0.00006	0.0077	0.0001
40	0.9996	0.0042	0.0085	0.00007	0.0083	0.0001
45	0.9994	0.0072	0.0112	0.00012	0.0109	0.0001
50	0.9993	0.0070	0.0111	0.00012	0.0108	0.0001

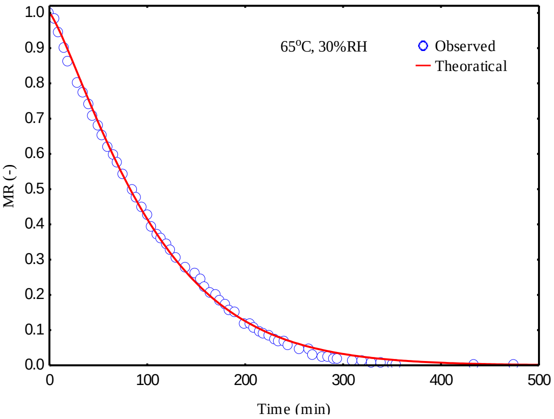

Figure 4a: MR vs. time (65°C,30%RH)

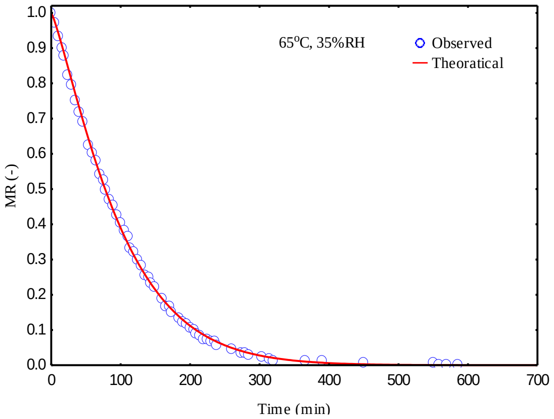

Figure 4b: MR vs. time (65°C,35%RH)

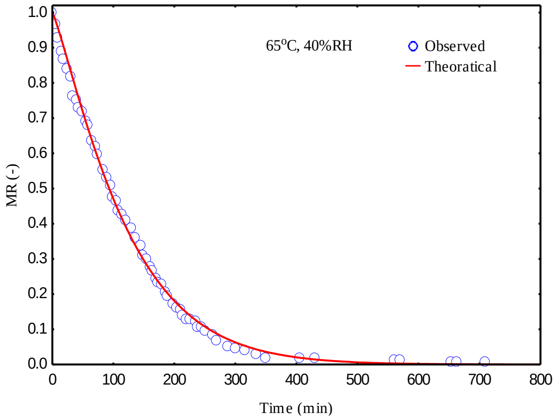

Figure 4c: MR vs. time (65°C,40%RH)

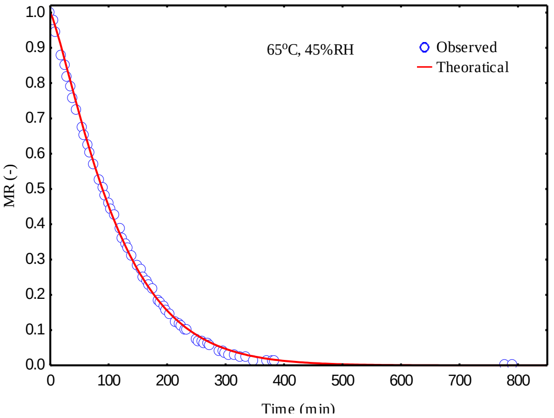

Figure 4d: MR vs. time (65°C,45%RH)

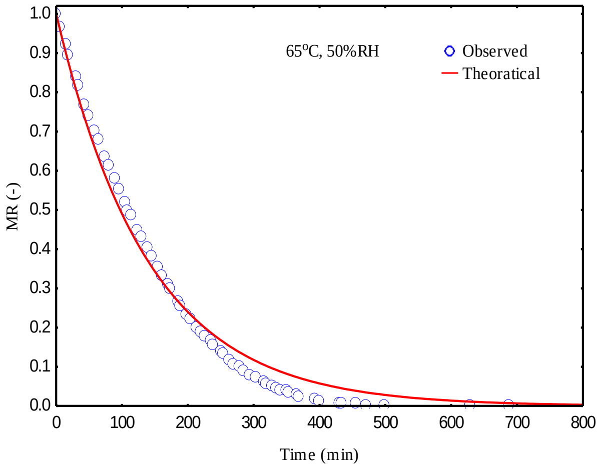

Figure 4e: MR vs. time (65°C,50%RH)

Table 4: Statistical-Measures at 65 °C

RH	R^2	SSE	SEE	RSSE	RMSE	MSE
30	0.9991	0.0097	0.0130	0.00016	0.0127	0.0002
35	0.9996	0.0045	0.0089	0.00007	0.0086	0.0001
40	0.9989	0.0148	0.0161	0.00025	0.0157	0.0003
45	0.9995	0.0055	0.0098	0.00009	0.0096	0.0001
50	0.9990	0.0108	0.0137	0.00018	0.0134	0.0002

3.1 Drying-Rate (DR)

Figure 5 illustrates how the drying-rate (*DR*) is correlated with the moisture-ratio (*MR*) in different drying-settings (Chabane and Adouane, 2018; Imad, 2010a). Initially, drying-process of Cut-Roselle showed a rapid decrease in moisture-content, which accelerated as the temperature is increased from 35°C to 65°C, and then slowed down as the drying neared completion and as moisture-level is reduced. Apparently, the drying-rate is higher when there is more moisture existent, which aligns with observations made by other studies (Saeed, et al., 2008b; Ingle et al., 2022). As drying continues, the rate gradually reduced to nearly-zero, reflecting the reduced-moisture in the Cut-Roselle and the minimal water-extraction. Notably, the drying-temperature is substantially, impacted the drying-rate of Cut-Roselle, with the rate increased as the temperature raised (35 - 65°C). This observation is in agreement with the results from other drying studies, like okra, Roselle hot-air drying, pumpkin-slices drying, and Roselle solar-drying (Doymaz, 2005; Saeed, et al., 2008a; Doymaz, 2007; Imad, 2010a).

The moisture content during the initial drying-phase is high, leading to increased heat-absorption and faster-drying rates due to enhanced moisture-diffusion. However, as the drying process continued, the reduction in moisture-content resulted in decreased heat-absorption and a subsequent decline in the drying-rate (Ingle et al., 2022). Using high-temperatures for drying results in greater moisture-diffusivity and creates a significant deficit in water vapour-pressure, which drives the drying-process. Gentle heating also promotes faster movement of water within the product (Kouhila et al., 2002). The rise in drying-temperature boosts the rate at which heat is delivered to the product, leading to quicker internal-water movement, especially at elevated-temperatures (Krokida et al., 2004 Kouhila et al., 2002; Belghit et al., 2000). Elevated-temperatures during the drying-process lead to increased drying-rates for the same level of water-content, resulting in a more rapid-reduction of moisture in Cut-Roselle. This phenomenon is supported by various studies (Lahsasni et al.,2004b; Kouhila et al., 2002; Belghit et al., 2000). Furthermore, it is consistently observed that higher drying-air temperatures significantly shorten the drying-time for Cut-Roselle, as it observed by others (Saeed et al., 2008a). The air's ability to retain moisture rises with temperature. However, if the relative-humidity of the air increases while the temperature remains the same, the drying-speed of Cut-Roselle slows down; which is consistent with results from other studies (Saeed et al., 2008a; Doymaz and Pala, 2002). Yet, the impact of humidity is significantly less than the effect of air-temperature (Saeed et al.2008a). It has been noted that during drying, certain crops may develop a crusty/hard outer-layer, that blocks further moisture-loss if the drying occurs too-quickly (Ekechukwu and Nortonb, 1999).

Researchers noted that Roselle calyxes are coated with a natural-wax that largely, hinders moisture movement from inside to the drying-air (Janjai and Tung, 2005). Once the surface-wax dried and cracked, it allowed some of the internal-moisture to escape. Towards, end-of-drying, the rate diminishes considerably due to the minimal moisture-content difference. Generally, at the commencement of drying, the internal water-movement to the surface is not as rapid as the evaporation-rate, leading to an increasingly dry-surface. Under the conditions applied, the drying of Cut-Roselle took-place exclusively, in the falling-rate-period (Mbegbu, et al., 2021; Togrul and Pehlivan, 2003). During the falling-rate phase of drying, the process is controlled by the diffusion of water within the solid. This intricate process includes the movement of water as both a liquid and a vapour, typically described through a concept known as effective-diffusivity (Lahsasni et al., 2004b). The average drying-rates for different moisture-ratio intervals as: (1.00-0.90), (0.90-0.50), (0.50-0.20), (0.20-0.10), (0.10-0.05), (0.05-0.02), (0.02-0.01), and (0.01-0.00), which are related and characterised (0.0-10%), (10-50%), (50-80%), (80-90%), (90-95%), (95-98%), (98-99%) and (99-100%), of drying-process, are shown, at fixed-temperature and fixed-RH, in Figure 6a and 6b, respectively.

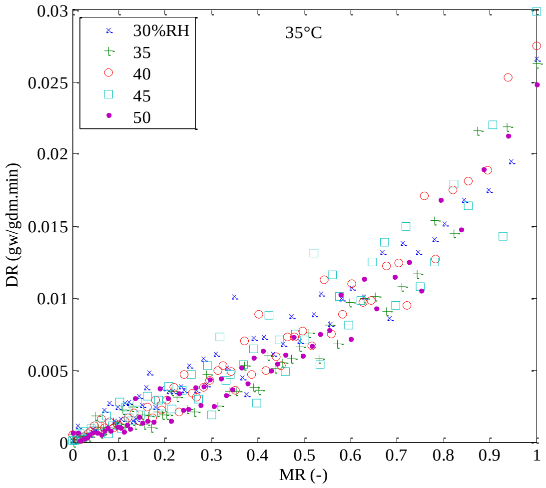

Figure 5a: DR vs. MR (35°C:30-50%RH)

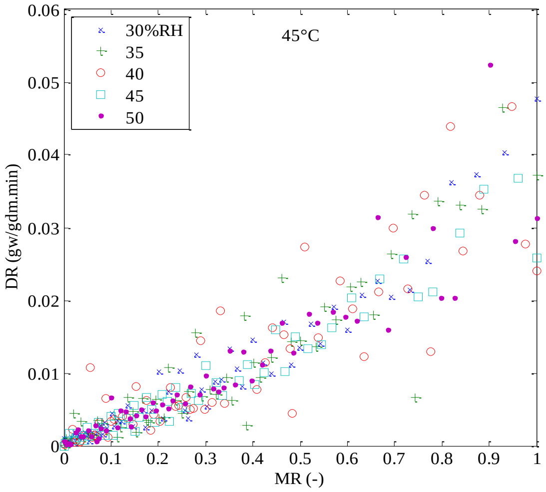

Figure 5b: DR vs. MR (45°C:30-50%RH)

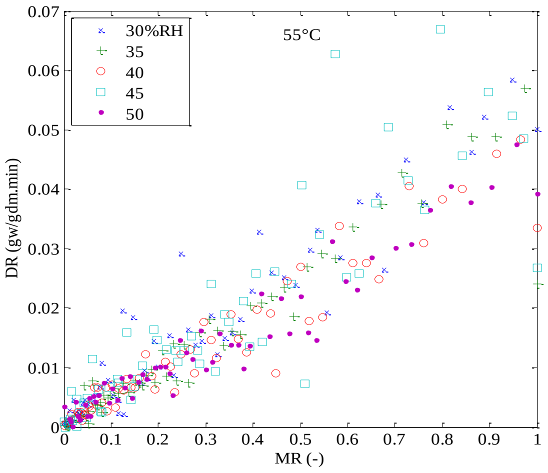

Figure 5c: DR vs. MR (55°C:30-50%RH)

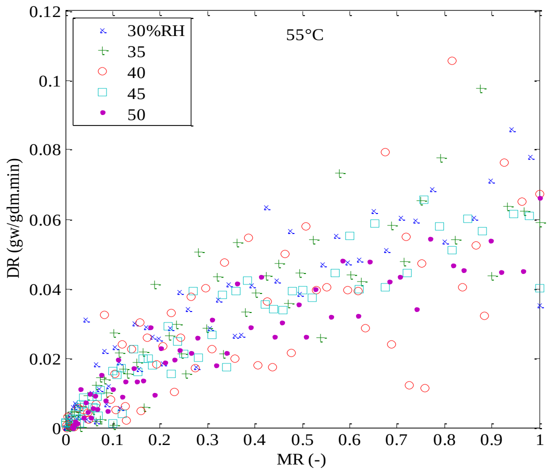

Figure 5d: DR vs. MR (65°C:30-50%RH)

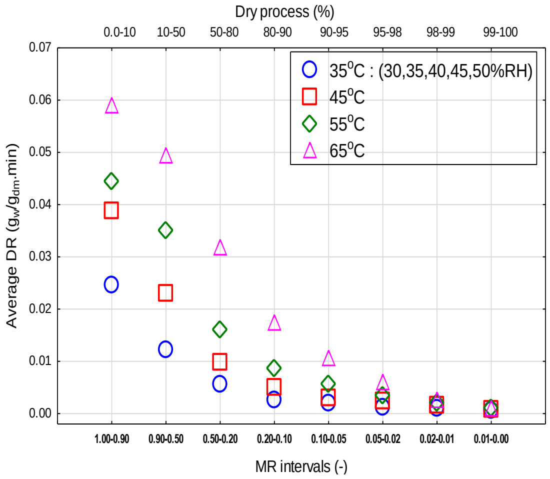

Figure 6a: DR vs. MR intervals (Fixed-T)

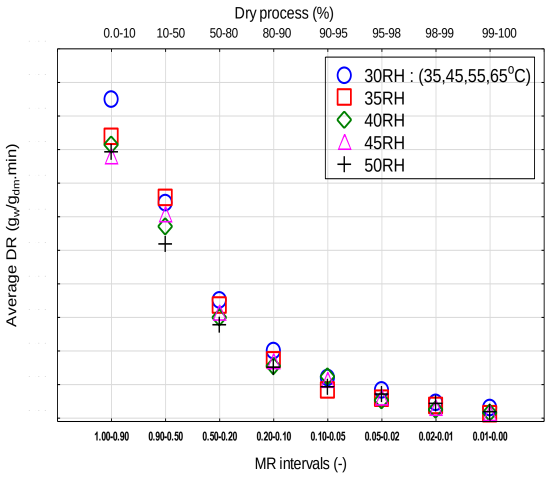

Figure 6b: DR vs. MR intervals (Fixed-RH)

3.2 Drying-Coefficients

3.2.1 Drying-Constant (k)

The rate-constant of the drying (k) can be defined by means of the thin-layer-equation. The scarceness of literature on the drying-constant (k) is attributed to the variability in the composition of materials and the conditions under which experiments are conducted, as noted by (Krokida et al., 2004). The mean-value of the drying-constant (k), as calculated using the Modified-Page II model under different conditions of drying-air, is 0.00343 (min^{-1}). As shown in Table 5, the drying-rate constant for Cut-Roselle is considerably, effected by temperature of the drying-air, with a p-value of 0.001. This correlation is supported by findings from other research, including works by (Imad, 2010b; Saeed, et al., 2008b).The drying-constant (k), generally, exhibited a decrease form when the temperature is raised, as depicted in Figure 7a. Similar results are shown by (Soysal, et al., 2006; Overhults et al., 1973). Conversely, the relative-humidity of the drying-air had a less-significant effect on the drying-constant (k), with a p-value of 0.449, as indicated in Table 6. The constant (k) declined when the relative-humidity is raised from 30% to 50%, shown in Figure 7b. Additionally, the mean-values of (k) are lower than those predicted by this model for some agricultural-products, for instance, (k) equals 0.0338 according to Wang et al. (2007), k=0.01096 as found by Gunhan et al. (2005), and k=0.024520 as reported by Tahir (2008), k=0.00618 as in Imad, (2010b).

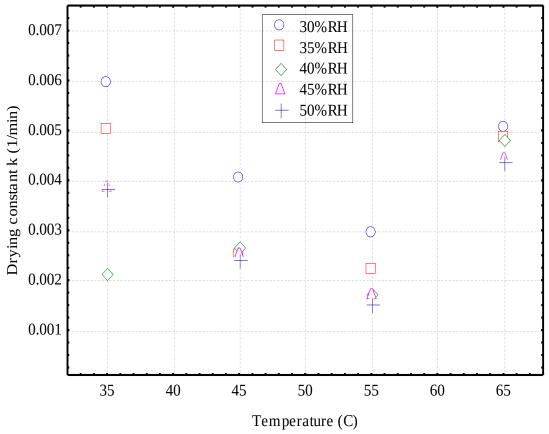

Figure 7a: Drying-constant (k) vs. temperature

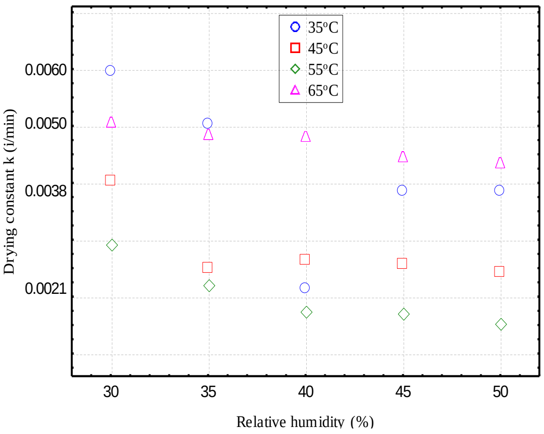

Figure 7b: Drying-constant (k) vs. RH

Table 5: One-way ANOVA: Drying-constant (k) vs Temperature

```
Source  DF         SS         MS      F      P
Temp     3  0.0000226  0.0000075  10.19  0.001
Error   16  0.0000118  0.0000007
Total   19  0.0000345
S = 0.0008603   R-Sq = 65.65%   R-Sq(adj) = 59.21%
                         Individual 95% CIs For Mean Based on Pooled StDev
Level  N       Mean      StDev    +---------+---------+---------+---------
35     5  0.0041692  0.0014476                   (------*------)
45     5  0.0028286  0.0006800          (------*-----)
55     5  0.0020246  0.0005662     (------*------)
65     5  0.0047120  0.0002861                      (------*------)
                                 +---------+---------+---------+---------
                                 0.0012    0.0024    0.0036    0.0048
Pooled StDev = 0.0008603
```

Cite the Article: I.E. Saeed, Zulkhairi Zainol Abidin (2024). Environment-Controlled Drying Of Cut-Roselle: Analysis Of Drying-Parameters & Validation Of Modified-Page Ii: Research Article. Acta Mechanica Malaysia, 7(2): 139-163.*

Table 6: One-way ANOVA: Drying-constant (k) vs Temperature

```
Source  DF        SS        MS     F      P
RH       4  0.0000071  0.0000018  0.98  0.449
Error   15  0.0000273  0.0000018
Total   19  0.0000345
S = 0.001350   R-Sq = 20.68%   R-Sq(adj) = 0.00%
                           Individual 95% CIs For Mean Based on Pooled StDev
Level  N      Mean     StDev  --------+---------+---------+---------+-
30     4  0.004500  0.001311             (-----------*-----------)
35     4  0.003650  0.001502       (-----------*-----------)
40     4  0.002833  0.001375  (-----------*-----------)
45     4  0.003151  0.001247   (-----------*-----------)
50     4  0.003035  0.001302  (-----------*-----------)
                              --------+---------+---------+---------+-
                                  0.0024    0.0036    0.0048    0.0060
Pooled StDev = 0.001350
```

The rate-constant of the drying k, may be expressed using a type of Arrhenius-equation, and absolute-temperature. This association is characterised by equation (12) and equation (13). The correlation and the fitting process outcomes are presented in Table 7.

Table 7: Arrhenius-equation

Formula	R²	*p*-value	Eq.
$k = (340.127) * exp(-(0.0000000145)/(0.000000395 * \mathrm{T}))$	0.9984688	0.00	12
$k = (343.617) * exp(-(0.03677)/\mathrm{T})$	0.9984695	0.00	13

The graphs that embody these Arrhenius equations (Equation 12 and Equation 13) and drying-constant as function of the inverse-absolute temperature (K), are given in Figure 8. The fitting resulted in an R^2 values of 0.9985 and 0.9985, for Equation 12 and Equation 13, respectively. The R^2 values are greater than those found in former research on various produces, for instances, R^2= 0.995 and 0.997 as in Tahir (2008), R^2= 0.976 and R^2= 0.980: stored-unshelled candle-nuts, and fresh-nuts drying (Tarigan et al., 2007).

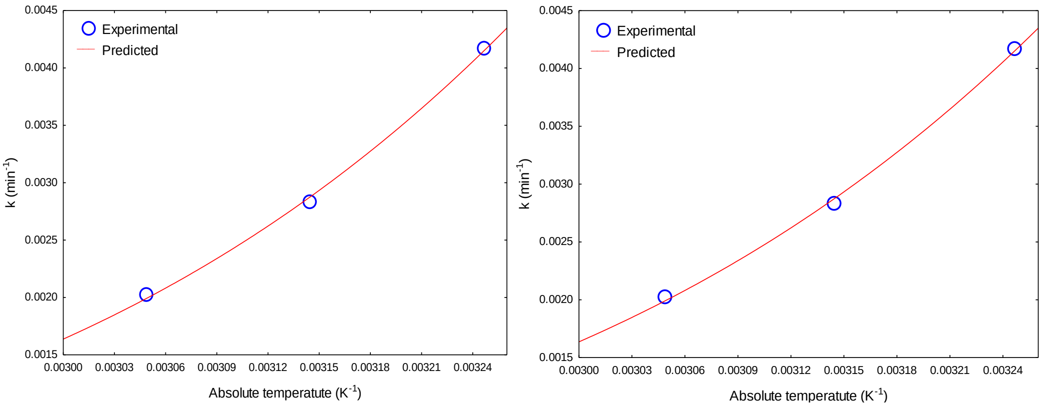

Figure 8: Drying-constant vs. Inverse Absolute-Temperature (1/K)

(left: Equation 12 and right: Equation 13)

3.2.2 Drying-Parameter (L)

Figures 9a and 9b illustrate the relationship between the drying-coefficient (L) and both the drying-temperature and relative-humidity, respectively. The Modified-Page Model II showed an average drying-coefficient (L) of (-0.87306). This coefficient typically, demonstrates a direct-correlation with the temperature, showing a significant impact (p-value =0.000), as presented in Table 8. Conversely, relative humidity's influence on this drying-coefficient is not substantial (p-value =0.704), as given in Table 9. Additionally, the values of (L) align with those reported in the existing literature for various agri-products, e.g., L=3.8498 as noted by Wang et al. (2007), L=-2.3921 as found by Saeed et al. (2008a), L= -2.08952 as reported by Tahir (2008).

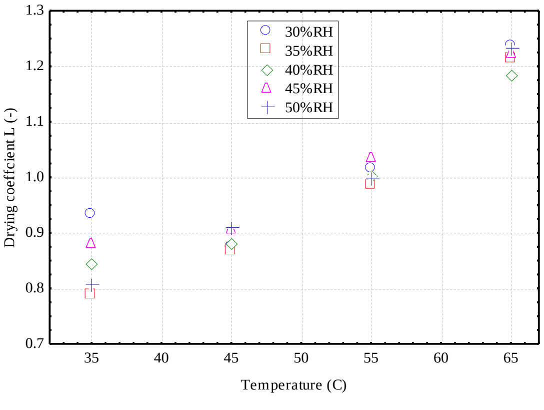

Figure 9a: Coefficient (L) vs. T (°C)

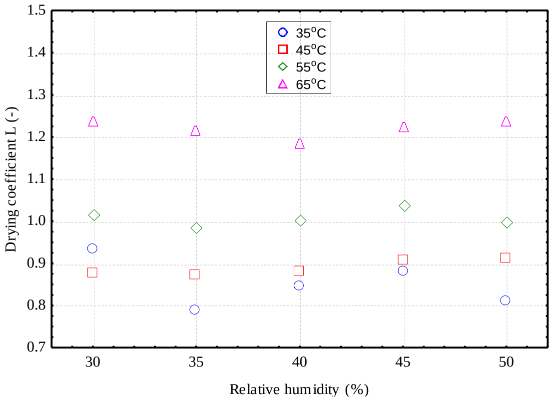

Figure 9b: Coefficient (L) vs. RH **(%)**

Table 8: One-way ANOVA: Drying-Parameter (L) versus Temp

```
Source  DF      SS      MS      F      P
Temp     3  1.1950  0.3983  13.35  0.000
Error   16  0.4772  0.0298
Total   19  1.6723
S = 0.1727   R-Sq = 71.46%   R-Sq(adj) = 66.11%

                           Individual 95% CIs For Mean Based on Pooled StDev
Level  N     Mean   StDev  -----+---------+---------+---------+----
35     5  -0.9818  0.3230        (------*-----)
45     5  -0.6566  0.0697                   (------*-----)
55     5  -0.6315  0.0695                    (------*-----)
65     5  -1.2223  0.0727  (-----*------)
                           -----+---------+---------+---------+----
                             -1.25     -1.00     -0.75     -0.50
Pooled StDev = 0.1727
```

Table 9: One-way ANOVA: Drying-Parameter (L) versus RH

```
Source  DF      SS      MS     F      P
RH       4  0.2128  0.0532  0.55  0.704
Error   15  1.4595  0.0973
Total   19  1.6723
S = 0.3119   R-Sq = 12.72%   R-Sq(adj) = 0.00%
                           Individual 95% CIs For Mean Based on Pooled StDev
Level  N     Mean   StDev  ------+---------+---------+---------+---
30     4  -1.0634  0.3762  (------------*-------------)
35     4  -0.8040  0.2700          (------------*------------)
40     4  -0.7685  0.2772           (------------*-------------)
45     4  -0.8884  0.2775       (------------*-------------)
50     4  -0.8410  0.3439         (------------*-------------)
                           ------+---------+---------+---------+---
                              -1.25     -1.00     -0.75     -0.50
Pooled StDev = 0.3119
```

3.2.3 Drying-Parameter (n)

Figures 10a and 10b demonstrate the impact of temperatures and relative-humidity on the drying-coefficient (n). The mean-value of (n) is found to be =0.99219. This coefficient is substantially, influenced by the drying-temperature, with a p-value of (0.000), as indicated in Table 10. The (n) values tend to rise with the increase in drying-temperature (maintaining a constant relative-humidity), between 35 to 55°C, similar results are shown by (Overhults et al., 1973). On the contrary, changes in relative-humidity do not significantly alter (n) when the temperature is held steady, with a p-value of (0.990), as shown in Table 11. Additionally, the observed values of (n) are within the range predicted by this Model for drying various agricultural products. For instance, the values of (n) reported in previous studies include: 1.01729 by (56), 1.5974 by Tahir (2008), 1.226754 by Gunhan et al., (2005), and 0.992678 by Saeed et al., (2008a). It's important to notice that the drying-parameters (k), (L), and (n) of the Modified-Page II model, do not exhibited uniform behaviour; this is in line with the findings of researchers, who acknowledged that, it's not mandatory for all-coefficients to increase or decrease in similarity (Jayas et al., 1991).

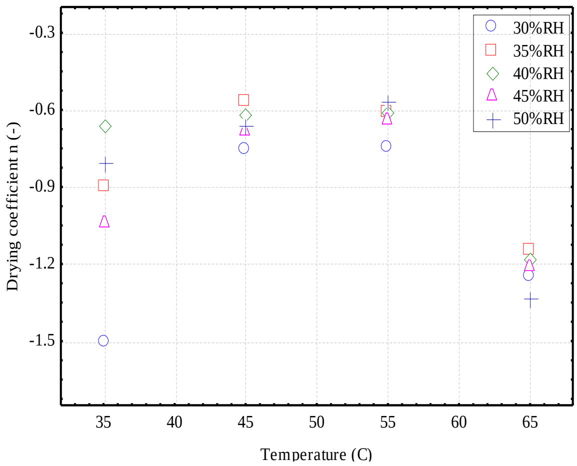

Figure 10a: Coefficient (n) vs. temperature (°C)

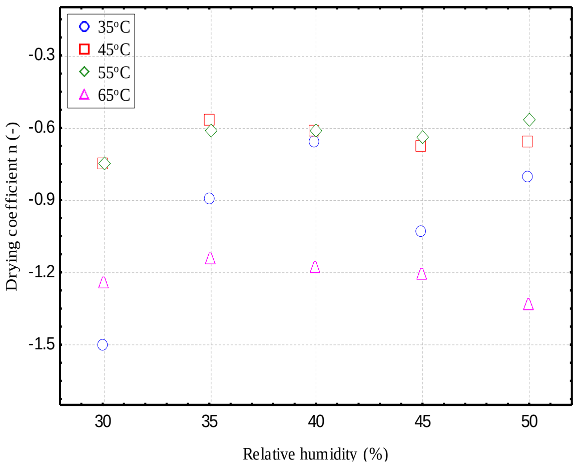

Figure 10b: Coeff. (n) vs. relative humidity (%)

Table 10: Moisture-Ratio (*MR*) and Drying-Time

Drying Process	MR	RH%									
		30%	35%	40%	45%	50%	30%	35%	40%	45%	50%
(%)	(-)	35°C					45°C				
0.0	1.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.90	45	45	45	50	45	25	25	30	30	35
50	0.50	365	420	415	385	400	210	205	200	215	215
80	0.20	920	1265	1145	1030	1145	545	560	555	575	550
90	0.10	1310	1910	1710	1515	1785	800	855	820	845	810
95	0.05	1570	2430	2185	1890	2480	1045	1075	1030	1065	1065
98	0.02	2045	3015	2740	2265	3150	1245	1280	1335	1305	1270
99	0.01	2295	3250	3160	2590	3935	1410	1355	1475	1375	1475
End	0.00	2705	3900	3475	3885	3945	1550	1555	1805	1495	1925
		55°C					65°C				
0.0	1.00	0	0	0	0	0	0	0	0	0	0
10	0.90	15	20	20	20	20	15	15	15	15	20
50	0.50	120	120	145	130	145	80	75	95	90	110
80	0.20	280	290	340	300	340	165	150	185	180	210
90	0.10	390	420	475	405	465	210	205	245	235	275
95	0.05	475	530	575	485	555	250	240	290	285	330
98	0.02	575	640	725	585	665	285	290	335	335	375
99	0.01	615	720	765	675	1165	320	365	560	385	425
End	0.00	745	1190	970	1010	1190	475	585	710	790	690

Table 11: One-way ANOVA: Drying Parameter (n) versus RH

```
Source  DF      SS      MS     F      P
RH       4  0.0078  0.0019  0.07  0.990
Error   15  0.4227  0.0282
Total   19  0.4305
S = 0.1679   R-Sq = 1.80%   R-Sq(adj) = 0.00%
                             Individual 95% CIs For Mean Based on Pooled StDev
Level  N    Mean   StDev  -----+---------+---------+---------+----
30     4  1.0158  0.1591       (--------------*--------------)
35     4  0.9648  0.1857  (--------------*--------------)
40     4  0.9784  0.1527   (--------------*-------------)
45     4  1.0129  0.1572       (-------------*--------------)
50     4  0.9890  0.1819    (-------------*--------------)
                             -----+---------+---------+---------+----
                               0.84      0.96      1.08      1.20

Pooled StDev = 0.1679
```

3.3Validation of Modified-Page II

To confirm the Modified-Page II drying-model, precision; the predicted/estimated MR is compared with the actual MR measured-data, as referenced in various studies (Midilli et al., 2002; Simal, et al.,2005, Togrul, and Pehlivan,2003; Imad, 2010a). Figure 11 illustrates the correlation between the predicted MR (MR_{pred}) and the observed MR (MR_{obser}) under varied drying situations. The data-points are evenly-distributed around the established linear-trend, signifying minimal-variance between the predicted and observed MR values. This uniform-distribution implies that the Modified-Page II model is highly effective in representing the dynamics of the drying-process. Tables 12 and 13 examines the linearity-hypothesis, namely $y=Ax+B$, with the ideal scenario of A=1 and B=0; here $Y= MR_{predicted}$ and $x=MR_{observed}$. The hypothesis is tested at fixed-RH (Table12) and fixed-T (Table 13). In addition, the correlation-coefficient (r^2) values are also given. Using mean-values of the experimental-data, for T and RH, a hypothesis-testing formula is:

$$MR_{predicted} = 0.9958 * MR_{observed} + 0.0033$$

With, r^2=0.9989, the values for A=0.9958 which is very close to 1, while the value of B=0.0033 which is similarly close to zero.

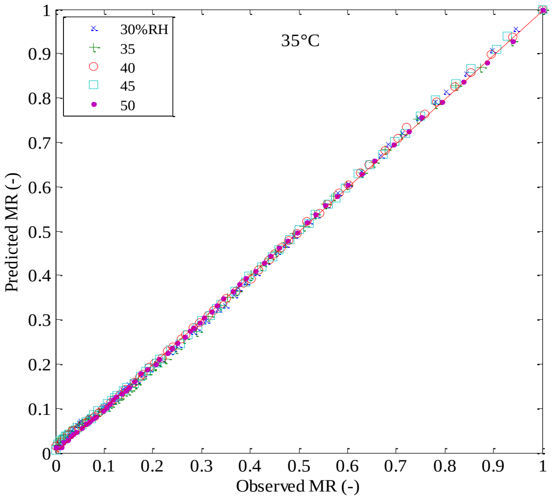

Figure 11a: MR_{pred} vs. MR_{obser} (35°C,30-50%RH)

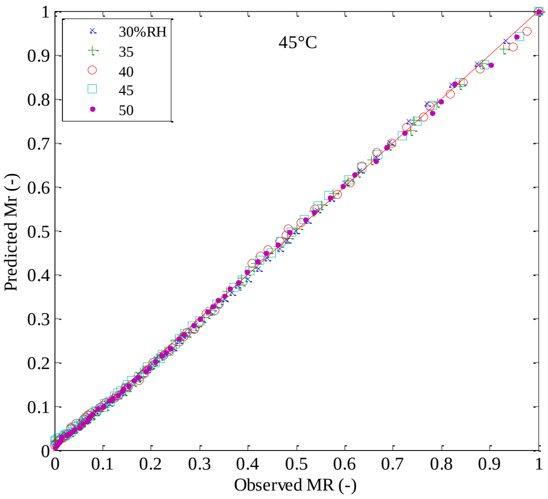

Figure 11b: MR_{pred} vs. MR_{obser} (45°C,30-50%RH)

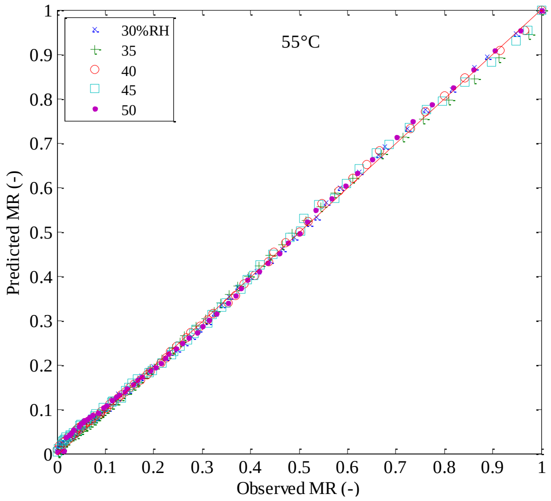

Figure 11c: MR_{pred} vs. MR_{obser} (55°C,30-50%RH)

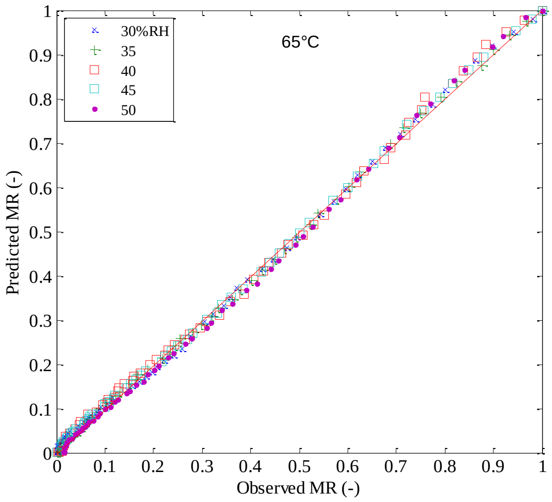

Figure 11d: MR_{pred} vs. MR_{obser} (65°C,30-50%RH)

Table 12: Hypothesis-Testing: Y=Ax+B; (A=1 & B=0); at Fixed-RH

RH%	Formulae	*A*	*B*	r^2
30	MR_{pred}=0.997*MR_{obser}+0.003	0.9968	0.0038	0.9989
35	MR_{pred}=0.994*MR_{obser}+0.003	0.9943	0.0029	0.9991
40	MR_{pred}=0.996*MR_{obser}+0.003	0.9960	0.0030	0.9987
45	MR_{pred}=0.995*MR_{obser}+0.003	0.9945	0.0038	0.9990
50	MR_{pred}=0.997*MR_{obser}+0.003	0.9973	0.0028	0.9990

Table 13: Hypothesis-Testing: *Y=Ax+B*; (*A*=1 & *B*=0); at Fixed-T

T°C	**Formulae**	***A***	***B***	**r^2**
35	MR_{pred}=0.996*MR_{obser}+0.003	0.9962	0.0031	0.9992
45	MR_{pred}=0.992*MR_{obser}+0.004	0.9922	0.0036	0.9991
55	MR_{pred}=0.993*MR_{obser}+0.004	0.9934	0.0036	0.9989
65	MR_{pred}=1.001*MR_{obser}+0.003	1.0012	0.0028	0.9985

The graphing of residuals against the predicted values from the model, serves as an another method to confirm the Modified-Page II model precision, as showed by (Keller, 2001; Spatz, 2001). Figure 12 illustrates the residuals and predicted values derived from applying the Modified-Page II model to actual-data. The residuals are strewn-randomly around the zero-mark-line, which showed that the model accurately represented the data. There is no consistent negative or positive deviations in the residuals across most of the data-range, nor do the data-points showed any bias or form any discernible-patterns (Saeed et al., 2008b; Xanthopoulos et al., 2007). It showed that the Modified-Page II model is appropriate for adequately, characterizing the drying-performance of Cut-Roselle. Overall, the residuals plots confirmed the absence of systematic-errors. As seen in Table 13, the model, slightly more-accurate predicted the Cut-Roselle drying-curves at lower temperatures (with an r^2=0.9992), compared to higher temperatures (with an r^2=0.9985). When drying at temperatures =35°C, the model initially underestimates the moisture content, then overestimates it when the moisture-ratio is between 0.9 and 0.5, underestimates again between 0.5 and 0.1, and finally overestimates towards the end of the drying-process. In drying with temperatures =65°C, the model overestimates the moisture-content at the beginning, underestimates between a moisture ratio of 0.7 and 0.2, overestimates from 0.2 to 0.09, and then underestimates from 0.9 until end-of drying-process. As a result of comparing the predicted-MR with actual-MR, and plotting the residuals vs. predicted values; the model's reliability in predicting the moisture-content of Cut-Roselle is thus validated.

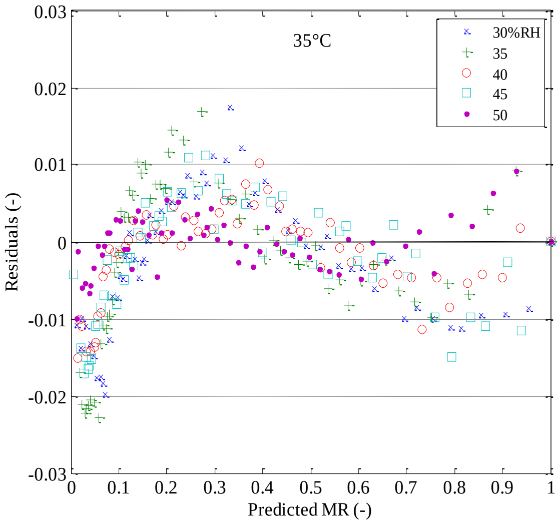

Figure 12a: Resid. vs. MR_{pred} 35°C(30-50%RH)

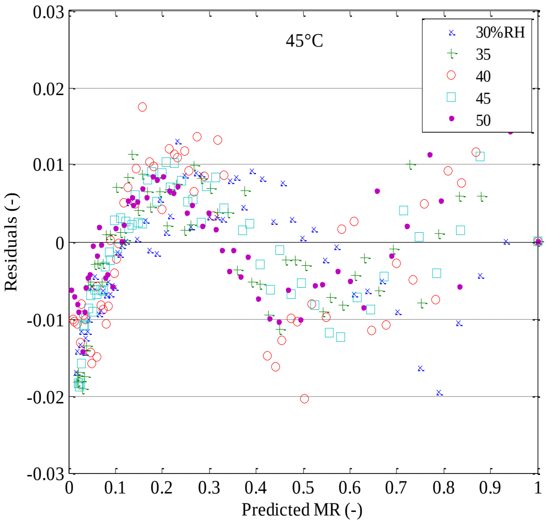

Figure 12b: Resid. vs. MR_{pred} 45°C(30-50%RH)

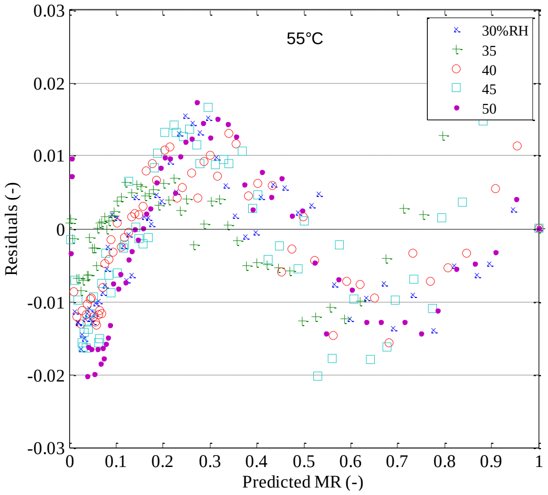

Figure 12c: Resid. vs. MR$_{pred}$ 55°C(30-50%RH)

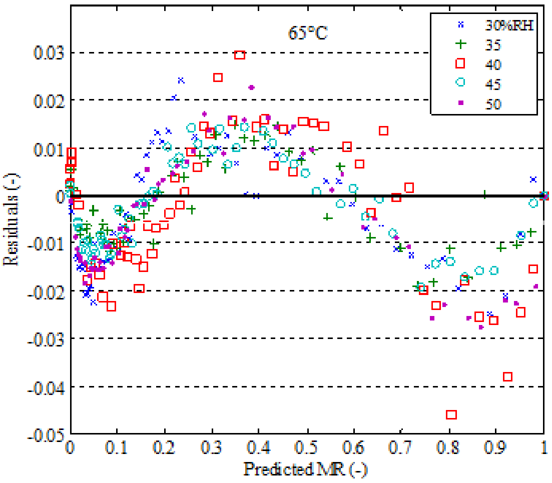

Figure 12: Resid. vs. MR$_{pred}$ 65°C(30-50%RH)

A general-formula for Modified-Page II model, to compute the drying-characteristic of Cut-Roselle, adequately, with R^2 =0.99949, is established as:

$$MR(k,l,n,t) = \frac{M - M_e}{Mo - M_e} = \exp(-0.00343(t/-0.87306^2)^{0.99219})$$

The constant and coefficients (*k*, *l*, and *n*) are correlated with drying-temperatures (35,45,55°C), such that:

$$k = 0.0078 - 0.0001 * T \quad (r^2{=}0.9796,\ p{=}0.0913)$$

$$l = -1.5448 + 0.0175 * T \quad (r^2{=}0.8034,\ p{=}0.2924)$$

$$n = 0.5623 + 0.0079 * T \quad (r^2{=}0.9170,\ p{=}0.1860)$$

4. CONCLUSIONS

This part of the study on controlled-environment drying of Cut-Roselle, provided a thorough-evaluation of Modified-Page II drying-model. The study also investigated the impact of drying-environments on the drying-rate and drying-coefficients. The experimental-data and analysis, showed that, the drying-process of Cut-Roselle occurs solely, in the falling-rate-period. The drying-rates are increased with temperature elevation from 35°C to 65°C, while an increase in air-humidity at a constant-temperature reduced the drying-rates. The influence of temperature on the drying-constant is significant, evidenced by a p-value of 0.001, whereas air relative-humidity exerted a less significant-impact, with a p-value of 0.449. The drying-parameter (*L*) showed a considerable sensitivity to temperature-variations (*p*=0.000) and is slightly, influenced as relative-humidity is changed with *p*=0.704. In a similar vein, the drying-coefficient (*n*) is noticeably affected by alterations in temperature (*p*=0.000), with relative-humidity also had a role, though to a slighter degree (*p*=0.990). The correlation between the predicted moisture-ratios with the experimental data, in addition to the residual-analysis against the predicted-values; functioned as standards in validating the Modified-Page II model. The results proved the model's accuracy in predicting the drying performance of Cut-Roselle within the specified drying-conditions.

REFERENCES

Ahiduzzaman, M., Jamini, T.S., and Aminul Islam, A.K.M., 2021. Roselle Production, Processing, Products and Biocomposites. Chapter 4- Roselle (Hibiscus-sabdariffa L.): Processing for Value Addition, Pp. 53-65, Academic Press: London. https://doi.org/10.1016/B978-0-323-85213-5.00005-6

Atalay, H. 2019. Performance analysis of a solar dryer integrated with the packed bed thermal energy storage (TES) system. *Energy*, 172, Pp. 1037-1052, https://doi.org/10.1016/j.energy.2019.02.023

Azzouz, S., Guizani, A., Jomaa, W., and Belghith, A. 2002. Moisture diffusivity and drying kinetic equation of convective drying of grapes. Journal of Food Engineering, 55, Pp. 323-330, https://doi.org/10.1016/S0260-8774(02)00109-7

Babalis, S.J., Papanicolaou, E., Kyriakis, N., and Belessiotis, V.G. 2006. Evaluation of thin-layer drying models for describing drying kinetics of figs (*Ficus carica*). Journal of Food Engineering, 75, Pp. 205-214, https://doi.org/10.1016/j.jfoodeng.2005.04.008

Belghit, A., Kouhila, M., and Boutaleb, B.C. 2000. Experimental Study of Drying Kinetics by Forced Convection of Aromatic Plants. Energy Conversion Management, 44, Pp. 1303-1321, https://doi.org/10.1016/S0196-8904(99)00162-4

Buzrul, S. 2022. Reassessment of Thin-Layer Drying Models for Foods: A Critical Short Communication. Processes, 10, Pp 118, https://doi.org/10.3390/pr10010118

César, L.E., Lilia, C.M.A., Octavio, G.V., Isaac, P.F., and Rogelio, B.O. 2020. Thermal performance of a passive, mixed-type solar dryer for tomato slices (Solanum lycopersicum). Renewable Energy, 147, Pp. 845-855, https://doi.org/10.1016/j.renene.2019.09.018

Chabane, F., and Adouane, F. 2018. Experimental investigation of the solar drying and solar collector design for drying agricultural product (mint). Chemical Engineering Transactions, 71, Pp. 1387-1392, DOI:10.3303/CET1871232

Chen, C. 2002. Sorption isotherms of sweet potato slices. Biosystems Engineering, 83, (1), Pp. 85-95, https://doi.org/10.1006/bioe.2002.0093

Coumans, W.J. 2000. Models for drying kinetics based on drying curves of slabs. Chemical Eng. and Processing, 39, Pp. 53-68, https://doi.org/10.1016/S0255-2701(99)00084-7

Dasore, A., Krishna, K.R., and Puppala, N. 2019. Method for Determining the Appropriate Thin Layer Drying Model for a Feedstock. International Journal of Recent Technology and Engineering, 8 (3) Pp. 2277-3878, DOI:10.35940/ijrte.C5335.098319

Dissa, A.O., Bathiebo, D.J., Desmorieux, H., Coulibaly, O., and Koulidiati, J. 2011. Experimental characterisation and modelling of thin layer direct solar drying of Amelie and Brooks mangoes. Energy, 36 (5), Pp. 2517-2527, https://doi.org/10.1016/j.energy.2011.01.044

Doymaz, I. 2005. Sun drying of figs: an experimental study. Journal of Food Engineering, 71, Pp. 403-407, https://doi.org/10.1016/j.jfoodeng.2004.11.003

Doymaz, I. 2007. The kinetics of forced convective air-drying of pumpkin slices. Journal of Food Engineering, 79, Pp. 243-248, https://doi.org/10.1016/j.jfoodeng.2006.01.049

Doymaz, I., and Pala, M. 2002. Hot-air drying characteristics of red pepper. Journal of Food Engineering, 55, Pp. 331-335, https://doi.org/10.1016/S0260-8774(02)00110-3

Ekechukwu, O.V., and Nortonb, B. 1999. Review of solar-energy drying systems II: an overview of solar drying technology. Energy Conversion and Management, 40, Pp. 615-655, https://doi.org/10.1016/S0196-8904(98)00093-4

Ekka, J.P., and Palanisamy, M. 2020. Determination of heat transfer coefficients and drying kinetics of red chilli dried in a forced convection mixed mode solar dryer. Thermal Science and Engineering Progress, 19, Pp. 100607, https://doi.org/10.1016/j.tsep.2020.100607

El-Aouar, A.A., Azoubel, P.M., and Xidieh Murr, F.E. 2003. Drying kinetics of fresh and omatically pre-treated papaya (*Carica papaya* L.). Journal of Food Engineering, 59, Pp 85-91, https://doi.org/10.1016/S0260-8774(02)00434-X

Engin, D., and Tulek, Y. 2014. Drying characteristics of garlic (*Allium sativum* L) slices in a convective hot air dryer. Heat and Mass Transfer, 50, Pp. 779-786, http://dx.doi.org/10.1007/s00231-013-1286-9

Górnicki, K., and Kaleta, A. 2007. Drying curve modelling of blanched carrot cubes under natural convection condition Journal of Food Engineering, 82, Pp. 160-170, https://doi.org/10.1016/j.jfoodeng.2007.02.002

Gunhan, T., Demir, V., Hancioglu, E., and Hepbasli, A. 2005. Mathematical modelling of drying of bay leaves. Energy Conversion and Management, 46, Pp 1667-1679, https://doi.org/10.1016/j.enconman.2004.10.001

Gupta, P., Ahmed, J., Shivhare, U.S., and Raghavan, G.S.V. 2002. Drying characteristics of red chilli. Drying Technology, 20, (10) Pp. 1975-1987, https://doi.org/10.1081/DRT-120015579

Imad, I.S 2010b. Solar drying of Roselle (*Hibiscus sabdariffa* L.): mathematical modeling, drying experiments, and effects of the drying conditions. Agric Eng Int, CIGR Journal, 12 (3), Pp. 115-123, https://cigrjournal.org/index.php/Ejounral/article/view/1484

Imad, I.S. 2010a. Solar drying of Roselle (*Hibiscus sabdariffa* L.): effects of drying conditions on the drying constant and coefficients, and validation of the logarithmic model. Agric Eng Int, CIGR Journal, 12 (1), Pp. 167-181, https://cigrjournal.org/index.php/Ejounral/article/view/1488

Ingle, M., Tapre, A., and Katke, S. 2022. Drying kinetics and mathematical modeling of beetroot. The Pharma Innovation Journal, 11 (5) Pp 1558-1562, https://www.thepharmajournal.com/archives/2022/vol11issue5/PartQ/11-4-350-420.pdf

Inyang, U.E., Oboh, I.O., and Etuk, B.R. 2018. Kinetic Models for Drying Techniques-Food Materials. Advances in Chemical Engineering and Science, 8, Pp. 27-48, https://doi.org/10.4236/aces.2018.82003

Ismail, O. and Kocabay, Ö.G. 2018. Drying kinetics of hot-air dried beef meat: Application of mathematical models, energy consumption, and color characteristics. Heat Transfer Res., 4914, Pp. 1353-1366, doi: 10.1615/HeatTransRes.2018020385

Izli, N., Izli, G., and Taskin, O. 2018. Impact of different drying methods on the drying kinetics, color, total phenolic content and antioxidant capacity of pineapple. *CyTA-Journal of Food*, 16 (1), Pp. 213-221, https://doi.org/10.1080/19476337.2017.1381174

Jain, D., and Pathare, P.B. 2004. Selection and evaluation of thin layer drying models for infrared radiative and convective drying of onion slices. Biosystems Engineering, 89 (3), Pp. 289-296, https://doi.org/10.1016/j.biosystemseng.2004.07.011

Janjai, S., and Tung, P. 2005. Performance of a solar dryer using hot air from roof-integrated solar collectors for drying herbs and spices. Renewable Energy, 30, Pp. 2085-2095, https://doi.org/10.1016/j.renene.2005.02.006

Jannot, Y., Talla, A., Nganhou, J., and Puiggali, J.R. 2004. Modelling of Banana Convective Drying by the Drying Characteristic Curve (DCC) Method. Drying Technology, 22 (8), Pp. 1949-1968, https://doi.org/10.1081/DRT-200032888

Jayas, D.S., Cenkowski, S., Pabis, S., and Muir, W.E. 1991. Review of thin-layer drying and wetting equations Drying technology, 9, (3) Pp. 551-588, https://doi.org/10.1080/07373939108916697

Jayasuriya, H., Pathare, P.B., Al-Attabi Z., and Al-Hamdani, A. 2023. Drying Kinetics and Quality Analysis of Coriander Leaves Dried in an Indirect, Stand-Alone Solar Dryer. Processes, 11 (6), Pp. 1596, https://doi.org/10.3390/pr11061596

Joshy, G., Parvathy, U., Ninan, G., Kumar K.A., and Ravishankar, C.N. 2021. Drying Kinetic Models: Performance Evaluation under Auto-Correlated Observations. Fishery Technology, 58, Pp. 166-170, https://krishi.icar.gov.in/jspui/bitstream/123456789/69955/1/Drying%20Kinetic%20Models.pdf

Keller, G. 2001. Applied statistics with Microsoft excel. Duxbury: Wadsworth group.

Kingsly, A.R.P., and Singh, D.B. 2007. Drying kinetics of pomegranate arils. Journal of Food Engineering, 79, Pp. 741-744, https://doi.org/10.1016/j.jfoodeng.2006.02.033

Kipcak A.S., and Doymaz, I. 2020. Mathematical Modeling and Drying Characteristics Investigation of Black Mulberry Dried by Microwave Method. International Journal of Fruit Science, 20, S3, Pp. S1222-S1233, https://doi.org/10.1080/15538362.2020.1782805

Kiranoudis, C.T., Maroulis, Z.B., Tsami, E., and Marinos-Kouris, D. 1997. Drying kinetics of some fruits. Drying Technology, 15 (5), Pp. 1399-1418, https://doi.org/10.1080/07373939708917300

Kouhila, M., Kechaou, N., Otmani, M., Fliyou, M., and Lahsasni, S. 2002. Experimental study of sorption isotherms and drying kinetics of Moroccan Eucalyptus Globulus. Drying Technology, 20, Pp 2027-2039, https://doi.org/10.1080/07373939708917300

Krokida, M.K., Foundoukidis, E., and Maroulis, Z. 2004. Drying constant, literature data compilation for foodstuffs. Journal of Food Engineering, 61, Pp. 321-330, https://doi.org/10.1016/S0260-8774(03)00136-5

Krokida, M.K., Karathanos, V.T., Maroulis, Z.B., and Marinos-Kouris, D. 2003. Drying kinetics of some vegetables. *Journal of Food Engineering*, 59, Pp 391-403, https://doi.org/10.1016/S0260-8774(02)00498-3

Lahsasni, S., Kouhila, M., Mahrouz, M., and Jaouhari, J.T. 2004b. Drying kinetics of prickly pear fruit (Opuntia ficus indica). Journal of Food Engineering, 61, Pp. 173-179, https://doi.org/10.1016/S0260-8774(03)00084-0

Lema, A.A., Mahmod, N.H., and Khandaker, M.M. 2021. Therapeutic and economic Impacts of Roselle (Hibiscus sabdariffa L.) Anthocyanin; A Review. Bioscience Research, 18, SI-2, Pp. 284-294

Lingayat, A., Chandramohan, V.P., Raju, V.R.K., and Kumar, A. 2020. Development of indirect type solar dryer and experiments for estimation of drying parameters of apple and watermelon. Thermal Science and Engineering Progress, 16, Pp. 100477, https://doi.org/10.1016/j.tsep.2020.100477

Mariod, A.A., Tahir, H.E., and Mahunu, G.K. Eds., 2021.Roselle (Hibiscus sabdariffa) Chemistry, Production, Products, and Utilization. Academic Press: London, UK.

Mbegbu, N.N., Nwajinka, C.O., and Amaefule, D.O., 2021. Thin layer drying models and characteristics of scent leaves (Ocimum gratissimum) and lemon basil leaves (Ocimum africanum). *Heliyon*, 7, e05945, https://doi.org/10.1016/j.heliyon.2021.e05945

Mellalou, A., Riad, W., Bacaoui, A., and Outzourhit, A., 2023. Experimental investigations on drying kinetics and modeling of two-phase olive pomace dried in a hybrid solar greenhouse dryer. Journal of Thermal Analysis and Calorimetry, 148, Pp. 5471-5483, https://doi.org/10.1007/s10973-023-12063-x Mugi, V.R., and Chandramohan, V.P. 2022. Comparison of drying kinetics, thermal and performance parameters during drying guava slices in natural and forced convection indirect solar dryers. Solar Energy, 234, Pp. 319-329, https://doi.org/10.1016/j.solener.2022.02.012

Mghazli, S. Ouhammou, M., Hidar, N., Lahnine, L., Idlimam, A., and Mahrouz, M., 2017. Drying characteristics and kinetics solar drying of Moroccan rosemary leaves. Renewable Energy. 108, Pp. 303-310, https://doi.org/10.1016/j.renene.2017.02.022

Midilli, A., Kucuk, H., and Yapar, Z., 2002. A new model for single-layer drying. Drying Technology, 20 (7), Pp. 1503-1513, https://doi.org/10.1081/DRT-120005864

Morton, J.F., 1987. Fruits of Warm Climates. Miami: USA. Morton, J.F. Pp. 281-286, http://www.hort.purdue.edu/newcrop/morton/Index.html

Nguyen, M-H., and Price, W.E., 2007. Air-drying of banana, Influence of experimental parameters, slab thickness, banana maturity and harvesting season. Journal of Food Engineering, 79, Pp. 200-207, https://doi.org/10.1016/j.jfoodeng.2006.01.063

Overhults, D.G., White, G.M., Hamilton, H.E., and Ross, I.J., 1973. Drying soybeans with heated air. Transactions of the ASAE, 16, Pp. 112-113, https://uknowledge.uky.edu/bae_facpub/134

P.P. Lewicki, 2006. Design of hot air drying for better foods. Trends in Food Science and Technology, 17, Pp. 153-163, https://doi.org/10.1016/j.tifs.2005.10.012

Patel, V., Judal, K.B., Panchal, H., Singh, B., Jomde, A., Kumar, A., Patel, A., Jain, R., and Sadasivuni, K.K., 2023. Investigation on drying kinetics analysis of gooseberry slices dried under open sun Environmental Challenges, 13, 100778, https://doi.org/10.1016/j.envc.2023.100778

Pi-Jen, T., John, M., Philip, P., Blake, C., and Brian, R.J., 2002. Anthocyanin and antioxidant capacity in Roselle (Hibiscus Sabdariffa L.) extract. Food Research International, 35(4) Pp 351-356, https://doi.org/10.1016/S0963-9969(01)00129-6

Polat, A., Taskin, O., Izli, N., and Asik, B.B. 2019. Continuous and intermittent microwave-vacuum drying of apple: Drying kinetics, protein, mineral content, and color. *J Food Process Eng*., e13012, https://doi.org/10.1111/jfpe.13012

Rapusas, R.S., and Driscoll, R.H., 1995. The thin-layer drying characteristics of white onion slices. *Drying Technology*, 13, (8-9), Pp. 1905-1931, https://doi.org/10.1080/07373939508917056

Saeed, I.E., Sopian, K., and Abidin, Z.Z., 2008a. Thin-Layer Drying of Roselle (I): Mathematical Modeling and Drying Experiments. Agricultural Engineering International, Manuscript FP 08 015. X. September, https://cigrjournal.org/index.php/Ejounral/article/view/1161/1117

Saeed, I.E., Sopian, K., and Abidin, Z.Z., 2008b. Drying Characteristics of Roselle: Study of the Two-term Exponential Model and Drying Parameters. Agricultural Engineering International, Manuscript FP 08 016. X. December, https://cigrjournal.org/index.php/Ejounral/article/view/1226

Saeed, I.E., Sopian, K., and Abidin, Z.Z., 2012. Evaluation of solar-assisted dehumidification drying-system (i): Study of drying-air properties, energy and exergy analyses, and some drying measures. Sudan Engineering Society Journal, 58, (2) Pp. 63-75, http://khartoumspace.uofk.edu/handle/123456789/7335

Sapuan, S.M., Nadlene, R., Radzi, A.M., and Ilyas, R.A. Eds. 2021. Roselle: Production, Processing, Products and Biocomposites, Academic Press: London, UK.

Shimpy, M., Kumar, M., Kumur, A., Sahdev, R.K., and Manchanda, H. 2022. Comparison of groundnut drying in simple and modified natural convection greenhouse dryers: Thermal, environmental and kinetic analyses. Journal of stored products research, 98, 101990, https://doi.org/10.1016/j.jspr.2022.101990

Shivhare, U.S., Gupta, A., Bawa, A.S., and Gupta, P. 2000. Drying Characteristics and Product Quality of Okra. *Drying Technology*, 18, (1-2) Pp. 409-419, https://doi.org/10.1080/07373930008917712

Shruthi, V.H., Ramachandra, C.T., Nidoni, U., Hiregoudar, S., Naik, N., and Kurubar, A.R. 2016. Roselle (*Hibiscus sabdariffa* L.) As a source of natural colour: A review. Plant Archives, 16(2), Pp. 515-522, https://www.plantarchives.org/PDF%20162/515-522.pdf

Simal, S. Femenia, A., Garau, M.C., and Roselló, C. 2005. Use of exponential Page's and diffusional models to simulate the drying kinetics of kiwi fruit. Journal of Food Engineering, 66, Pp. 323-328, https://doi.org/10.1016/j.jfoodeng.2004.03.025

Sogi, D.S., Shivhare, U.S., Garg, S.K., and Bawa, S.A., 2003. Water sorption isotherms and drying characteristics of tomato seeds. Biosystems Engineering, 84, Pp. 297-301, https://doi.org/10.1016/S1537-5110(02)00275-1

Soysal, Y., Öztekin, S., and Eren, Ö. 2006. Microwave Drying of Parsley: Modelling, Kinetics, and Energy Aspects Moisture-Contents. *Biosystems Engineering*, 93 (4), Pp. 403-413, https://doi.org/10.1016/j.biosystemseng.2006.01.017

Spatz, C. 2001. Basic statistics, Tales of distributions 7th Ed. Belmont: Wadsworth/Thomson learning.

Suherman, B.F., Satriadi, H., Yuariski, O., Nugroho, R.S., and Shobib, A. 2012. Thin Layer Drying Kinetics of Roselle. Advance Journal of Food Science and Technology, 4, Pp. 51-55, https://maxwellsci.com/print/ajfst/v4-51-55.pdf

Tahir, I.S.M., 2008. Techno-economic analysis of solar assisted dehumidification drying system for agricultural products. MSc Thesis, Faculty of Engineering and Built Environment National University of Malaysia, Bangi, Malaysia, (unpublished)

Tarigan, E., Prateepchaikul, G., Yamsaengsung, R., Sirichote, A., and Tekasakul, P. 2007. Drying characteristics of unshelled kernels of candle nuts. Journal of Food Engineering, 79, Pp. 828-833, https://doi.org/10.1016/j.jfoodeng.2006.02.048

Taskin, O., Polat, A., Etemoglu, A.K., and Izli, N. 2021. Energy and exergy analysis, drying kinetics, modeling, microstructure and thermal properties of convective-dried banana slices. Journal of Thermal Analysis and Calorimetry, https://doi.org/10.1007/s10973-021-10639-z

Téllez, M.C. Figueroa, I.P. Téllez, B.C. Vidaña, E.C.L. and Ortiz, A.L. 2018. Solar drying of Stevia (Rebaudiana Bertoni) leaves using direct and indirect technologies. Solar Energy, 159, Pp. 898-907, https://doi.org/10.1016/j.solener.2017.11.031

Therdthai, N., and Zhou, W. 2009. Characterization of microwave vacuum drying and hot air drying of mint leaves (Mentha cordifolia Opiz ex Fresen). Journal of Food Engineering, 91, (3) Pp. 482-489, https://doi.org/10.1016/j.jfoodeng.2008.09.031

Thuy, N.M., Tram, N.B., Cuong, D.G., An, L.T., Duy, H.K., and Tai, N.V. 2023. Mathematical modelling of roselle seeds (Hibiscus sabdariffa L.) drying kinetics. Food Research, 7(4), Pp. 84-90, https://doi.org/10.26656/fr.2017.7(4).121

Togrul, I.T., and Pehlivan, D. 2003. Modelling of drying kinetics of single apricot. *Journal of Food Engineering,* 58 (1), Pp. 23-32, https://doi.org/10.1016/S0260-8774(02)00329-1

Wang, Z., Sun, J., Liao, X., Chen, F., Zhao, G., Wu, J., and Hu, X. 2007. Mathematical modelling on hot air drying of thin layer apple pomace. Food Research International, 40, Pp. 39-46, https://doi.org/10.1177/1082013207078525

Xanthopoulos, G., Oikonomou, N., and Lambrinos, G. 2007. Applicability of a single-layer drying model to predict the drying rate of whole figs. Journal of Food Engineering, 81, Pp. 553-559, https://doi.org/10.1016/j.jfoodeng.2006.11.033

Yuan, Y., Tan, L., Xu, Y., Yuan, Y., and Dong, J., 2019. Numerical and experimental study on drying shrinkage-deformation of apple slices during process of heat-mass transfer. International Journal of Thermal Science, 136, Pp. 539-548, https://doi.org/10.1016/j.ijthermalsci.2018.10.042

Zhang, J., Zheng, X., Xiao, H., Li, Y., and Yang, T., 2023. Effect of Combined Infrared Hot Air Drying on Yam Slices: Drying Kinetics, Energy Consumption, Microstructure, and Nutrient Composition. *Foods*, 12, Pp. 3048, https://doi.org/10.3390/foods12163048

* * *