NONLINEAR MODELS FOR INFRARED DRYING OF MINT

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Abstract–– **In this paper, 105 different semi-theoretical and empirical thin layer drying models were used for describing the drying process of the mint leaves. Comparisons of the overall goodness of fit were based on Coefficient of Determination (R^2), Root Mean Square Error (RMSE), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). It was concluded that five parameter Cedergreen-Ritz-Streibig modified log-logistic functions with alpha equal to 0.25 (CRS5C) model describe the infrared drying process of the mint leaves. Furthermore, temperature effect was investigated by using reduction test. Finally, it was found that the effect is statistically significant and the model with separate trends fits these data better.**

Keywords–– **Nonlinear Modeling; AIC; BIC; Infrared Drying; Mint.**

I. INTRODUCTION

Drying is one of the oldest methods of food preservation. Also it represents a very important aspect of food processing. Infrared heating provide many advantages over hot air and sun drying under similar drying conditions. Drying time is shorter in infrared drying process than hot air or sun drying process (Hebbar and Rastogi, 2001; Nowak and Lewicki, 2005). Because the material is heated rapidly and more uniformly, the infrared energy is transferred from the heating element to the product without heating the surrounding air (Heybeli and Ertekin, 2011). When used other drying method combined with IR drying has recently accepted more attention in drying of fruits (Nimmol *et al.*, 2007; Swasdisevi *et al*., 2009). The irradiated surface evaporates much more water than that of not heated until removing the 80% of water. And drying time could be shortened by up to 50% by using infrared energy for drying different products (Nowak and Lewicki, 2004). According to Sun *et al.* (2007), infrared drying combined with hot air predrying can save 20% of drying time as compared to the infrared drying alone in apple pomace drying. When infrared radiation is used to heat or dry moist materials, the radiation in deep the exposed material, penetrates it and the energy of radiation converted into heat. The depth of penetration of radiation depends upon the characteristics of the material and wavelength of radiation. Some studies are on infrared drying of different products (Table 1).

Table 1. Different studies on infrared drying.

Product	Reference
Cashew kernel	Hebbar and Rastogi (2001)
Parboiled rice	Das *et al.* (2004)
Apple	Togrul (2005)
Onion	Sharma *et al.* (2005), Pathare and Sharma (2006), Kumar *et al.* (2006)
Celery	Jezek *et al.* (2008)
Red pepper	Nasiroglu and Kocabiyik (2008)
Olive husk	Celma *et al*. (2008)
Blueberries	Shi *et al.* (2008)
Seedless grape	Caglar *et al.* (2009)
Carrot	Togrul (2006), Kocabiyik and Tezer (2009)
Mint	Kocabiyik and Demirturk (2008), Ertekin and Heybeli (2014)
Strawberries	Ertekin *et al.* (2014)

II. MATERIALS AND METHODS

A. Materials

Mint leaves (*Menthaspicata L.*) are a common name for members of the Labiatae (Laminaceae Family) (Ozbek and Dadali, 2007; Kadam *et al*., 2011; Nayak *et al.*, 2011). Several species are shrubby or climbing forms or, rarely, small trees. It is especially widely grown in Mediterranean region, where these plants form a dominant part of the vegetation. Mint has been used as a medicinal and aromatic plant since ancient times. Its initial moisture content is about 78–82% (w.b.) (Therdthai and Zhou, 2009; Akpinar, 2010; Nayak *et al.*, 2011).

Mint (Mentha piperita var. Crispa) was procured from local market and cleaned by removing undesired stems and waste materials. The excess water was removed with the help of blotting paper. The damaged and black leaves were separated manually under careful observation before putting them into dryer. We used about 1.5 g whole leaves in each experiment.

In this study, infrared dryer and moisture analyzer equipment (OHAUS MB25 Basic Moisture Analyzers, Germany) transmitting electromagnetic radiation in the range medium to shortwave infrared radiation (radiator) was used as drying equipment (Fig. 1). The drying temperature was constantly set in keyboard of the equipment as 60, 70, 80°C in each experiment. The amount of evaporated water during drying was determined at about 2 min intervals in each drying temperature. Drying tests were replicated three times and average weight loss was reported.

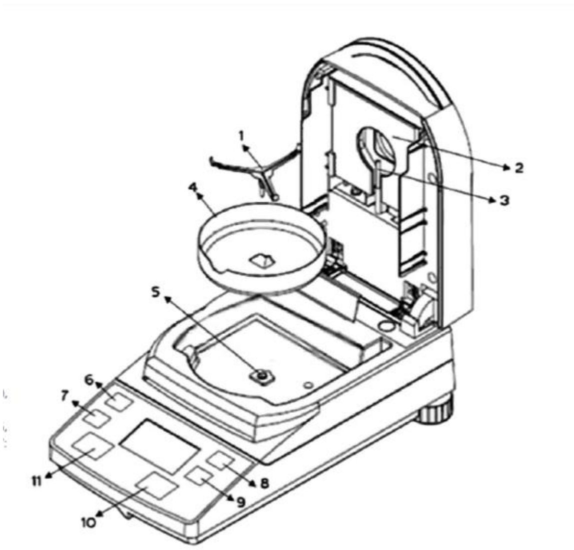

Fig. 1. Ohaus Mb25 Basic Moisture Analyzers; (1) Pan Support (2) Halogen Heater, (3) Moisture Sensor, (4) Draft Shield, (5) Load Cell, (6) Print, (7) Passing of Betweenthe Loss Weight (G), Loss Moisture (%) And Dry Matter (%), (8) Temperature Setting. (9) Time Setting, (10) Tare, (11) Open and Close

B. Methods

The moisture ratio (MR) of mint leaves during drying experiment was calculated using the following equation:

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_t is the moisture content at a specific time, M_e is the equilibrium moisture content, M_0 is the initial moisture content and t is drying time in minutes.

In this study, 105 different semi- theoretical and empirical thin layer drying models which were presented as a comprehensive review by Ertekin and Firat (2017) used for describing the moisture ratio drying curve of the mint. Non-linear least square regression analysis was employed to evaluate the parameters of the selected models using NLIN procedure with the Levenberg–Marquardt method in SAS 9.3 software (SAS Institute Inc 2009). Comparisons of the overall goodness of fit of the models to describe thin-layer drying curves were based on Coefficient of Determination (R^2), Root Mean Square Error (RMSE), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). These parameters can be described by the following equations:

$$R^2 = 1 - \frac{\text{Residual SS}}{\text{Corrected total SS}} \quad (2)$$

$$RMSE = \left\{ \frac{1}{N} \sum_{i=1}^{N} \left(MR_{\exp,i} - MR_{pre,i} \right)^2 \right\}^{\frac{1}{2}} \quad (3)$$

$$AIC = -2l_i + 2k_i \quad (4)$$

$$BIC = -2l_i + k_i \log(N) \quad (5)$$

where $MR_{\exp,i}$ is the experimental moisture ratio at observation i, $MR_{\text{pre},i}$ is the predicted moisture ratio at this observation, N is number of experimental data points, l_i is the maximum value of the log likelihood of the *ith* model and k_i is the number of the parameters of the *ith* model. The higher the values of the R^2 (the closer to 1) and the lower the values of RMSE, AIC and BIC, the better the goodness of fit (Akaike, 1974; Schwarz, 1978; Neter *et al*., 1990; Togrul, 2006; Wang *et al*., 2007; Doymaz, 2007a; Doymaz, 2007b; Menges and Ertekin, 2006; Changrue *et al*., 2008; Ertekin and Firat, 2017). AIC and BIC may not necessarily agree on the best model because the BIC has a stronger penalty. Since our objective is to choose the most parsimonious model, we rely more on the BIC than the AIC criterion Ertekin and Firat (2017). These 105 different models were compared according to these statistical criteria and the best 10 models were choosen. From the conducted non-linear least square regression analysis the constants and coefficients of the best model, in terms of fitting, were determined. Following, the effect of temperature on the moisture ratio of the chosen empirical drying expression was investigated and determined by a sum of square reduction test.

III. RESULTS AND DISCUSSION

In Fig. 2, the box plot of MR changes at 60, 70 and 80°C can be seen. According to this plot, 60 °C has the highest median value and 80 °C has the lowest median value.

The MR of the mint as a function of drying time at three different temperatures is shown in Fig. 3. It can be observed that for the moisture ratio decreased dramatically with increasing drying time and that for a constant temperature, drying curves exhibited a steep slope. The drying temperatures had a significant effect on drying behavior of mint leaves. The increase in temperature resulted in a decrease in drying time. The time needed to reduce the MR to any given level was dependent on the drying condition. It was highest at 60°C and lowest at 80°C. The moisture ratio decreased drastically with the increase in temperature.

A. Comparing the temperature effect

In order to compare the effect of three different temperatures on the MR of mint in a nonlinear regression problem, a sum of square reduction test is used. This is a very general procedure that can be used to test all kinds

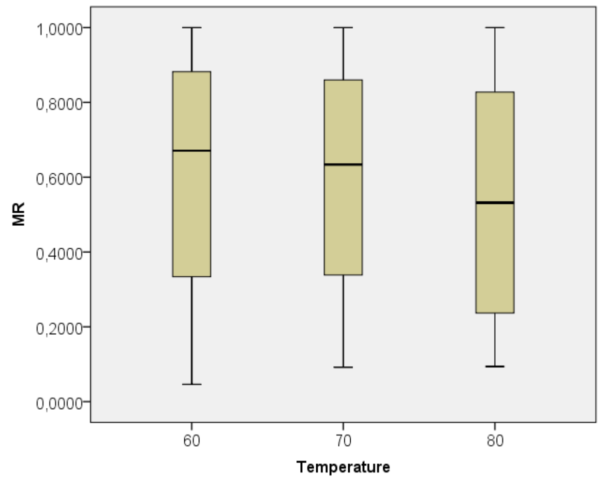

Fig. 2. The box plot of MR changes at 60,70 and 80 °C.

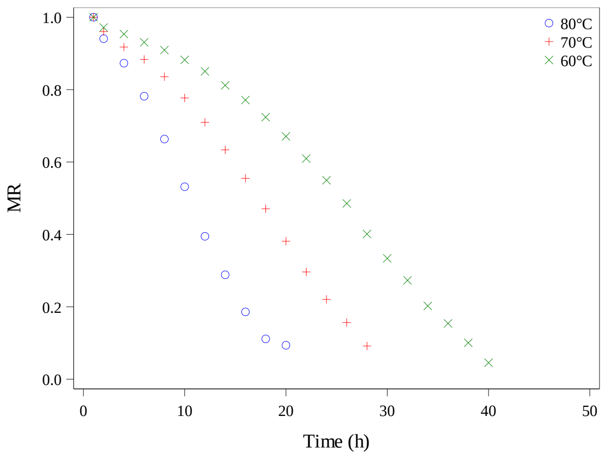

Fig. 3. Effect of drying temperature and drying time on the MR of mint.

of hypotheses. The idea is to fit two versions of the model. One is considered the full model and has more parameters. The reduced model with fewer parameters is a constrained version of the full model. While the full model parameters are predicted for each temperature settings, the parameters related with the temperature is not used in the reduced model.

In this study, we first fitted the reduced models for each of 105 different semi- theoretical and empirical thin layer drying functions without considering the effect of temperature. . The best fitting 10 models are chosen namely, Five parameter Cedergreen-Ritz-Streibig modified log-logistic functions with alpha equal to 0.25 (CRS5C), Five parameter Cedergreen-Ritz-Streibig modified log-logistic functions with alpha equal to 0.50 (CRS5B), Six parameter Cedergreen-Ritz-Streibig modified log-logistic function (CRS6), Five parameter Cedergreen-Ritz-Streibig modified log-logistic functions with alpha equal to 1 (CRS5A), Growth curve model (BC5), Five parameter log-logistic function (LL5), Haghi and Angiz II model, Five parameter Cedergreen-Ritz-Streibig modified log-logistic functions for describing u-shaped hormesis with alpha equal to 1 (UCRS5A), Four parameter Weibull function (W14) and Five parameter Cedergreen-Ritz-Streibig modified log-logistic functions for describing u-shaped hormesis with alpha equal to 0.5 (UCRS5B) in Table 2.

Table 3 presents the values of R^2, MSE, RMSE, AIC and BIC which are the model selection criteria for the most suitable first ten models. The derived drying models were sorted in ascending order of BIC. As can be seen from this table, the results of the analysis indicated that the CRS5C model was the most appropriate one in terms of four goodness of fit criteria out of six (MSE=0.000026864, RMSE=0.005183, AIC= -489.949, BIC=-480.698) followed by the CRS5B and CRS6 models, while it was the second best fitting model with regard to R^2 and SSE criteria (R^2= 0.99975, SSE=0.001128). Therefore, the fitting procedure indicated that the results of the following single-layer CRS5C model among the 105 candidate models could be used to model the drying behavior of mint leaves in the first part of the analysis:

$$MR = c + \frac{d - c + f\exp\left(-1/t^{\alpha}\right)}{1+\exp\{b[\log(t)-\log(e)]\}} \tag{6}$$

The estimated values of parameters of the CRS5C model are given in Table 4. However, this model does not indicate the effects of temperature of drying air. To account for the effect of the drying temperature, we fitted the following full model for the selected CRS5C function in terms of three temperature groups in the second part of the analysis

$$MR_i = c_i + \frac{d_i - c_i + f_i\exp\left(-1/t^{\alpha}\right)}{1+\exp\{b_i[\log(t)-\log(e_i)]\}} \quad i = 1,2,3 \tag{7}$$

Where α=0.25 and i represent the temperatures. The reduced model in (6) is nested within the full model in (7) and the following sum of squares reduction test statistic can be used to test hypotheses about these nested nonlinear models

$$F_R = \frac{(SSE_{Reduced} - SSE_{Full})/(dfError_{Reduced} - dfError_{Full})}{MSE_{Full}} \tag{8}$$

where SSE_{Reduced} and SSE_{Full} denote the residual sum of squares in the reduced and the full model, respectively, MSE_{Full} is the residual mean of squares in the full model, $dfError_{\text{Reduced}}$ and $dfError_{\text{Full}}$ are the error degrees of freedom for the reduced and the full model, respectively. In the present study, to test whether there is any difference among the three temperatures, or equivalently, whether any model parameters are varied between the three temperatures, the following null hypothesis is used.

$$H_o : \begin{cases} b_1 = b_2 = b_3 \\ c_1 = c_2 = c_3 \\ d_1 = d_2 = d_3 \\ e_1 = e_2 = e_3 \\ f_1 = f_2 = f_3 \end{cases} \tag{9}$$

The fit results from the reduced model and full model are given in Table 5-6. To perform the sum of squares reduction test, the sum of squares and the means squares are used in Table 4. The F statistic and p-value of the sum of square reduction test for the above hypothesis of equal trends are obtained as 3259.89 and 0.0000, respectively. It can easily be concluded that there is clear evidence that the model with separate trends fits these data significantly better.

Finally, the resulted CRS5C model was evaluated, comparing the predicted moisture ratios with the observed ones for thin layer of mint at 60, 70 and 80°C. Figure 4 compare observed and fitted MR with CRS5C model against drying time for thin layer of mint at 60, 70 and 80°C. It can be clearly seen from this figure that the observed values show the best fitting to the predicted values. The performance of the model at temperatures of 60, 70 and 80°C is illustrated in Fig. 5. It is obvious from this figure that the predicted data for each temperature scattered around the line. The conducted statistical analysis revealed that the predicted data would be handled closely, by 99% probability, around

Table 2. The equations of the best ten models.

Model name	Model Equation	Explanation
CRS5C	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\{b_i[\log(t)-\log(e_i)]\}}$	where α=0.25 and i represent the temperatures
CRS5B	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\{b_i[\log(t)-\log(e_i)]\}}$	where α=0.50 and i represent the temperatures
CRS6	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\{b_i[\log(t)-\log(e_i)]\}}$	i represent the temperatures
CRS5A	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\{b_i[\log(t)-\log(e_i)]\}}$	where α=1 and i represent the temperatures
BC5	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\left\{b_i\left[\log(t)-\log(e_i)\right]\right\}^{f_i}}$	i represent the temperatures
LL5	$MR_i = c_i + \frac{d_i - c_i}{1+\exp\left\{b_i\left[\log(t)-e_i\right]\right\}^{f_i}}$	i represent the temperatures
HAGHI-ANGIZ II	$MR_i = a_i + b_i t + c_i t^2 + d_i t^3$	i represent the temperatures
UCRS5A	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\left\{b_i\left[\log(t)-\log(e_i)\right]\right\}}$	where α=1 and i represent the temperatures
W14	$MR_i = a_i - b_i \exp\left[-\left(k_i t^{n_i}\right)\right]$	i represent the temperatures
UCRS5B	$MR_i = c_i + \frac{d_i - c_i + f_i \exp\left(-1/t^{\alpha}\right)}{1+\exp\left\{b_i\left[\log(t)-\log(e_i)\right]\right\}}$	where α=0.5 and i represent the temperatures

Table 3. Results obtained from the selected ten nonlinear models

Model	**SSE**	R^2	**MSE**	**RMSE**	**AIC**	**BIC**
CRS5C	0.0011	0.9998	2.69×10^{-5}	0.0052	-489.95	-480.70
CRS5B	0.0012	0.9997	2.83×10^{-5}	0.0053	-487.47	-478.22
CRS6	0.0011	0.9998	2.69×10^{-5}	0.0052	-488.97	-477.87
CRS5A	0.0014	0.9997	3.22×10^{-5}	0.0057	-482.35	-474.95
BC5	0.0013	0.9997	3.12×10^{-5}	0.0056	-482.97	-473.72
LL5	0.0028	0.9994	6.78×10^{-5}	0.0082	-446.44	-437.19
HAGHI-ANGIZ II	0.0047	0.9990	11.01×10^{-5}	0.0105	-424.56	-417.16
UCRS5A	0.0047	0.9990	10.99×10^{-5}	0.0105	-423.73	-414.48
W14	0.0057	0.9987	12.91×10^{-5}	0.0114	-417.98	-412.43
UCRS5B	0.0051	0.9989	12.16×10^{-5}	0.0110	-418.96	-409.71

Table 4. Fit results from the reduced and full models using CRS5C.

		Reduced Model	
Source	df	Sum of squares	Mean Square
Model	4	3.3749	0.8437
Error	42	1.1505	0.0274
Corrected Total	46	4.5255	
		Full Model	
Model	14	4.52430	0.32320
Error	32	0.00113	0.00003
Corrected Total	46	4.52550	

Table 5. Parameter estimations of the reduced model using CRS5C

Parameter	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
b	13.226	18.194	-23.491	49.943
c	-0.3474	14.889	-33.523	26.571
d	0.8891	10.753	-12.809	30.592
e	224.271	22.455	-22.889	67.437
f	0.3311	31.081	-59.413	66.036

the perfect fit (X=Y). This trend also provides an evidence for the suitability of the selected model to predict drying of mint leaves.

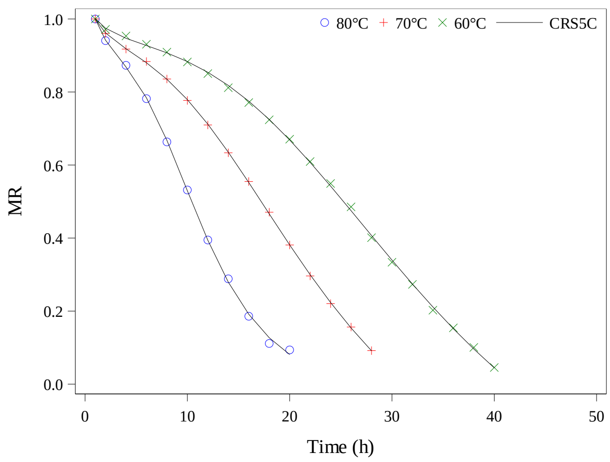

Fig. 4. Observed MR and fitted MR using CRS5C

Table 6. Parameter estimations of the full model using CRS5C.

	Estimate	Approx Std Error	Approximate 95% Confidence Limits	
b_1	2.9670	0.1209	2.7208	3.2132
c_1	-0.5052	0.0695	-0.6467	-0.3637
d_1	1.1532	0.0205	1.1115	1.1950
e_1	34.7962	1.1071	32.5411	37.0514
f_1	-0.4132	0.0439	-0.5026	-0.3238
b_2	2.7768	0.1608	2.4493	3.1043
c_2	-0.3874	0.0797	-0.5497	-0.2252
d_2	1.2110	1.2110	1.1532	1.2688
e_2	23.8476	23.8476	21.7733	25.9219
f_2	-0.5747	-0.5747	-0.7085	-0.4408
b_3	3.3859	0.1738	3.0317	3.7400
c_3	-0.0508	0.0217	-0.0949	-0.0066
d_3	1.3269	0.0354	1.2547	1.3990
e_3	12.2539	0.1845	11.8780	12.6298
f_3	-0.8874	0.0850	-1.0606	-0.7143

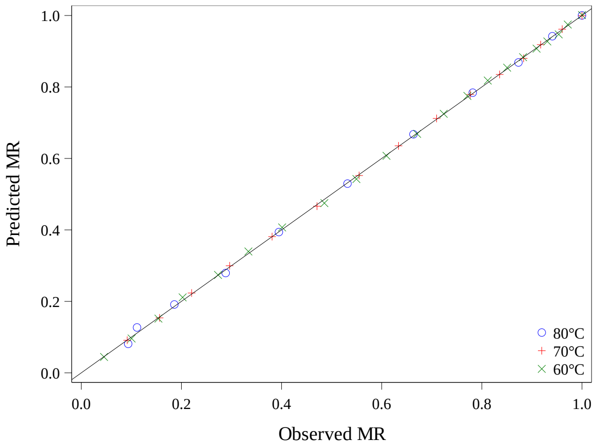

Fig. 5. Observed and predicted moisture ratio at 80, 70 and 60°C temperatures

IV. CONCLUSIONS

In this study, 105 different semi- theoretical and empirical thin layer drying models have been analyzed for their suitability for the intermittent drying of thin layer whole mint leaves at 60, 70 and 80°C temperatures. To the best of our knowledge, this study is the first to use a sum of square reduction test in order to compare the effect of three different temperatures on the MR of mint in a nonlinear regression problem.

Ten thin layer drying models have been analyzed for their suitability for the intermittent drying of thin layer mint leaves. The results show that the CRS5C model is the best fit as it produces the most suitable results in terms of four goodness of fit criteria out of six, MSE, RMSE, AIC, and BIC. The CRS5B and CRS6 models are other acceptable drying models in describing the experimental data.

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