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STATISTICAL EVALUATION OF THIN-LAYER DRYING OF BANANA

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Abstract

Drying of food materials is a complex process of simultaneous heat and mass transfer within dried material and from its surface to the surroundings, caused by a number of transport mechanisms. There are several different methods of describing the complex simultaneous heat and moisture transport processes within drying material. Thin-layer drying models are important tools in mathematical modeling of drying processes. In scientific literature generally for evaluation of thin-layer models, that use approximation of experimental drying data, the values of the coefficient of determination (R^2), correlation coefficient (r), reduced chi-square, root mean square error (RMSE), and mean bias error (MBE) are the most common criteria to select the best model. In this paper one approach for selection of a thin-layer drying model based on serial statistical criteria was proposed.

Fresh banana were used in this study. The experimental data set of thin-layer drying kinetics of banana slices at four drying air temperatures (40, 50, 60 and 70 ^{0}C) and three drying air velocities (1, 2 and 3 ms^{-1}) were obtained on the experimental setup, designed to imitate an industrial convective dryer.

The experimental data of drying kinetic of banana slices were fitted to twenty four thin-layer mathematical models by means of indirect non-linear regression analysis. For each model and data set, the statistical performance index was calculated and models were ranked afterwards. After that, several statistical rejection criteria were checked. The performed statistical analysis shows that the Modified Henderson-Pabis model gives the best results for approximation of experimental drying data.

The single statistical criterion cannot be used to select the thin-layer drying model. The model must always be chosen based on multiple statistical criteria.

***Key words**: Thin-layer models, Banana, Statistical criteria.*

1. Introduction

Fruits and vegetables play an important role in human diet and nutrition as sources of vitamins and minerals. The banana is a tropical fruit rich in vitamins like thiamine, riboflavin, niacin, pantothenic acid, vitamin B_6, moderate amounts of vitamin C, and contains magnesium, potassium, and soluble fiber. The production of banana in 2011 was estimated to 107 million tons [1]. With 29.67 million tons, India was the largest producer, followed by China (10.40 million tons), Philippines (9.17 million tons), Ecuador (7.436 tons), Brazil (7.33 million tons) and Indonesia (6.13 million tons).

The drying of food materials is a complex process of simultaneous heat and mass transfer within dried material and from its surface to the surroundings caused by a number of transport mechanisms. There are several different methods of describing the complex simultaneous heat and moisture transport processes within drying material. In the approach initially proposed by Philip and De Vries and Luikov the moisture and temperature fields in the drying material are described by a system of two coupled linear partial differential equations [2]. On the other hand, thin-layer drying models are important tools in mathematical modelling of drying processes. They are often used to estimate drying time and generalize drying curves, and have wide application due to their ease of use and requirement of less data, unlike in complex models.

Several researchers have investigated the drying kinetics of banana [3], [4], [5], [6]. The thin-layer drying models which describe the drying rate of food materials are categorized into three groups: theoretical, semi-theoretical and empirical [7].

In scientific literature, generally, for evaluation of thin-layer models that use approximation of experimental drying data, the values of the coefficient of determination or R^2, correlation coefficient r, reduced chi-square χ^2, root mean square error RMSE and mean bias error MBE are the most common criteria used to select the best model. The selection of a thin-layer model with graphical evaluation of the residual randomness is also popular [8], [9]. In this paper, one approach for the selection of best thin-layer drying model based on serial statistical criteria was proposed.

2. Materials and Methods

Fresh bananas were used in this study. To prepare samples, bananas were peeled and sliced using a knife to obtain a uniform sample with thickness of 3± 0.1 mm, before being reduced to a cylinder form with diameter of 30 ± 0.1 mm. Several measurements were made using a caliper and only samples with a tolerance of ± 5% were used. The experimental data set of thin-layer drying kinetics of banana slices at four drying air temperatures 40, 50, 60 and 70 ^{0}C and three drying air velocities 1, 2 and 3 ms^{-1} were obtained on the experimental setup apparatus, designed to imitate an industrial convective dryer (Figure 1).

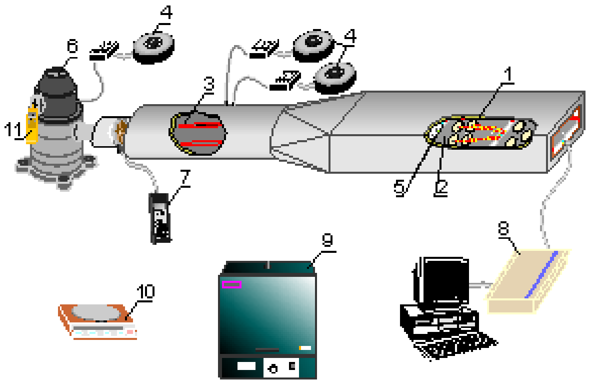

**Figure 1. Experimental apparatus:
1-material, 2-shelf, 3-electrical heaters, 4-transformers, 5-thermocouples, 6-centrifugal fan,
7-anemometer, 8-data acquisition system, 9-stove,
10-digital balance, 11-hygrometer**

The slices have been in contact with the drying air from top and bottom surfaces. Two shelves, each holding three moist banana slices have been introduced into the rectangular experimental channel with dimensions 25 x 200 x 2000 mm (Figure 2).

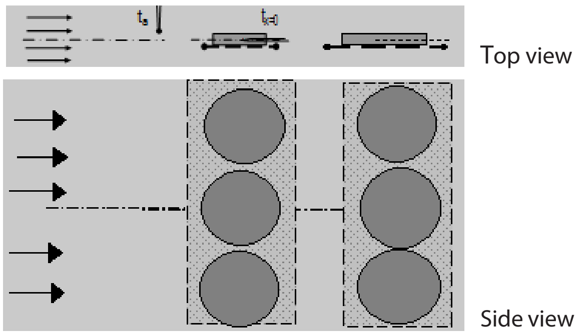

Figure 2. Scheme of the drying experiment

A micro-thermocouple was inserted in the mid-plane of each of the three slices on the first shelf in order to obtain temperature of dried slices. The banana slices on the second shelf were weighed every ten minutes in order to obtain the volume-averaged moisture content change during drying.

The temperature of the drying air, t_a, and temperature of slices, t, has been recorded as well. The initial moisture content, M_0, and the initial slices' thickness, $2L_0$, were measured in each experiment. The initial moisture content of fresh slices (2.66 ÷ 3.10 kg/kg d.b.) and the final moisture content of dried samples were determined by hot air oven method at 105 ^{0}C for 24 h.

3. Results and Discussion

For approximation of experimental data of the drying kinetic of banana slices, twenty-four thin-layer mathematical models were used (Table 1).

In these models, A, B, C, D, E, F, G, m are parameters, k_1 [min^{-1}] and k_2 [min^{-1}] drying constants, t [min^{-1}] drying time, while MR is the moisture ratio which is defined by the following equation

$$MR = \frac{M - M_{eq}}{M_0 - M_{eq}} \tag{1}$$

The values of equilibrium moisture content, M_{eq} [kgkg^{-1}] are relatively small compared to those of moisture content of dried samples, M [kgkg^{-1}] or initial moisture content, M_0 [kgkg^{-1}], so the error involved in the simplification is negligible. Thus, moisture ratio was calculated as:

$$MR = M / M_0 \tag{2}$$

In order to estimate and select the best thin-layer drying model, several statistical criteria were used. The value of performance index, φ which is calculated on the basis of calculated values for coefficient of determination R^2, the root mean squared error RMSE and the mean relative deviation MRD is the first statistical criterion for selection of the best thin-layer model, [8]:

$$R^2 = \frac{SS_M - SS_E}{SS_M},\ RMSE = \sqrt{MS_E},\ MRD = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{E_i}{M_i}\right| \tag{3}$$

$$MS_E = \frac{SS_E}{n-k},\quad SS_M = \sum_{i=1}^{n}(M_i - \overline{M}_i)^2,$$

$$SS_E = \sum_{i=1}^{n}E_i^2,\quad E_i = M_i - \hat{M}_i,\quad \overline{M}_i = \frac{1}{n}\sum_{i=1}^{n}M_i \tag{4}$$

$$\phi = \frac{R^2}{RMSE \text{ x } MRD} \tag{5}$$

where SS_E, is the sum of squares of errors about regression, SS_M, the sum of squares of errors adjusted for the mean, MS_E, the mean square of errors, E_i, [$kgkg^{-1}$], the moisture residual, M_i, [$kgkg^{-1}$] moisture content of samples, n, the number of experimental points, k, the number of parameter which are estimates. Higher values of performance index φ indicate that the thin-layer model better approximates the experimental data.

The D'Agostino-Pearson test of normality is the most effective procedure for assessing a goodness of fit for a normal distribution [20]. This test is based on the individual statistics for testing of the population of skewness z_1 and kurtosis z_2, respectively. This test is second statistical criterion as adequate of thin-layer model and it is based on the following equations [8], [20]:

$$SE_m = \sum_{i=1}^{n} \varepsilon_i^m \quad \text{for } m = 2, 3, 4,$$

$$\varepsilon_i = E_i - \bar{E}, \qquad s = \sqrt{\frac{SE_2}{n-1}} \tag{6}$$

$$m_3 = \frac{n SE_3}{(n-1)(n-2)},$$

$$m_4 = \frac{n(n+1)SE_4}{(n-1)(n-2)(n-3)} - \frac{3SE_2^2}{(n-2)(n-3)} \tag{7}$$

$$A_1 = \frac{m_3(n-2)}{s^3\sqrt{n(n-1)}}\sqrt{\frac{(n+1)(n+3)}{6(n-2)}},$$

$$B_1 = \frac{3(n^2+27n-70)(n+1)(n+3)}{(n-2)(n+5)(n+7)(n+9)} \tag{8}$$

$$C_1 = \sqrt{2(B_1-1)} - 1, \quad D_1 = \sqrt{C_1},$$

$$E_1 = \frac{1}{\sqrt{\ln(D_1)}}, \quad F_1 = \frac{A_1\sqrt{C_1-1}}{\sqrt{2}} \tag{9}$$

Table 1. Thin-layer drying models

Model	Equation	Name of Model	References
M01	$MR = \exp(-k_{1\tau})$	Lewis (Newton)	[7]
M02	$MR = \exp(-k_{1\tau}{}^{m})$	Page	[7]
M03	$MR = \exp[-(k_{1\tau})^{m}]$	Modified Page	[7]
M04	$MR = A\exp(-k_{1\tau})$	Henderson-Pabis	[7]
M05	$MR = A\exp(-k_{1\tau})+B\exp(-C_{\tau})+D\exp(-G_{\tau})$	Modified Henderson-Pabis	[7]
M06	$MR = A\exp(-k_{1\tau})+B$	Logarithmic (Asymptotic)	[7]
M07	$MR = A\exp(-k_{1\tau})+B\exp(-k_{2\tau})$	Two term	[7]
M08	$MR = A\exp(-k_{1\tau})+(1-A)\exp(-k_1 A_{\tau})$	Two term exponential	[7]
M09	$MR = A\exp(-k_{1\tau}{}^{m})+B_{\tau}$	Midilli	[10]
M10	$MR = A\exp(-k_{1\tau})+(1-A)\exp(-k_1 B_{\tau})$	Diffusion approach	[7]
M11	$MR = 1+A_{\tau}+B_{\tau}{}^{2}$	Wang and Singh	[7]
M12	$MR = \exp[-(\tau/A)^{B}]$	Weibull	[11]
M13	$MR = \exp[-k_1 t/(1+k_{2\tau})]$	Aghbashlo	[12]
M14	$MR = A\exp(-k_{1\tau})+(1-A)\exp(-B_{\tau})$	Verma	[13]
M15	$MR = A+B_{\tau}+C_{\tau}{}^{2}$	Parabolic	[14]
M16	$MR = A\exp(-k_{1\tau}{}^{m})+B\exp(-C_{\tau}{}^{m})$	HII	[15]
M17	$MR = A\exp(-k_{1\tau})^{m}+B$	Demir	[7]
M18	$MR = A+B\exp(-k_{1\tau})$	Logarithmic	[16]
M19	$MR = A/(1+B\exp(k_{1\tau}))$	Logistic	[16]
M20	$MR = (A+k_{1\tau})^{2}$	Vega-Lemus	[17]
M21	$MR = A\exp(-k_{1\tau}+ B_{\tau}{}^{0.5}) +C$	Jena and Das	[18]
M22	$MR = A\exp[(-k_{1\tau}{}^{m})+B_{\tau}] +C$	Alibas	[19]
M23	$MR = 1-\tau/(A+B_{\tau})$	Peleg	[3]
M24	$MR = \exp(A_{\tau}-B^{0.5})$	Silva	[3]

$$G_2 = \frac{24n(n-2)(n-3)}{(n+1)^2(n+3)(n+5)},$$

$$H_2 = \frac{(n-2)(n-3)|m_4|}{s^4(n-1)(n+1)\sqrt{G_2}},$$

$$J_2 = \frac{6(n^2-5n+2)}{(n+7)(n+9)}\sqrt{\frac{6(n+3)(n+5)}{n(n-2)(n-3)}} \qquad (10)$$

$$K_2 = 6 + \frac{8}{J_2}\left(\frac{2}{J_2} + \sqrt{1+\frac{4}{J_2^2}}\right),$$

$$L_2 = 1 - \frac{2}{K_2} / 1 + H_2\sqrt{\frac{2}{K_2-4}} \qquad (11)$$

$$z_1 = E_1 \ln(F_1 + \sqrt{F_1^2+1}),$$

$$z_2 = \left(\frac{2}{9K_2}\right)^{-\frac{1}{2}}\left(1 - \frac{2}{9K_2} - \sqrt[3]{L_2}\right) \qquad (12)$$

where SE_m, is the auxiliary variable for the calculation of the normality test statistic, ε_l, the error about the residual mean, s, the standard deviation of errors about residual mean, m_3, the third moment about the mean for the residual population, m_4, the fourth moment about the mean for the residual population, A_1-F_1, the auxiliary variables for calculation of the skewness test statistic, G_2-L_2, the auxiliary variables for calculation of the kurtosis test statistic.

The test statistic for the D'Agostino-Pearson test of normality is computed with equation:

$$\chi^2 = z_1^2 + z_2^2 \qquad (13)$$

where χ^2, is the statistic for testing the normality of the moisture residual. The χ^2 statistics has a chi-squared distribution with 2 degrees of freedom (df). The tabled critical .05 chi-square value for df = 2 is $\chi^2_{0.5} = 5.99$. Therefore, if the computed value of chi-square is equal to or greater than, either of the aforementioned values, the null hypothesis can be rejected at the appropriate level of significance [20], i.e. the thin-layer model should be rejected.

Because the χ^2 statistics is not recommended individually as an adequate measure of the effectiveness of thin-layer model to describe the experimental data, additional criterion has to be introduced. The single-sample run test is one of them and it is third statistical criterion adequate for thin-layer model. The single-sample run test is one of a number of statistical procedures that have been developed for evaluating whether or not the distribution of series is random.

The test evaluates the number of runs in a series in which, on each trial, the outcome must be one of k_1 = 2 alternatives. In this test, the number of positive and negative residuals (n_1 and n_2) and the number of times the sequence of residuals changes sign, g, are used to calculate the following test statistic [20]:

$$z_r = \frac{|g-g_1|-0.5}{\sigma_r} \qquad (14)$$

$$g_1 = \frac{2n_1n_2}{n_1+n_2} + 1,$$

$$\sigma_r = \sqrt{\frac{2n_1n_2(2n_1n_2-n_1-n_2)}{(n_1+n_2)^2(n_1+n_2-1)}} \qquad (15)$$

where z_r, is the statistic for testing of the randomness of moisture residual series, g_1, the mean of the sampling distribution of runs in a random series and s_r, is the expected standard deviation of the sampling distribution of runs in a random series. If the computed value of z_r is greater than the tabled critical two-tailed value $z_{.05}$ = 1.96, the null hypothesis should be rejected [20], i.e. the thin-layer model should be rejected.

A fourth statistical criterion for selection of thin-layer drying model is the significance and precision of the model constant. That can be done with construction of individual confidence intervals (CI). If the estimated value of parameters is out of the 95% confidence interval, the model contains irrelevant parameters for approximation of experimental data, i.e. the thin-layer model should be rejected.

The experimental data of drying kinetic of banana slices were fitted to twenty four thin-layer mathematical models by means of indirect non-linear regression analysis using computer program Statistica [21]. The methods of Quasi-Newton, Simplex, Simplex and quasi-Newton, Hooke-Jeeves pattern moves, Hooke-Jeeves pattern moves and quasi-Newton, Rosenbrock pattern search, Rosenbrock pattern search and quasi-Newton were used. When the results for coefficient of determination were different, the greatest value was accepted as relevant.

On the basis of experimental data and each model from Table 1, the average values of: coefficient of determination R, root mean squared error RMSE, the mean relative deviation MRD and performance index f were calculated. After that, the models were ranked on the basis of values of average performance index f (Table 2). The models (M05, M14, M07, M10, M21, M09, M08 and M24) have the highest average coefficient of determination i.e. the high average performance index in comparison with the other models.

From Table 2, it is evident that the model M05 i.e. the model of Modified Henderson-Pabis, has the highest value of average performance index φ = 4843.911, while the model M11 i.e. the Wang and Singh model, has the smallest value of average performance index $\varphi = 81.743$. In accordance with second and third statistical criterion, the computed average values for χ^2 and z_r are given in Table 3.

It is obvious that the models (M01, M04, M19, and M20), have values of χ^2 and z_r higher than the tabled critical values. In accordance with the second and third statistical criteria, these models were rejected in further consideration. While the models (M02, M03, M06, M08, M09, M10, M11, M12, M13, M14, M15, M16, M17, M18, M22, M23 and M24) have value of z_r higher than the tabled two-tailed value $z_{.05} = 1.96$. For this reason these models were rejected in further consideration in accordance with the third statistical criterion.

For the models M05, M07 and M21 computed average values of chi-square χ^2 and z_r are smaller than tabled critical values. In accordance with statistical criteria, those models are able to correlate the experimental values of drying kinetic of banana slices with 1 % average root mean squared error. But, from the first statistical criterion, the model M05 i.e. Modified Henderson-Pabis model has higher values of average performance index φ compared to other models, so this model is the best approximation of experimental data. The estimated values of parameters and 95% confidence intervals of estimated parameters for the model M05, for all air drying temperatures and air drying velocities are given in Table 4.

Table 2. Statistic summary of the regression analysis

Model	R^2	RMSE	MRD	φ	Rank	Model	R^2	RMSE	MRD	φ	Rank
M01	0,990	0,025	0,103	483,908	21	M13	0,995	0,018	0,075	919,870	18
M02	0,997	0,013	0,069	1551,277	11	M14	0,998	0,009	0,047	4420,141	2
M03	0,997	0,013	0,069	1551,046	12	M15	0,981	0,040	0,164	226,738	22
M04	0,995	0,019	0,078	780,219	19	M16	0,998	0,012	0,057	2436,665	9
M05	0,999	0,010	0,039	4843,911	1	M17	0,996	0,018	0,055	1178,758	15
M06	0,996	0,017	0,055	1224,885	14	M18	0,994	0,019	0,070	978,128	17
M07	0,998	0,010	0,047	4287,309	3	M19	0,988	0,025	0,102	602,951	20
M08	0,998	0,011	0,061	2903,380	7	M20	0,969	0,049	0,287	120,903	23
M09	0,999	0,010	0,052	3001,724	6	M21	0,998	0,009	0,051	3606,830	5
M10	0,998	0,010	0,059	4134,042	4	M22	0,998	0,014	0,063	1585,963	10
M11	0,958	0,057	0,267	81,743	24	M23	0,995	0,017	0,095	991,285	16
M12	0,932	0,029	0,106	1460,848	13	M24	0,998	0,011	0,064	2531,315	8

Table 3. Rejection criteria for models used

Model	χ^2	z_r	Rejection criteria	Model	χ^2	z_r	Rejection criteria
M01	8,386	2,903	χ^2, z_r	M13	2,546	2,723	z_r
M02	1,596	2,679	z_r	M14	3,221	2,102	z_r
M03	1,629	2,679	z_r	M15	9,643	2,650	z_r
M04	6,305	2,448	χ^2, z_r	M16	1,534	2,269	z_r
M05	2,303	1,723	-	M17	5,113	2,374	z_r
M06	5,095	2,374	z_r	M18	2,201	2,441	z_r
M07	2,845	1,891	-	M19	6,266	2,549	χ^2, z_r
M08	1,997	2,281	z_r	M20	6,447	2,973	χ^2, z_r
M09	1,298	2,017	z_r	M21	1,403	1,854	-
M10	2,830	2,204	z_r	M22	5,236	2,271	z_r
M11	2,394	3,026	z_r	M23	1,930	2,649	z_r
M12	1,403	2,715	z_r	M24	2,040	2,386	z_r

Table 4. Non-linear regression parameters and 95%CI

Drying conditions	Value of parameters	95% CI	Drying conditions	Value of parameters	95% CI
t = 40 ^{0}C, v = 1 m/s	A = 0.134 B = 0.433 C = 0.010 D = 0.433 G= 0.010 k_1= 0.132	(0.119 ÷ 0.150) (0.418 ÷ 0.449) (-0.006 ÷ 0.025) (0.417 ÷ 0.448) (-0.006 ÷ 0.025) (0.117 ÷ 0.148)	t = 60 ^{0}C, v = 1 m/s	A = 0.924 B = 0.038 C = 74.12 D = 0.038 G= 74.12 k_1= 0.021	(0.899 ÷ 0.950) (0.013 ÷ 0.063) (74.09 ÷ 74.14) (0.013 ÷ 0.063) (74.09 ÷ 74.14) (-0.004 ÷ 0.046)
t = 40 ^{0}C, v = 2 m/s	A = 0.125 B = 0.437 C = 0.006 D = 0.437 G= 0.006 k_1= 0.128	(0.099 ÷ 0.152) (0.411 ÷ 0.464) (-0.020 ÷ 0.033) (0.411 ÷ 0.464) (-0.020 ÷ 0.033) (0.101 ÷ 0.154)	t = 60 ^{0}C, v = 2 m/s	A = 0.104 B = 3.807E-05 C = - 0.047 D = 0.896 G= 0.023 k_1= 0.238	(0.091 ÷ 0.117) (-0.013 ÷ 0.013) (-0.060 ÷ -0.034) (0.883 ÷ 0.909) (0.010 ÷ 0.036) (0.225 ÷ 0.251)
t = 40 ^{0}C, v = 3 m/s	A = 0.806 B = 0.063 C = 0.010 D = 0.063 G= 0.010 k_1= 0.007	(0.741 ÷ 0.871) (-0.002 ÷ 0.128) (-0.058 ÷ 0.072) (-0.002 ÷ 0.128) (-0.058 ÷ 0.072) (-0.058 ÷ 0.072)	t = 60 ^{0}C, v = 3 m/s	A= 1.103 B =-0.073 C = 0.023 D =-0.073 G= 0.023 k_1= 0.023	(1.046 ÷ 1.160) (-0.130 ÷ -0.016) (-0.033 ÷ 0.080) (-0.130 ÷ -0.016) (-0.033 ÷ 0.080) (-0.033 ÷ 0.080)
t = 50 ^{0}C, v = 1 m/s	A = 0.084 B = 0.915 C = 0.015 D = 2.456E-07 G= -0.054 k_1= 0.177	(0.077 ÷ 0.092) (0.908 ÷ 0.923) (0.007 ÷ 0.022) (-0.007 ÷ 0.007) (-0.062 ÷- 0.047) (0.170 ÷ 0.185)	t = 70 ^{0}C, v = 1 m/s	A= 1.473 B =-0.243 C = 0.028 D =-0.243 G= 0.028 k_1= 0.028	(1.435 ÷ 1.511) (-0.282 ÷ -0.205) (-0.010 ÷ 0.067) (-0.282 ÷ -0.205) (-0.010 ÷ 0.067) (-0.010 ÷ 0.067)
t = 50 ^{0}C, v = 2 m/s	A = 0.170 B = 0.415 C = 0.015 D = 0.415 G= 0.015 k_1= 0.114	(0.160 ÷ 0.179) (0.406 ÷ 0.425) (0.006 ÷ 0.025) (0.406 ÷ 0.425) (0.006 ÷ 0.025) (0.104 ÷ 0.123)	t = 70 ^{0}C, v = 2 m/s	A= 1.424 B =-0.219 C = 0.034 D =-0.219 G= 0.034 k_1= 0.034	(1.371 ÷ 1.477) (-0.272 ÷ -0.166) (-0.019 ÷ 0.087) (-0.272 ÷ -0.166) (-0.019 ÷ 0.087) (-0.019 ÷ 0.087)
t = 50 ^{0}C, v = 3 m/s	A = 0.969 B =-0.014 C = 0.019 D =-0.014 G= 0.019 k_1= 0.019	(0.913 ÷ 1.024) (-0.07 ÷ 0.041) (-0.037 ÷ 0.074) (-0.07 ÷ 0.041) (-0.037 ÷ 0.074) (-0.037 ÷ 0.074)	t = 70 ^{0}C, v = 3 m/s	A= 1.150 B =-0.084 C = 0.033 D =-0.084 G= 0.033 k_1= 0.033	(1.098 ÷ 1.201) (-0.135 ÷ -0.032) (-0.019 ÷ 0.084) (-0.135 ÷ -0.032) (-0.019 ÷ 0.084) (-0.019 ÷ 0.084)

The values of parameters and 95% confidence intervals of the estimated parameters were determined by using the nlparci function of the Matlab Toolbox [22].

As shown in Figure 3, a good match was found between experimental and calculated values with the Modified Henderson-Pabis model. Analyzing the residues of the models M05 the plots of the residues against the experimental values did not indicate abnormal distribution for these models (not presented here).

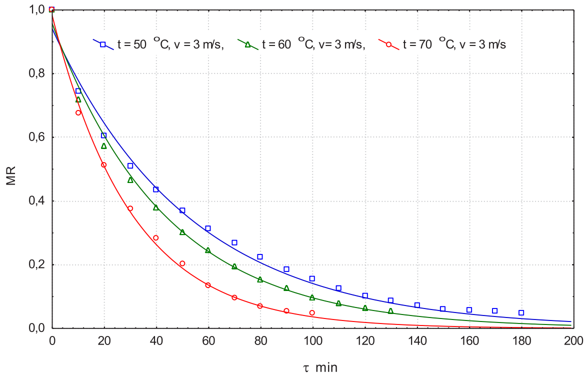

Figure 3. Experimental and predicted moisture ratio for different air drying temperatures and different air drying velocities

4. Conclusions

- In the presented paper, the drying kinetic of banana slices was investigated. For approximation of experimental data, twenty-four existing thin-layer drying models were used. In order to estimate and select the best thin-layer drying model several statistical criteria were used. From the performed statistical analysis it was concluded that eight models (M05, M14, M07, M10, M21, M09, M08 and M24) have the highest average coefficient of determination i.e. higher average performance index in comparison to the other models.

-From the second and third statistical criterion, only three models have lower values of χ^2 and z_r than the tabled critical value. Those facts indicate that those models are an accurate tool for approximation of the experimental drying data of banana. But, based on the results on the first statistic criterion, the highest value of the performance index φ, has the Modified Henderson-Pabis model. From this fact, this model exhibited the best ability to correlate to the experimental drying data.

- This model is able to explain 99.9% of the variation of MR when the experimental conditions and moisture content of drying material are known.

5. References

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