ANALYTICAL DETERMINATION OF THE DRYING CHARACTERISTICS OF *LABEO ROHITA*

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Abstract: Drying kinetics of fresh Rohu (*Labeo Rohita*) fish was experimentally investigated and studied in this paper. The experiments were performed on fish cut in butterfly style at regulated temperatures of 50º C, 60º C and 70º C to determine the effect of drying air temperature at constant air velocity of 3.6 m/s. Twelve well established mathematical drying models were compared on the basis of their correlation coefficient (R), root mean square error (RMSE) and reduced chi-square (χ^2) to establish a suitable model for drying of *Labeo Rohita*. The results showed that the correlation coefficient value was found to be higher than 0.99948, and the values of root mean square error and reduced chi-square were lower than 0.049446 and 0.002657 respectively in the Midili et al. model which was concluded to be the best in describing the drying behaviour of *Labeo Rohita* followed by the Wang and Singh model.

Index Terms **- Mathematical models, Drying, Drying curves, Labeo Rohita**

I. INTRODUCTION

Drying is a process involving transient heat, mass and momentum transport (Haghi et al, 2008). In today's market of food supply chain, dried foods are in high demand. In the whole of dried food industry, grains constitute the highest share followed by fruits, vegetables and meat. This process mainly targets on lowering and reducing the moisture content in order to avoid and slow down the spoilage of the food due to action of microorganism (Ahmed *et al*, 2013). Moreover, it provides lighter weight and smaller volumes for transportation and storage.

Labeo Rohita is known as the major Indian carp. It is a species of the carp family which is extensively used in the aquaculture. This fish finds widespread usage in both fresh and dried form. Removal of moisture from the flesh of the fish helps preserve it and edible for longer period of time. The basic principle of drying involving fish or any meat is that the action of the muscle catalyst and microorganism is decreased to a base through the denial of the water content in open sun drying in a traditional method (Marine et al, 2015). Numerical demonstrating of the drying procedure and equipment permit the structure architects to pick the appropriate working conditions and estimate the drying equipment and drying conditions likewise. (Gunhan et al, 2005).

Several studies have been made by different researchers for mathematical modelling of different drying products such as : Sardine fish (Darvishi et al, 2013), Tilapia fish (Guan et al, 2013), Chicken meat (Juneja et al, 2007), Pork meat (Graiver et al, 2009), Bay leaves (Gunhan et al, 2005), Sultana grape (Yaldiz et al, 2001), Kiwifruit (Mohammadi et al, 2008), Brown seaweed (Fudholi et al, 2012), Eggplant (Brasiello et al, 2013), Plum (Goyal et al, 2007), Sweet potato (Diamante et al,1993 and Doymaz 2011), Tomato (Taheri-Garavand et al, 2011).

The main objective of this paper is to estimate the values for constants of selected model equations and to develop a suitable mathematical model for drying characteristics of *Labeo Rohita*.

II. MATERIALS AND METHOD

2.1 Sample preparation

Labeo Rohita with average weight of 700-900g was purchased from the local fish market of Dehradun, Uttarakhand, India. The fish was headed & gutted such that around 500 g of it remained which was then rinsed in clean water. Prior to the drying experiment it was salted to retain the water out of the fish which was then blotted using an absorbent paper. It was then weighed in a digital weighing machine with a least count of 0.1g before starting the drying process.

2.2 Drying Process

Experiments were performed at three temperature points of 50ºC, 60ºC and 70 °C in a laboratory sized convective hot air dryer (Genetic India Pvt. Ltd.) with PID-93D temperature controller of least count 0.1°C. To determine the effect of drying air temperature, three experiments were conducted at a constant air velocity of 3.6 m/s, which was measured by using a digital anemometer of least count 0.1m/s. Before starting the experiment, the system was run for at least one hour to obtain steady state conditions. The fish after being prepared for the drying was then spread on to a thin steel mesh with minute holes to circulate constant air flow for even drying of the fish which was cut in butterfly style. The weight of the fish was measured after an interval of one hour and dried until the weight measured was found to be almost constant.

2.3 Modelling of drying curves

Twelve different mathematical models with distinct expressions for defining drying crying curves as mentioned in Table 1 have been used to plot the drying curves to obtain the drying curves. The initial moisture content on dry weight basis of Labeo *Rohita* was found to be 190.18% and was reduced to the final moisture content of 1.14%.

Table 1: Mathematical models used for obtaining drying curves of *Labeo Rohita*

Model no.	Model name	Model equation	References
1	Lewis	$M_R = \exp(-kt)$	(Lui et al,1997, Callaghen et al,1971)
2	Page	$M_R = \exp(-kt^n)$	(Agarwal et al,1997, Zhanget al,1991)
3	Modified page	$M_R = \exp[(-kt)^n]$	(Overhults et al,1973, White et al,1981)
4	Henderson and Pabis	$M_R = a\exp(-kt)$	(Henderson and Pabis,1961)
5	Yagcioglu et al.	$M_R = a\exp(-kt) + c$	(Yagcioglu et al,1999)
6	Two-term	$M_R = a\exp(-k_0 t) + b\exp(-k_1 t)$	(Henderson,1974, Rahman et al,1998)
7	Two-term exponential	$M_R = a\exp(-kt) + (1-a)\exp(-kat)$	(Sharaf-Elden et al,1980))
8	Wang and Singh	$M_R = 1 + at + bt^2$	(Wang and Singh,1978)
9	Diffusion approach	$M_R = a\exp(-kt) + (1-a)\exp(-kbt)$	(Kassem,1998)
10	Verma et al.	$M_R = a\exp(-kt) + (1-a)\exp(-gt)$	(Verma et al,1985)
11	Modified Henderson and Pabis	$M_R = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	(Karathanos,1999)
12	Midili and Kucuk	$M_R = a\exp(-kt^n) + bt$	(Midili et al,2002)

In the literature, there are few measurable test methods used to factually assess the performance of the drying models (Gunhan et al, 2005). The formulas used for calculations are as follows:

2.3.1 Moisture Ratio

The percentage of moisture ratio was determined on dry weight basis using the formula

$$M_R = \frac{M - M_{exp}}{M_0 - M_{exp}} \qquad (1)$$

Which was then simplified to M/M_0 because M_0 was much larger than M_{exp} (Goyal et al, 2007)

2.3.2 Correlation coefficient (R)

The correlation coefficient, R can be used to test the linear relation between measured and estimated values, which can be calculated from the equation,

$$R^2 = \frac{\sum_{i=1}^{N}(M_{r_i} - Mr_{pre,i}) * (Mr_i - Mr_{exp,i})}{[\sum_{i=1}^{N}(Mr_i - Mr_{pre,i})^2] * [\sum_{i=1}^{N}(Mr_i - Mr_{exp,i})^2]} \qquad (2)$$

the experimental moisture ratio is denoted by $M_{r\ exp,i}$, the predicted moisture ratio is denoted by $M_{r\ pre,i}$ and N is the total number of observations. R^2 is the coefficient of determination.

2.3.3 Mean Bias Error (MBE)

The mean bias error is given as:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(Mr_{pre,i} - Mr_{exp,i}) \qquad (3)$$

2.3.2 Root Mean Square Error (RMSE)

The root mean square error may be calculated by the following equation. The value of RMSE is always positive, where zero is the value obtained in the ideal case.

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{N}(Mr_{pre,i} - Mr_{exp,i})^2\right]} \qquad (4)$$

2.3.3 Reduced Chi-Square (χ^2)

The reduced chi-square may be calculated by the following equation. The better fitness of the model is defined by lower value of reduced χ^2,.

$$\chi^2 = \frac{\sum_{i=1}^{N} Mr_{exp,i} - Mr_{exp,i})^2}{N-n} \qquad (5)$$

2.3.4 Model Efficiency (EF)

The efficiency of the model is calculated using the following equation (Mohammadi et al, 2008)

$$EF = \frac{\sum_{i=1}^{N}(MR_{i,exp} - MR_{i,expmean})^2 - \sum_{i=1}^{N}(MR_{i,pre} - MR_{i,expmean})^2}{\sum_{i=1}^{N}(MR_{i,exp} - MR_{i,expmean})^2} \qquad (6)$$

The acceptability of a model depends on the higher value of efficiency.

III. RESULT AND DISCUSSION

Figure 1 shows the changes in the moisture proportions of Labeo Rohita with drying time. From Fig.1 it is clear that the moisture content decreases with time. The drying of fish mainly occurred in the falling rate period. In the initial few hours of starting the experiment, the moisture content of the fish decreased more compared to the final hours where the difference in weight of the fish was found to be only a few grams if not consistent, indicating not much moisture had remained in the fish. From Fig.2 it can be observed that the higher drying temperature decreased the time required for drying from 50 h to 17 h.

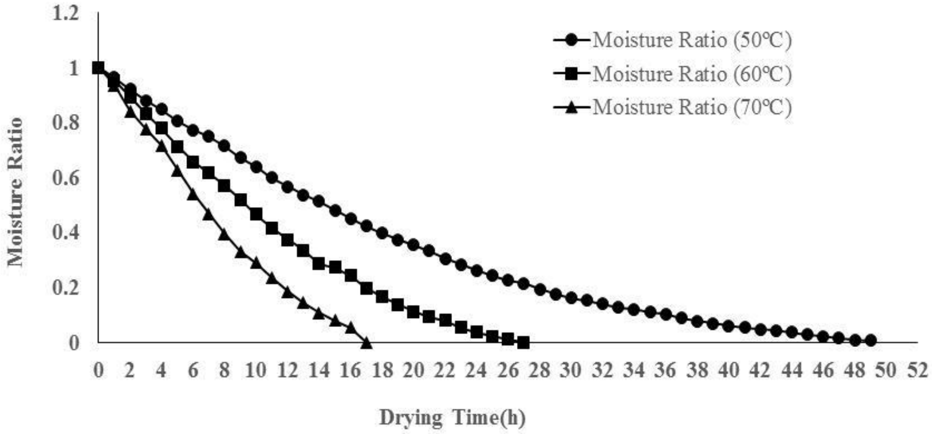

Fig.1. Relation between moisture ratio and drying time at various temperatures

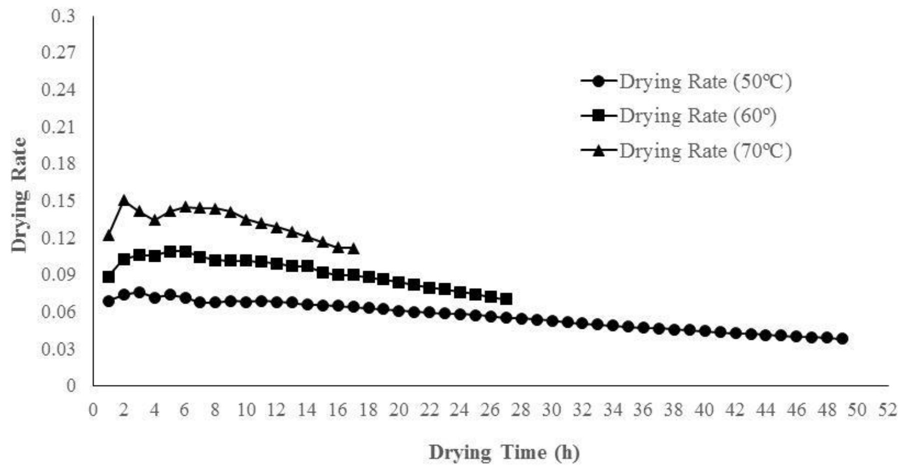

Fig.2. Drying rate versus drying time of Rohu fish

The moisture ratio of dried *Labeo Rohita* fish at various drying air temperatures were fitted in twelve mathematical models and in the several statistical test methods results of statistical analysis. The acceptability of drying model was based on the low values of chi-square (χ^2) and Root Mean Square Error (RMSE) and higher value of correlation coefficient (R). The results showed that in all drying temperatures the models that best fitted the mentioned conditions were the Midili drying model and Wang and Singh model which was in agreement to previous studies conducted on different fish species by Darvishi et al (2013) and Bello et al (2016). The statistical regression results including model constants, correlation coefficient, root mean square error and reduced chi-square obtained using the Midili model and Wang and Singh model have been shown in Table 2 and Table 3 respectively. The average correlation coefficient of Midili model 0.9997033 was 1.00041359 times as much as that of Wang and Singh model 0.99929. Therefore it was concluded that Midili model was superior to the Wang and Singh model in explaining the drying process of *Labeo Rohita*. Figure 3-5 depicts the relation between experimental moisture ratio and predicted moisture ratio in case of Midlil model at the three temperature points. The calculated values obtained using various models at the three temperatures has been arranged in Table 4-6.

Table 2: Values of the drying constants and coefficients of the Midili et al. model

Temperature (°C)	k	n	a	b	Correlation Coefficient (R)	Root Mean Square (RMSE)	Reduced Chi-Square (χ^2)
50	-0.026428	1.20743	0.986816	-0.001009	0.99987	0.049446	0.002657
60	-0.04025	1.226144	0.992316	-0.0041	0.99976	0.006715	5.29421E-05
70	0.052592	1.295695	0.99574	-0.00664	0.99948	0.010129	0.000132

Table 3: Values of the drying constants and coefficients of the Wang and Singh model

Temperature (°C)	a	b	Correlation Coefficient (R)	Root Mean Square (RMSE)	Reduced Chi-Square (χ^2)
50	-0.040593	0.000423	0.99966	0.007737015	6.623556E-05
60	-0.062827	0.0009433	0.99964	0.008268811	7.38431E-05
70	-0.08646	0.001628	0.99857	0.01679	0.000317

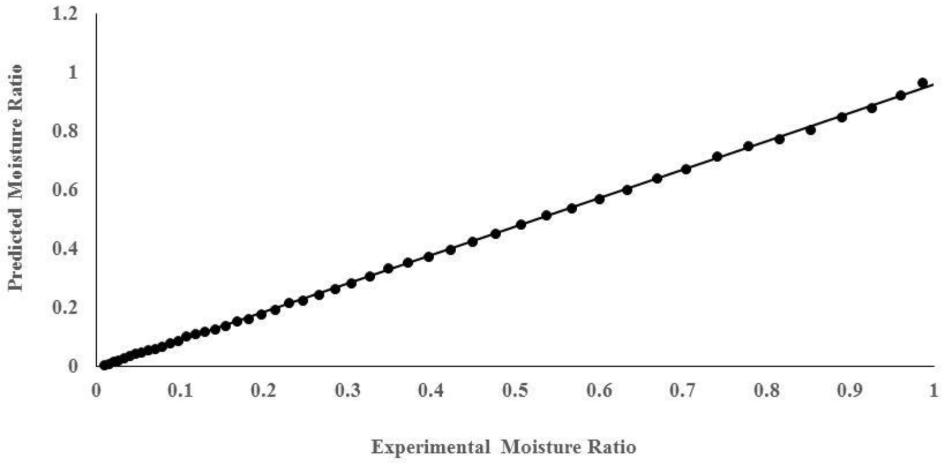

Fig. 3. Experimental and predicted moisture ratio at 50ºC air temperature for Midili et al, model

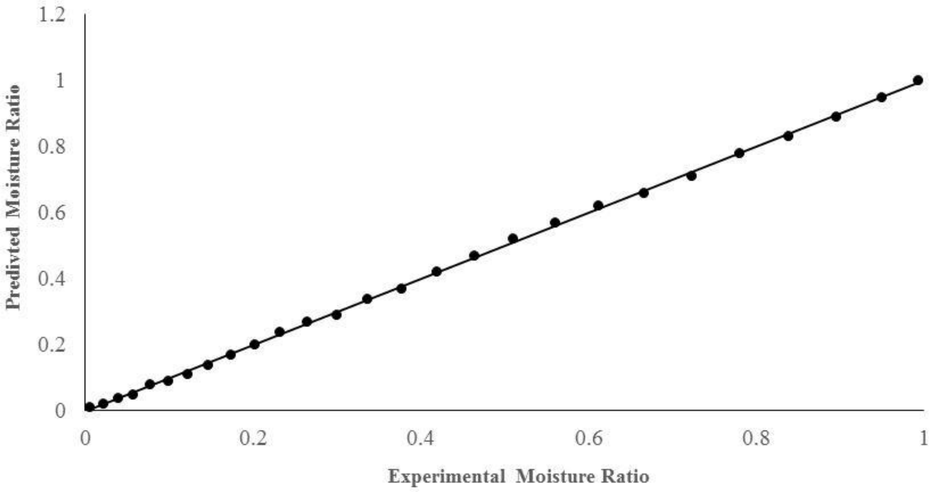

Fig. 4. Experimental and predicted moisture ratio at 60ºC air temperature for Midili et al, model

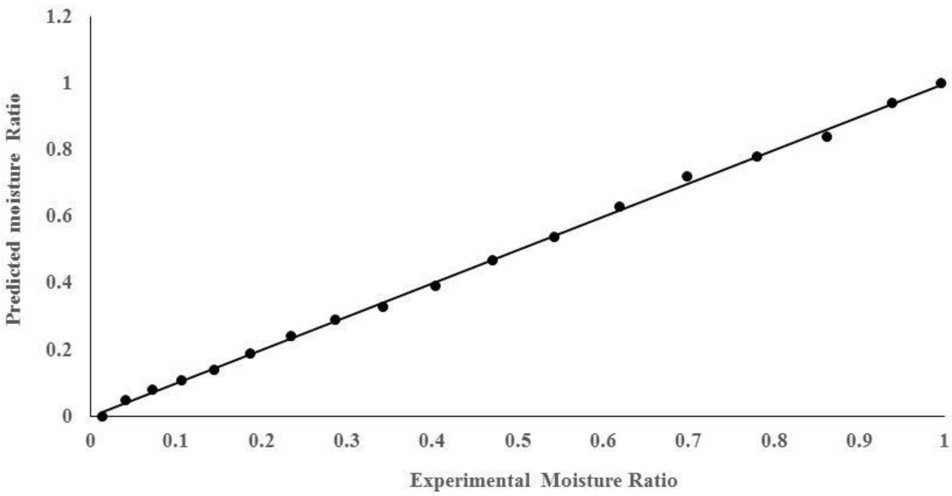

Fig. 5. Experimental and predicted moisture ratio at 70ºC air temperature for Midili et al, model

Table 4: Results of statistical analysis on the modeling of drying *Labeo Rohita* at 50ºC.

Model No.	Model Constant	Correlation Coefficient (R)	Mean Bias Error (MBE)	Root Mean Square Error (RMSE)	Reduced Chi-square ($\chi 2$)	Efficiency (EF)
1	k = 0.054961	0.98984	0.002983	0.041763	0.00178	0.980178
2	k=0.o23647374, n=1.277062	0.99891	-0.004226	0.013491	0.00019	0.99795
3	k=0.234437, n= 0.234437	0.98984	-0.00307	0.042239	0.001858	0.974075
4	k=0.059135, a=1.077078	0.99321	-0.008691	0.034557	0.001244	0.985249
5	k=0.041756, a=1.189923, c= -0.162827	0.99930	0.00300082	0.078574	0.000131	0.998599
6	k_o=0.059135, k_1=0.059135, a= 0.538539, b=0.538539	0.99321	-0.008691	0.244355	0.001298	1.014751
7	k= 19.52639, a=0.002801	0.98959	-0.00349	0.042763	0.001905	0.973277
8	a= -0.040593, b= 0.000423	0.99966	-0.00024	0.007737	6.23E-05	0.999324
9	k= 0.0099322, a= -24.87982, b= 0.972356	0.99896	-0.00433	0.013576	0.000196	0.997885
10	k= 0.05496, a=0.0563, g=0.054961	0.98984	-0.00307	0.042239	0.001898	0.974075
11	k= 0.059133, a=0.358967, b= 0.358967, c=0.358967, g=0.059134, h=0.059124	0.99321	-0.008653	0.034557	0.001357	0.985244
12	k= -0.026428, n= 1.20743, a=0.986816, b= -0.001009	0.99987	-0.006999	0.049446	0.002657	0.971517

Table 5: Results of statistical analysis in the modelling of Labeo Rohita at 60ºC

Model no.	Model Constant	Correlation Coefficient (R)	Mean Bias Error (MBE)	Root Mean Square Error, (RMSE)	Reduced Chi-square ($\chi 2$)	Efficiency (EF)
1	k = 0.122582	0.97716	0.001457	0.066763	0.00472	0.935187
2	k=0.044582, n=1.469056	0.99781	-0.00537	0.020784	0.000486	0.995625
3	k=0.350117, n= 0.350117	0.97716	0.001457	0.066763	0.005014	0.935187
4	k=0.134816, a=1.096493	0.98373	-0.01033	0.056433	0.003583	0.961394
5	k=0.061043, a=1.599775, c= -0.57065	0.99862	-3.40709E-08	0.016509	0.000327	0.997231
6	$?_0$ = 0.134817 $?_1$ = 0.134815, a= 0.548247, b=0.548247	0.98373	-0.01033	0.056433	0.004095	0.963194
7	k= 0.122582, a=0.999988	0.97716	0.001457	0.066763	0.005014	0.935187
8	a= -0.08646, b= 0.001628	0.99857	0.003418	0.01679	0.000317	0.997017
9	k= 0.258654, a= -13.3209, b= 0.936154	0.99679	-0.00597	0.025141	0.000758	0.993399
10	k= 0.122582, a=0.081613, g=0.122582	0.97716	0.001457	0.066763	0.005349	0.935187
11	k= 0.134816, a=0365498, b= 0.365498, c=0.365498, g=0.134816, h=0.134817	0.98373	-0.01033	0.056433	0.00477	0.963194
12	k= 0.052592, n= 1.295695, a=0.99574, b= -0.00664	0.99948	5.0129E-06	0.010129	0.000132	0.998959

Table 6: Results of statistical analysis in the modelling of *Labeo Rohita* at 70ºC

Model No	Model Constant	Correlation Coefficient (R)	Mean Bias Error (MBE)	Root Mean Square Error (RMSE)	Reduced Chi-square ($\chi 2$)	Efficiency (EF)
1	k = 0.0876267	0.98126	0.0014607	0.0581759	0.0035146	0.9504815
2	K=0.0318973, n=1.3966612	0.99746	-0.0055314	0.0210762	0.0004797	0.99533232
3	K=0.084859, n= 1.3966687	0.99746	-0.005534	0.0210763	0.0004797	0.9953232
4	K=0.0957483, a=1.0930788	0.98662	-0.008482	0.0490367	0.002597	0.971512
5	K=0.0517619, a=1.3930515, c= -0.367614	0.99926	-0.00086	0.0112683	0.0001428	0.9986396
6	$?_0$ = 0.0957483 $?_1$ = 0.0957483, a= 0.5465393, b=0.5465394	0.98662	-0.008482	0.0490367	0.0028228	0.971512
7	K= 0.0876267, a=0.9999911	0.98126	0.0014607	0.0581759	0.0036552	0.9504815
8	a= -0.062827, b= 0.0009433	0.99964	0.0015733	0.008268811	7.38431E-05	0.9992536
9	K= 0.1763306, a= -9.757313, b= 0.9215609	0.99671	-0.00559	0.023731	0.0006336	0.9938844
10	k=0.0876266, a=0.110444, g=0.0876267	0.98126	0.0014607	0.0581759	0.0038075	0.9504815
11	k= 0.0957484, a=0.3643597, b= 0.36436, c=0.36436, g=0.095748, h=0.095748	0.98662	-0.008482	0.0490367	0.0030916	0.971512
12	k= -0.04025, n= 1.226144, a=0.992316, b= -0.0041	0.99976	-0.000397	0.006715564	5.29421E-05	0.999519

IV. CONCLUSION

In this study a model has been developed to predict heat and momentum transfer in *Labeo Rohita.* The data obtained were fitted into twelve different drying models. On comparing outcomes obtained by different models the results showed that the correlation coefficient value was found to be higher than 0.99948 and the values of root mean square error and reduced chi-square were lower than 0.049446 and 0.002657 respectively in the Midili et al. model . Thus it was concluded that Midili et al. model satisfactorily explained the drying behaviour of *Labeo Rohita* at constant air velocity of 3.6m/s. Another model worth mentioning is the Wang and Singh model which also gave optimum result while the model that was found to be least fitting was Verma et al. model .

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