Empirical Investigation of Thin-Layer Dehydration of Guava Slices

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ABSTRACT

The main aim of the study was to analyze the drying process utilizing the thin-layer models suggested by Lewis, Page, and Henderson and Pabis. The guava fruit was meticulously prepared and subsequently diced into small pieces measuring 0.4 cm, 0.6 cm, and 0.8 cm for the drying process. Three distinct temperatures—60°C, 70°C, and 80°C—were employed during this drying session. The graph of moisture ratio against time showed the falling rate period. It was observed that drying temperature and slice thickness had effect on the rate of drying. A three-model statistical analysis was crucial to guarantee the reproducibility of the drying behavior. In all temperature ranges analyzed, the page model consistently offered the most compelling explanation for the drying process of guava fruit with highest value of R^2 was 0.9898, RMSE of 0.03077 and SSE value of 0.009466 at drying temperature of 80^oC and slice thickness of 0.6cm.

Keywords: Thin-layer drying, guava fruit, hot air drying, drying models, temperature

INTRODUCTION

Guava (Psidium guajava L.) is a tropical fruit tree belonging to the Myrtaceae family [1] and is believed to have originated in Peru before spreading to other tropical and subtropical regions [2]. The tree thrives in a wide variety of climatic conditions and soil types, making it a widely cultivated fruit across many developing countries. Guava is nutritionally important: it is exceptionally rich in vitamin C [5], dietary fibre, antioxidants, and minerals, and its outstanding flavour has earned it the classification of a "super-fruit" [6,7,8].

Despite its nutritional and economic value[9], guava fruit deteriorates rapidly due to its high moisture content, soft texture, and intense metabolic activity. The fruit's succulent nature makes it highly susceptible to insect attack and microbial spoilage. Under ambient conditions, guava has a shelf life of only 2–3 days, after which it undergoes rapid quality degradation [10,11]. This poses major challenges for farmers, processors, distributors, and consumers, particularly in tropical regions where post-harvest losses are already significant. Consequently, there is a need for effective preservation technologies that extend shelf life while maintaining nutritional and sensory attributes.

Drying is one of the most widely used methods for fruit preservation because it reduces water activity, concentrates nutrients, extends shelf life, and allows easier packaging, storage, and transportation[12,13, 14]. Several mathematical models have been developed to describe the thin-layer drying behaviour of food materials [15]. Among these, thin-layer drying is particularly favoured due to its efficiency, uniform exposure of samples, minimal energy consumption, and reduced quality loss[16,17]. It also allows clear evaluation of parameters such

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as slice thickness, temperature, air velocity, and relative humidity, which significantly influence the drying process.

Understanding the thin-layer drying kinetics of guava is essential for optimizing drying systems, predicting drying behaviour, and guiding the design of industrial dryers. This study aims to generate experimental drying data and apply mathematical modelling techniques to explain the drying behaviour of guava slices. The models investigated include the Lewis model [18], Page model [19], and Henderson and Pabis model [20], which are widely used in fruit and vegetable drying studies.

The research focuses on evaluating how slice thickness, drying duration and drying temperature affect moisture ratio, drying rate, and model performance. By identifying the most suitable thin-layer model, the study contributes to the development of energy-efficient drying processes and supports the potential commercialization of dried guava products. Ultimately, the findings are expected to help reduce post-harvest losses, enhance value addition in the guava value chain, and promote sustainable utilization of tropical fruits. Accurate modelling is vital for designing reliable dryers, minimizing nutrient degradation, and ensuring uniform product quality during dehydration.

Although several studies [20, 21, 22, 23,24] have focused on drying kinetics of fruits, there is inadequate empirical data on thin-layer drying behaviour of guava slices at systematically varied slice thicknesses and temperature combinations. Furthermore, limited studies compare the predictive ability of Lewis, Page, and Henderson & Pabis models for guava under these specific conditions. This study addresses these gaps by experimentally evaluating drying behaviour, fitting models, and identifying the most suitable thin-layer model for guava dehydration.

MATERIAL AND METHODS

Theoretical Principle

The thin layer drying process is governed by both physical and thermal properties of the material and the drying condition. Mathematical models used to explain and predict moisture reduction relating moisture ratio (MR) to drying time were Lewis, Page, and Henderson & Pabis because of their simplicity, accuracy, and wide usage in fruit drying research. Moisture ratio of the process is given as Equation 1

$$MR = \frac{M_t - M_e}{M_0 - M_e} = e^{-kt} \quad 1$$

Where**:**

MR = moisture ratio

M_t = moisture content at time‘t’ (% db.)

M_0 = initial moisture content (% db.)

M_e = equilibrium moisture content (% db.) K = drying constant(mins^{-1}) t = drying time (mins)

Since M_e for hot air drying is assumed to be zero. Equation 1 becomes $MR = \frac{M_t}{M_0}$

The drying curve obtained using the experimental data where fitted using three models

The Lewis Model

The Lewis model is the simplest thin-layer exponential model derived from Fick’s second laws given in Equation 2:

$$MR = e^{-kt} \quad 2$$

The Page Model

The Page model modifies the Lewis equation by introducing an empirical exponent n, which adjusts the drying curve to account for non-linear internal moisture diffusion

$$MR = e^{-kt^n} \quad 3$$

K = drying constant (**mins**$^{-1}$)

t = drying time (mins)

n = exponent

Henderson and Pabis Model

$$MR = ae^{-kt} \quad 4$$

a is a constant

The accuracy of thin-layer drying models is determined using statistical indicators like Coefficient of Determination (R^2) which measures goodness of fit, Sum of Squares Error (SSE(χ^2)) where lower values indicate more accurate predictions, Root Mean Square Error (RMSE) that measures deviation between predicted and experimental values whereas Adjusted R^2 measures level of correctness of predictors in model selection. Models with high R^2 and low SSE/RMSE are considered more suitable.

The best fitted curve indexes used were given in Equation 5 to 7

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(MR_{exp,i} - MR_{exp,i})^2}\right] \quad 5$$

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{(MR_{exp,i} - MR_{pre,i})^2}{N-m}\right) \quad 6$$

$$RMSE = \left(\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right)^{1/2} \quad 7$$

Where$MR_{exp,i}$ = the ith experimental moisture ratio; $MR_{pre,i}$ =the ith predicted moisture ratio; N = number of observations: m = number of constants in the drying models; MR_{pre} = mean of predicted moisture ratio

Experimental Procedure

Fresh guava fruits (1,000 g) were procured from New Market, Enugu, Nigeria. The fruits were sorted to remove damaged or overripe samples, washed thoroughly with clean water, and drained to remove surface moisture. Each fruit was then sliced using a sharp stainless-steel knife and grouped into three thickness categories: 0.4 cm,

0.6 cm, and 0.8 cm, with the thickness of each slice verified using a Vernier caliper to ensure uniformity. A Zenithlab hot-air oven dryer was used for the drying experiments. For each slice thickness, 30 pieces of freshly cut guava were selected. The weights of the 30 slices were separately taken, and the mean value was recorded as the initial mass for that thickness category.

Before loading the samples, the oven was preheated and stabilized at the selected drying temperatures of 60°C, 70°C, and 80°C. The prepared guava slices were then placed in a single layer on drying trays to ensure uniform

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airflow and heat distribution.

During drying, the samples were weighed every 30 minutes using a digital weighing balance. The slices were returned to the oven immediately after each weighing to minimize heat loss. The drying process for each batch continued until successive weight measurements showed no significant difference, indicating that the slices had reached a constant weight.

The recorded weights and drying times were used to calculate the moisture removed and subsequently determine the moisture ratio, drying rate, and other drying parameters required for model fitting.

RESULTS AND DISCUSSION

The impact of moisture ratio in relation to time

Figures 1.1-1.9 showed the graphs of moisture ratio (MR) with time (t) of 0.4cm, 0.6cm and 0.8cm thickness at temperatures of 60 ^{O}C, 70 ^{O}C and 80^{O}C for experimental, Lewis model, Page model and Henderson & Pabis model whereas the summary is presented in Table 1

Table 1 : Sample Regression Analysis for guava at 60,70,80^{0} C for 0.4,0.6,0.8cm Thickness

Model Name	Temperature (^{0}C)	Thickness (cm)	Coefficients				Regression Parameters	
			K	**A**	**N**	**R^2**	**RMSE**	**SSE**
Lewis	60^{o}C	0.8	0.005041			0.8506	0.138	0.2476
		0.6	0.004478			0.8746	0.1207	0.1892
		0.4	0.004518			0.8553	0.1343	0.2526
	70^{o}C	0.8	0.005893			0.903	0.1032	0.1277
		0.6	0.005649			0.8979	0.108	0.1401
		0.4	0.004811			0.8247	1.555	0.2902
	80^{o}C	0.8	0.005107			0.8909	0.1067	0.1252
		0.6	0.004559			0.9336	0.0748	0.06152
		0.4	0.004531			0.8698	0.1154	0.1465
Page	60^{o}C	0.8	0.000027		1.970	0.9668	0.0677	0.0550
		0.6	0.000041		1.862	0.9837	0.0453	0.0246
		0.4	0.000023		1.970	0.9743	0.0587	0.0448
	70^{o}C	0.8	0.000234		1.616	0.9755	0.5411	0.1277
		0.6	0.000113		1.744	0.9893	0.03662	0.1401
		0.4	0.000004		2.331	0.9866	0.04496	0.2902
	80^{o}C	0.8	0.0001522		1.664	0.9734	0.05528	0.03056
		0.6	0.000356		1.480	0.9898	0.03021	0.00947
		0.4	0.000073		1.772	0.9667	0.06126	0.03752
Henderson and Pabis	60^{o}C	0.8	0.006607	1.331		0.9179	0.1065	0.1361
		0.6	0.005879	1.308		0.9452	0.08304	0.0828
		0.4	0.005961	1.332		0.9279	0.9224	0.1258
	70^{o}C	0.8	0.007637	1.311		0.9622	0.06729	0.04981
		0.6	0.007415	1.330		0.9654	0.06568	0.04745
		0.4	0.006326	1.409		0.9252	0.1061	0.1238
	80^{o}C	0.8	0.006519	1.264		0.9474	0.0777	0.0604
		0.6	0.005651	1.206		0.9800	0.04308	0.01856
		0.4	0.005786	1.248		0.9273	0.09046	0.08182

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From Table 1, the R^2 value of 0.4cm, 0.6cm and 0.8cm thickness at temperatures of 60 ^{O}C for Lewis Model was 0.8506 indicating a moderately good fit, but the model did not capture complex drying behaviour. Page Model with $R^2 = 0.967$ is an excellent fit, the model captures the curvature better than Lewis. R^2 for Henderson & Pabis was 0.918 which is good, better than Lewis but not as good as Page model. From the R^2 values Page model fits guava drying data the best**.** Figures 1.1 to 1.3 of Plot of MR vs t of 0.8cm, 0.6cm and 0.4cm thickness at 60^{0}C showed generally exponential curve indicating a that moisture ratio decrease exponentially with time of drying [25,26,27].

Page model flexibility with exponent (n) allows it to accurately model both early rapid drying and slower later stages. Lewis and Henderson & Pabis are simpler and could be used for approximate predictions, but for precision.

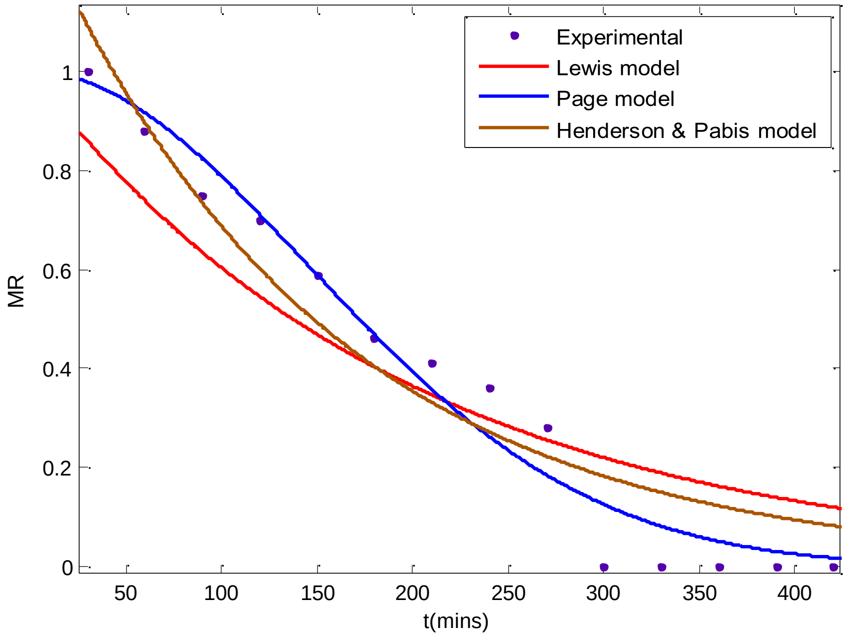

Fig. 1.1 Plot of MR vs t at 0.8cm thickness for 60^{0}C

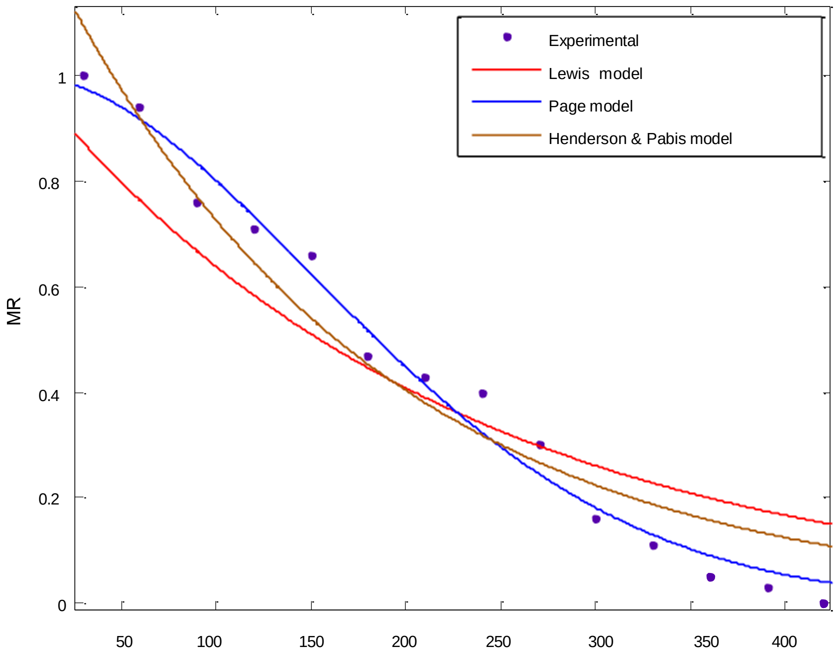

Fig. 1.2 Plot of MR vs t at 0.6cm thickness

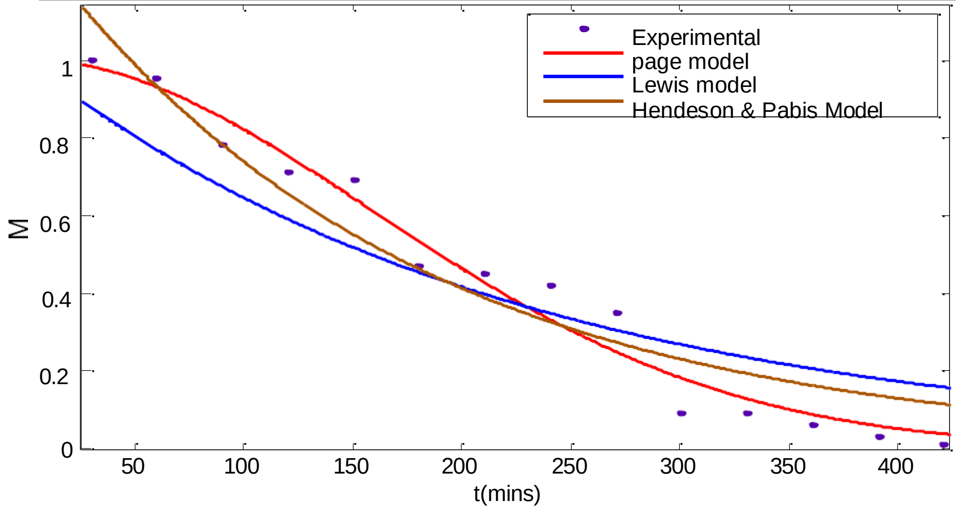

Fig. 1.3 Plot of MR vs t at 0.4cm thickness

Also, from Table 1 the values of R^2 on drying 0.4cm, 0.6cm and 0.8cm thickness at 70 ^{O}C for Lewis model gives a moderate fit (R^2 = 0.875) reasonable, but it may not capture the non-linear aspects of drying for this thinner slice. Page Model (R^2 = 0.9837) was excellent fit and very close to experimental data and better fit than Lewis due to the scaling factor while Henderson & Pabis Model R^2 = 0.945 was very good, but not as precise as Page. RMSE = 0.083 was lower error than Lewis but higher than Page. Figures 1.4 to 1.6 of model fittings for 0.8cm, 0.6cm and 0.4cm thickness at 70^{0}C

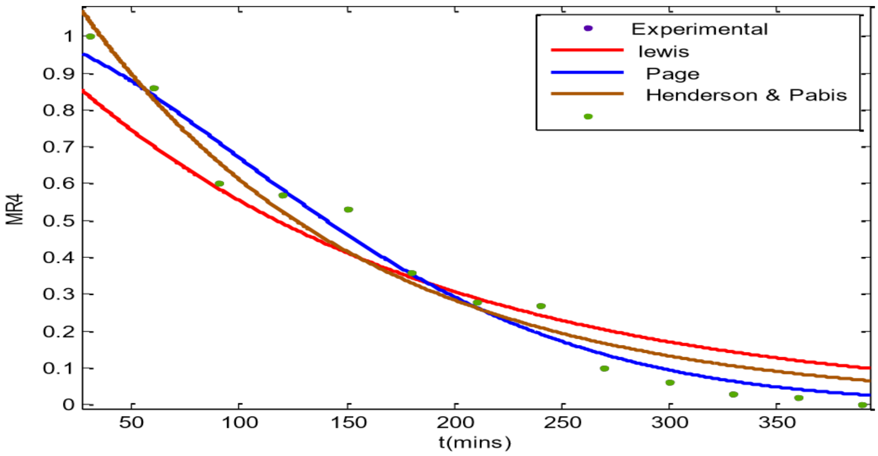

Fig. 1.4 Plot of MR vs t at 0.8cm thickness for 70^{0}C

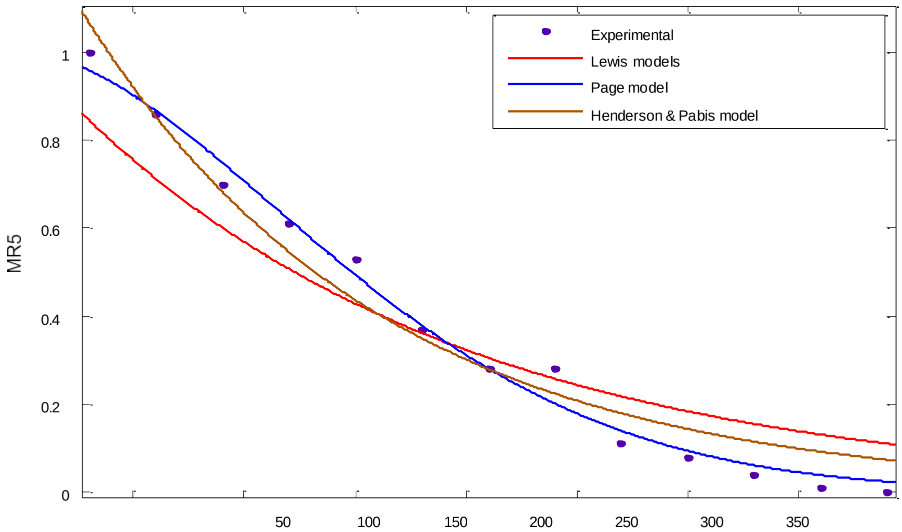

Fig. 1.5 Plot of MR vs t at 0.6cm thickness

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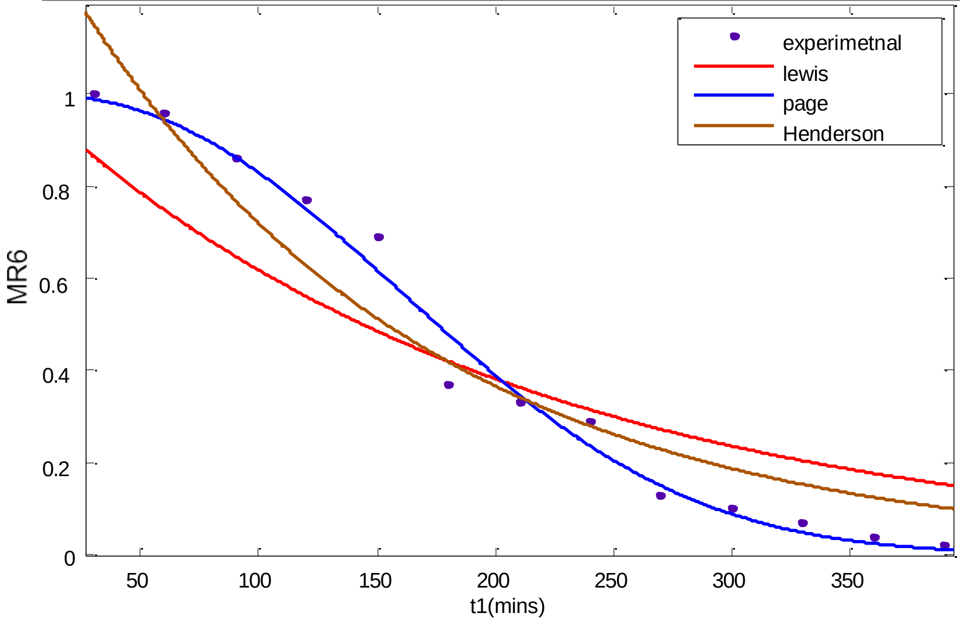

Fig. 1.6 Plot of MR vs t at 0.4cm thickness

From figures 1.4 to 1.6 showed Lewis with simple exponential, moderate fit, Page of best fit and captures non-linear drying while Henderson &Pabis was good fit, simpler than Page. It implies that Page model is the most accurate for predicting the drying of 0.6 cm guava slices, Henderson & Pabis is a good alternative if simplicity is preferred whereas Lewis is the least precise but can give a rough estimate. Both 0.8 cm and 0.6 cm slices show that Page model consistently provides the best fit. The drying exponent (n) decreases slightly with thinner slices (from 1.97 to 1.862), which aligns with the idea that thinner slices dry faster and slightly less non-linearly.

Also, from Table 1 the values of R^2 on drying 04.cm, 0.6cm and 0.8cm thickness at 80 ^{O}C. Lewis model is slightly improved compared to 70 °C (R^2 = 0.8979) due to faster drying at higher temperature. Page Model provides the best fit R^2 = 0.9898 which is excellent and RMSE = 0.0308 is very low error. Also (n = 1.48) at 80^{O}C is lower than at 70 °C (1.744), suggesting drying becomes closer to exponential at higher temperature for 0.6 cm slices. Henderson & Pabis Model is Good fit, slightly worse than Page but better than Lewis. Higher (k) than Lewis (0.004559 to 0.005651) reflects faster drying at 80 °C. From figures 1.7 to 1.9 below showed exponential decrease of moisture ratio with increase in time [28,29].

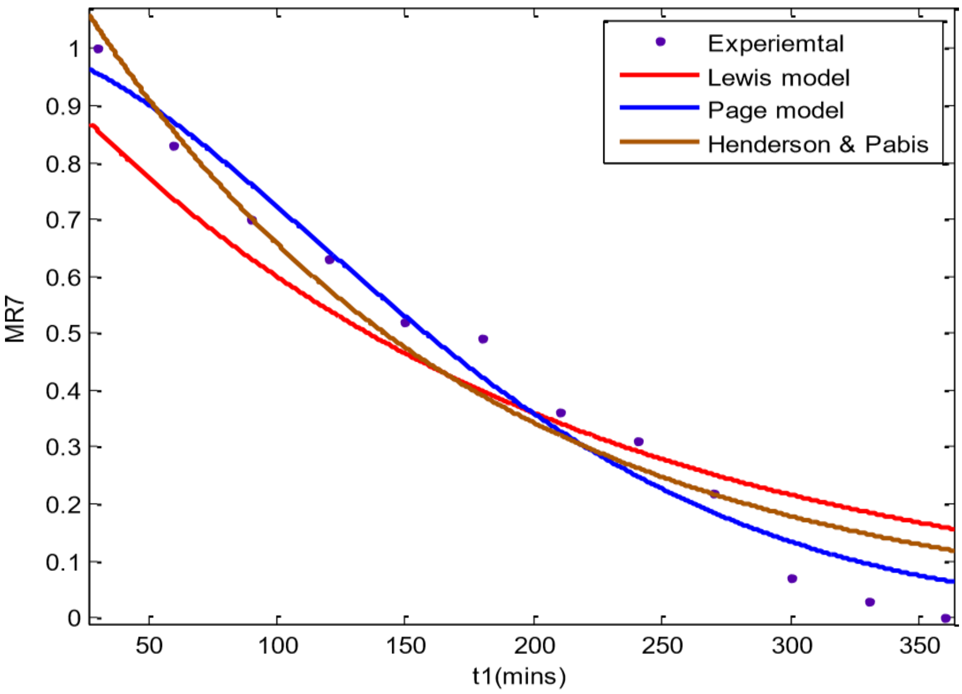

Fig. 1.7 Plot of MR vs t at 0.8cm thickness for 80^{0}C

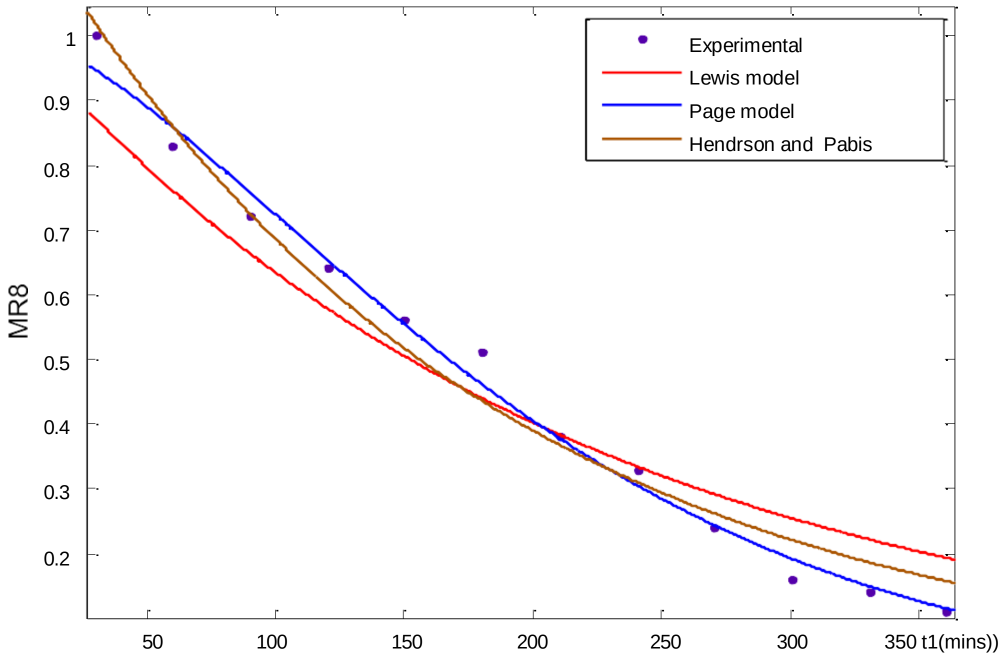

Fig. 1.8 Plot of MR vs t at 0.6cm thickness 80^{O}C

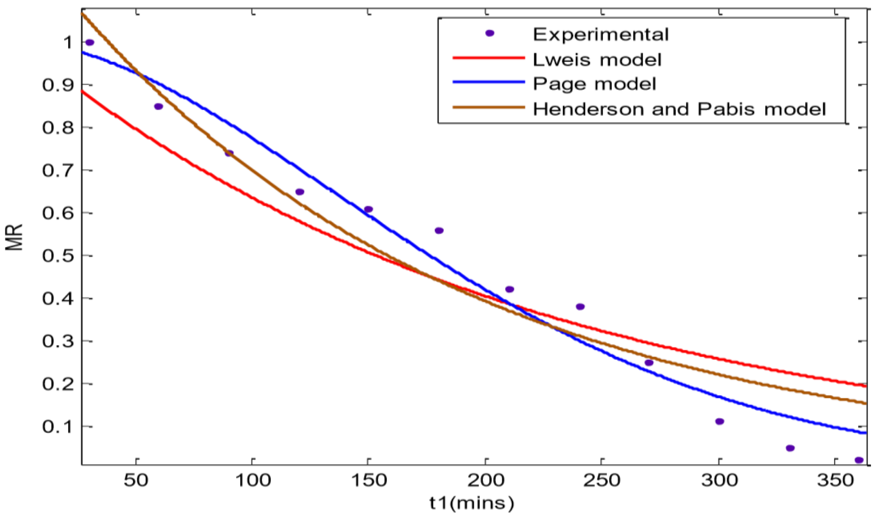

Fig. 1.9 Plot of MR vs t at 0.4cm thickness 80^{O}C

By implication Page model remains the most accurate at High temperature reduces exponent (n) and drying becomes more exponential. Lewis improves slightly but is still the least accurate.

CONCLUSION

Across all temperatures (60–80°C) and thicknesses (0.4–0.8 cm) it can be concluded that Lewis model gave moderate fits with R^2 between 0.82 and 0.90, indicating that simple diffusion can explain part of the drying behaviour. The drying constant (k) increased with temperature, confirming faster moisture removal at higher thermal energy. Thinner slices (0.4 cm) had higher k values than thicker slices (0.8 cm), consistent with reduced diffusion path. However, the Lewis model underestimated the curvature of the drying data, showing that guava drying is not a simple first-order process.

Across all temperatures and thicknesses, the Page model consistently gave the best fit with R^2 values between 0.96 and 0.99, confirming its suitability for guava drying. The exponent n increased 1.5–2.4 indicates a strong non-linear moisture diffusion pattern, typical for fruits with high sugar and pectin. Very low SSE and RMSE values show that the model accurately follows the behaviour of your MR curves. The improvement over Lewis confirms that guava does not follow simple exponential decay. Thus, the Page model best represents the empirical drying kinetics of guava slices.

For Henderson and Pabis Model Good fits were obtained, with R^2 between 0.92 and 0.95, showing better accuracy than Lewis. The coefficient a ≈ 1.2–1.4 indicates non-ideal initial conditions, likely due to guava's soft tissue, high initial surface moisture, rapid initial evaporation k values were consistently higher than in the Lewis model, reflecting better representation of the empirical data. Although it performs better than Lewis, it is still less accurate than the Page model. Drying of guava occurs entirely in the falling-rate period, controlled by internal moisture diffusion.

Higher temperatures (70–80°C) increase the drying constant k, confirming enhanced diffusion. Thinner slices dry faster due to shorter diffusion paths while the drying mechanism is non-linear, validating advanced models like Page.

The Page model provided the best theoretical and empirical description of moisture behaviour.

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