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Drying Behaviour and Kinetic Modelling of Shweta and Purple Guava (Psidium guajava L.) Leaves under Various Drying Techniques

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Abstract

Guava is a delicious fruit loaded with essential nutrients; in addition, its leaves are equally beneficial. It contains various nutritional and bioactive compounds that offer a range of health benefits and can be used as a complement to medicines. The experiments were carried out and replicated thrice to evaluate the concentration of bioactive compounds in the dried leaves. Guava leaves were dried in shade under ambient conditions as well as using tray (50°C, 60°C and 70°C) and microwave drying (360 W, 540 W and 720 W). To explain the drying process, nineteen available models were evaluated for the best fit. The drying data were best explained by the Page model and Verma model in shade drying; Midilli and Kuck model, as well as the Jena and Das model at 70°C tray drying; Midilli and Kuck and Logarithmic model for 360 W microwave drying of Purple guava and Shweta guava, respectively. In both guava varieties, L*, a*, b* values were higher in fresh leaves in comparison to shade, tray and microwave dried leaves. The flavonoid contents for fresh Purple and Shweta guava leaves were 49.81 and 31.71 mg QE/ mg dry weight, respectively in comparison to 208.62 mg QE/mg dry weight & 84.79 mg QE/mg dry weight for Purple and Shweta dried leaves.

Keywords: Shweta; Purple Guava; Leaf drying; Drying techniques; Modelling

Introduction

Guava (Psidium guajava L.) belongs to the Myrtaceae family (Kaneria et al., 2011) and is native to tropical America. Due to its wide range of adaptability to soil and climatic conditions, it is grown commercially in tropical and subtropical regions across the world (Singh, 2005). In India, guava is the fourth most important fruit crop after mango, citrus and banana with 265 thousand hectares of cultivated area and an annual production of 4054 thousand MT (Kumar et al., 2019). In the state of Punjab, guava is the 2nd most important fruit crop grown commercially after citrus (Kocher, 2011). The leaves are also known to have several health benefits, such as curing vomiting, diarrhoea, sore throats and inflamed intestinal problems (Gutierrez, 2008). The leaves when chewed are known to give relief to mouth sores and bleeding gums (Kukreja et al., 2012). Anti-viral, anti-inflammatory, anti- plaque and anti-mutagenic activities of guava leaves are also reported by Naseer et al., (2018). The fresh leaves are perishable. The moisture-induced enzymatic and microbiological activities; poor post-harvest handling, delayed transit, and improper storage are the possible reasons for post-harvest losses (Babu et al., 2018). Hence, to preserve the leaves in dried/ powder form with shelf-stable water activities, an adequate drying process is a necessary pre-requisite. The drying is generally done either under natural or artificial conditions. The goal of the optimal leaf drying process is to achieve the required final moisture content while preserving the same high level of nutrients as fresh leaves.

Extensive work on utilization of guava leaf extracts for medicinal purposes has been reported over the past decades, however, limited research information is available on variety specific drying approaches. Thus, keeping in view the guava leaves as a potential source of bioactive compounds, their extensive use reported for medicinal purposes and scope for expanding guava cultivation within the state of Punjab, the present investigation was planned with two guava varieties, namely Shweta and Purple Guava with the objective to evaluate different drying methods namely shade, tray and microwave drying.

Materials and methods

Experimental Site

The present study was carried out in the Post harvest Laboratory, Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana during the year 2020-22.

Experimental Plant Material

The fully mature leaves of two guava varieties namely Shweta and Purple Guava were obtained from the Fruit Research Farm, Punjab Agricultural University (PAU), Ludhiana. The trees of these guava varieties were being maintained as per PAU's recommended Package of Practices for guava cultivation in the state. The trees of the Shweta cultivar are the spreading type. The trees of the Purple Guava are the upright type with purple-fleshed mature fruits and dark purple skin colour, while the leaves are dark red to purple in colour.

Experiment details

The present research was performed in two parts, with the first dedicated to the study of drying behaviour of guava leaves, while the second part involved the evaluation of the quality of the dried product via the extraction and quantification of its flavonoids from the dried leaf powders.

Physical properties of Guava leaves

The guava leaves (Fig. 1) from 5-15 nodes from the shoot tip, free from any visible insect pest or disease damage were selected from both guava varieties namely Shweta and Purple guava. The physical properties like leaf size and weight were measured. Twenty leaves per replication were taken. The data was recorded for three replications. The length, width and thickness of guava leaves were measured with a vernier calliper (DIGIMATIC). The leaf weight was measured using a weighing balance (WENSAR, An ISO 9001: 2015 Company). Average weight was calculated for each treatment and expressed in g. The selected leaves were washed with running tap water to remove any dirt particles before proceeding further.

a) Purple Guava leaves **(b) Shewta leaves**

Fig 1. Pictorial representation of guava leaves used in the current study

Initial Moisture Content of Fresh Leaves

The moisture content of freshly harvested leaves of both varieties of Guava has been evaluated using hot oven method as per AOAC 934.06. Five grams of Guava leaves evenly spread over a dish were used for this purpose. These weighed samples were kept in oven at 135°C for 2 hours and again weighed. The difference in the weights reflects the moisture content of the leaves. The moisture content of Shweta and Purple Guava leaf powder was measured by using an HR73 Halogen Moisture analyzer.

Methods for Drying

Three methods namely Shade drying (using ambient air), Tray Drying, and Microwave drying have been used during the study. In case of tray drying, three different temperatures (50°C, 60°C, 70°C) were considered while for microwave drying, three different incident powers (360, 540, 720 W) were used, to obtain the best possible quality dried product.

Moisture ratio

The moisture ratio (MR), is the ratio of free water to be removed at time t to the total free water initially available (Babalis and Belessiotis, 2004). MR was calculated using Equation (1)

$$MR = (M_t - Me) / (Mo - Me) \quad (1)$$

Where M_t is the moisture content at time t, Me is the equilibrium moisture content and Mo is the initial moisture content (Akpinar et al., 2003).

Colour measurements

Leaf colour was determined by two readings on the two different symmetrical faces of the leaf, each in duplicate, using a Hunter Colourimeter, calibrated with a white standard tile. The colour brightness coordinate *L* measures the whiteness value of a colour and ranges from black at 0 to white at 100. The chromaticity coordinate *a* measures red hues when positive and green hues when negative, and the chromaticity coordinate *b* measures yellow hues when positive and blue hues when negative. Also, the chroma C (equation 2) and hue angle α (equation 3) were calculated from the values for L a b and used to describe the colour change during drying.

$$\text{Chroma} = a^2 + b^2 \quad (2)$$

$$\text{Hue angle} = \tan^{-1}(b/a) \quad (3)$$

Compositional/ Analytical Studies

Determination of total flavonoid content

The total flavonoid content of guava leaves was determined following the method described by Chang et al. (2002), with slight modifications. The reagents used were:

a) **Aluminium chloride solution (1.2%)**, prepared by dissolving 1.2 g of aluminium chloride in distilled water and making up the volume to 100 mL.
b) **Potassium acetate solution (120 mM)**, prepared by dissolving 1.6 g of potassium acetate in distilled water and making up the volume to 100 mL.

For the extraction of flavonoids, 500 mg of guava leaf powder was refluxed with 10 mL of hot 80% methanol for 1 hour. The mixture was then filtered, and the final volume of the extract was adjusted to 10 mL with hot methanol. This extract was used for the subsequent flavonoid analysis. To determine total flavonoid content, a 3.0 mL reaction mixture was prepared containing 1.0 mL of the diluted extract, 1.0 mL of methanol, 0.5 mL of 1.2% aluminium chloride, and 0.5 mL of 120 mM potassium acetate. The mixture was incubated at room temperature for 30 minutes, and the absorbance was measured at 415 nm using a UV-Visible spectrophotometer against a methanol blank. A standard calibration curve was simultaneously prepared using quercetin at concentrations ranging from 10 to 100 µg/mL. The total flavonoid content in the samples was expressed as milligrams of quercetin equivalents (mg QE) per gram of dry weight.

For statistical analysis, the obtained biochemical data, including total flavonoid content and other measured parameters, were analyzed using analysis of variance (ANOVA) to assess the significance of differences between treatments. Statistical analyses in the present study were conducted using SPSS software.

Drying data analysis and model fitting

Regression analysis has been performed for each model to estimate the drying constants under different experimental conditions, including varying drying temperatures and drying methods (shade, tray, and microwave drying). The most appropriate drying model was identified based on the drying kinetics of guava leaves from two varieties—Shweta and Purple Guava—under these diverse drying conditions.

The modelling of drying kinetics was carried out using Curve Expert Professional software (version 2.7.3), which offers robust tools for non-linear regression and model comparison. Experimental data comprising time and corresponding moisture ratio (MR) values were first organized into two-column data sets, with time as the independent variable and MR as the dependent variable. Within the software environment, a selection of nineteen thin-layer drying models—covering both theoretical and semi-theoretical formulations—was added from the model library for analysis.

Each model was fitted to the experimental data using the Levenberg-Marquardt algorithm, which is embedded in the software and designed for efficient non-linear regression (Table 2). Upon fitting, the software provided the estimated model parameters (such as drying rate constant *k*, shape constants *n*, *a*, or *b*, depending on the model), along with detailed statistical outputs including the coefficient of determination (R^2), sum of squared errors (SSE), root mean square error (RMSE), and standard error of estimate. These metrics were used to assess the goodness-of-fit for each model under each drying condition. Curve Expert also offered visualization tools such as plots of experimental vs. predicted values and residual analysis, which were used to further evaluate the model performance.

The goodness-of-fit was assessed using statistical parameters: the coefficient of determination (R^2), sum of squared errors (SSE), chi-square (χ^2), and root mean square error (RMSE). The model that yielded the highest R^2 and the lowest SSE, RMSE, and chi-square (χ^2). The Akaike Information Criterion (AIC) a statistical method for model selection has been used to represent the drying process. In addition to the software-generated parameters, the Corrected Akaike Information Criterion (AICc) was calculated externally based on the model residuals and number of parameters, and the F-test was applied to assess the statistical significance of model differences. All statistical tests were considered significant at the 5% probability level ($p < 0.05$). This procedure was repeated for all experimental conditions to systematically identify the most appropriate drying models describing the drying behaviour of guava leaves.

Table 1. Mathematical models used to describe the drying kinetics

Model No.	Model equation	Model name
1	$MR = a\exp(-kt^n + bt) + g$	Alibas
2	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Diffusion approach
3	$MR = a\exp(-kt)$	Henderson and Pabis
4	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Modified Henderson and Pabis
5	$MR= a + bt - ct^2$	Inverse Quadratic Dave
6	$MR = a\exp(-t + bt^{1/2}) + c$	Jena and Das
7	$MR = a\exp(-kt) + c$	Logarithmic
8	$MR = a_0 / (1 + a\exp(kt))$	Logistic
9	$MR = a\exp(-kt^n) + bt$	Midilli and Kucuk
10	$MR = \exp(-kt)$	Newton
11	$MR = \exp(-kt^n)$	Page
12	$MR = \exp(-kt)^n$	Modified Page
13	$MR = a + bt + ct^2$	Parabolic
14	$MR = 1-(t/(a+bt))$	Peleg
15	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	Two-Term
16	$MR = a\exp(-kt) + (1 - a)\exp(-kat)$	Two-term exponential
17	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	Verma et al.
18	$MR = 1 + at + bt^2$	Wang and Singh
19	$MR = \exp(-(t/\alpha)^{\beta})$	Weibull Distribution

Results and discussion

The initial parameters of two guava genotypes—Purple Guava and Shweta—were recorded during the year 2020–22. The experimental results obtained for the various parameters studied are presented and discussed in the following sections. Observations are interpreted in the context of existing literature, highlighting differences or similarities with previously reported findings where relevant.

Physical characteristics of fresh guava leaves

Physical parameters of fresh guava leaves estimated during the study have been tabulated below (Table 3). The variety Shweta had longer leaves (117.32 mm) as compared to Purple Guava (108.80 mm), while the leaf width was more (62.09 mm) as compared to variety Shweta (46.62 mm). No significant difference in leaf thickness was recorded among the two varieties under evaluation. The leaf colour values represented by L, a, b were 36.93, -2.53, 14.33 and 41.46, - 6.56, 17.5, respectively in Purple Guava and Shweta.

Table 3. Fresh leaf parameters of guava varieties Purple Guava and Shweta

Variety / Leaf parameters*	Purple Guava	Shweta
Leaf length	108.80 mm	117.32 mm
Leaf width	62.09 mm	46.62 mm
Leaf thickness	0.45 mm	0.45 mm
Fresh weight	1.30 g	1.22 g
Leaf colour		
L*	36.93	41.46
a*	- 2.53	- 6.56
b*	14.33	17.5
Initial Moisture Content (% wb)	63.67	64.78

Effect of shade drying on moisture content

The changes in moisture content during shade drying followed a similar behaviour in both guava genotypes, as illustrated in Fig. 2. The initial moisture content of leaves was 63.67% for Purple Guava and 64.78% for the Shweta variety. The drying started at a constant rate and reached critical moisture content after two & half hours of exposure for Shweta and six hours of exposure for purple varieties, respectively. Overall, the leaves dried out in fourteen hours of ambient exposure during the month of January when relatively dry conditions occurred with relative humidity less than 75%.

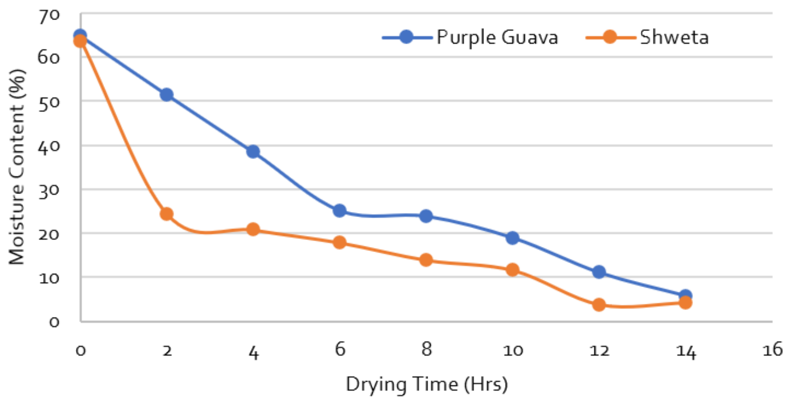

Fig. 2. Drying behaviour of fresh guava leaves under shade

Effect of Microwave Power on Moisture Content in Guava Varieties

The moisture content reduction during microwave drying varied between the two guava varieties — Purple Guava and Shweta — with different microwave power settings. Drying time for Shweta varied between 220 to 320 seconds while for Purple Guava, it varied between 160 to 300 seconds (Fig 3). Higher microwave power consistently reduced drying time and moisture content of leaves, similar to observations in other materials like Pandanus leaves (Rayaguru and Routray, 2011), where drying time dropped from 14 to 2 minutes as power increased from 180W to 900W. The first falling rate period was observed at 40 seconds at 360 W, however, it was at 20 seconds for both 540 and 720 W. The drying of shweta leaf at microwave power of 360 W and Purple variety at power of 720W showed extreme end points. The drying rate decreased i.e. 0.12, 0.1, 0.07 g H_2O/g DM/Sec for 720 W, 540 W and 360 W, respectively with a decrease in microwave power. Increasing microwave power enhances drying efficiency by reducing the drying time and increasing the drying rate. However, higher powers may bypass certain drying phases, such as the constant rate period, which could impact product quality and uniformity in moisture removal. Varietal differences also influence drying behaviour, emphasizing the need for optimized, variety-specific drying protocols. Microwave power directly influences both the drying time and drying rate. Higher power levels result in faster moisture removal but may also eliminate certain drying phases - for example, the constant rate period was absent at 720 W. The Shweta variety exhibited a more pronounced sensitivity to specific microwave powers, as indicated by the presence of a transient stage only at 540 W. This behaviour likely stems from variety-specific structural or internal moisture distribution characteristics, which affect heat and mass transfer during microwave exposure.

Effect of Tray drying on Moisture content

The change in moisture content varied for both the tested varieties of Purple Guava and Shweta (Figure 4). With the increase in temperature from 50°C to 70°C, the drying time decreased from 140 to 100 minutes for Shweta and Purple Guava varieties (Fig. 4). The change in graphical curves pattern indicating the non uniform changes in moisture content while drying. The initial drying rate for Shweta leaves was found to be least at 50°C in comparison to 60°C and 70°C. In Purple Guava, the highest drying rate (0.61 g H_2O/g DM/min) was noted for 50° C, followed by 0.21 g H_2O/g DM/min for 60°C and 0.16 g H_2O/g DM/min for 70°C. Tray drying at elevated temperatures generally reduced drying time and moisture content. However, Shweta's drying behaviour appears linear rather than exponential, maintaining higher moisture levels and showing lower initial drying rates at lower temperatures. These differences underscore the importance of varietal characteristics in determining optimal drying parameters or temperature of the leaves rather than temperature of heating air.

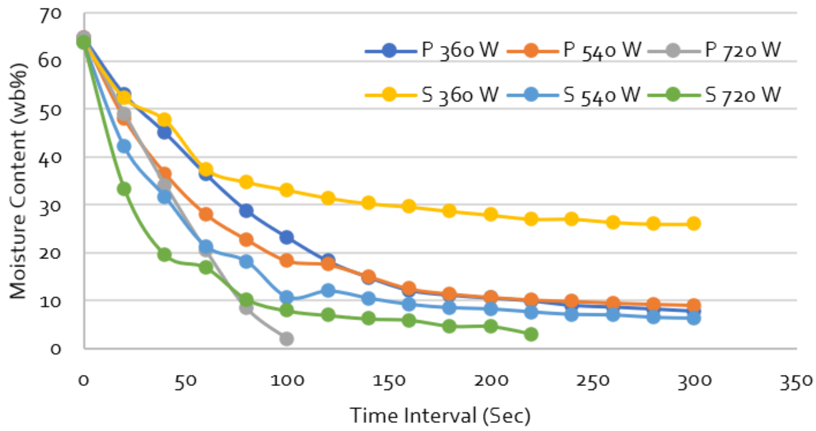

Fig. 3. Drying behaviour of Purple Guava and Shweta leaves (wb) during microwave drying at 360, 540 and 720 W powers

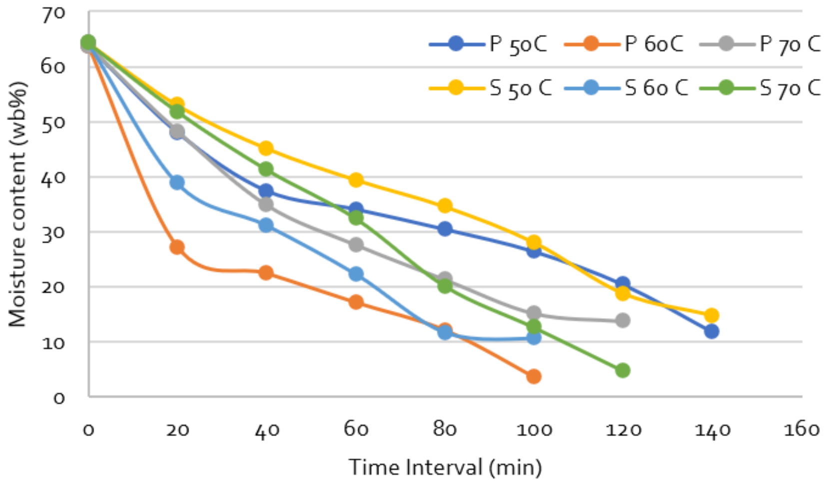

Fig. 4. Graph showing the relation between moisture content (db) and drying time (min) for Purple Guava and Shweta leaves dried in Tray dryer at 50, 60 and 70°C temperatures

Model application and analysis of drying data

In this study, nineteen distinct mathematical drying models were applied to characterize the drying kinetics of leaves from two guava varieties under various drying conditions. Statistical evaluations—conducted via Curve Expert Professional 2.7.3—utilized metrics such as the coefficient of determination (R^2), sum of squared errors (SSE), Akaike Information Criterion (AIC), and F-tests to identify the most suitable models for each variety and drying condition.

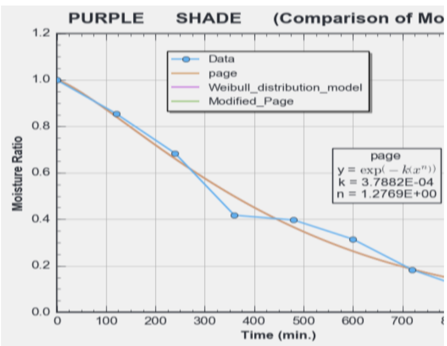

Fig 4a. Comparison of experimental curve with predicted for Purple Guava leaves under shade

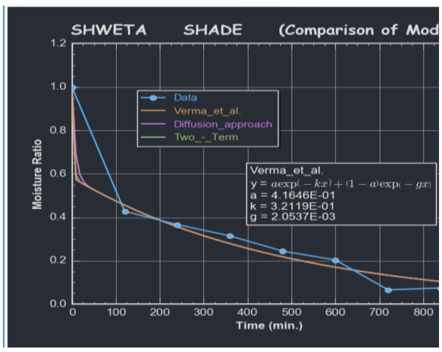

Fig 4b. Comparison of experimental curve with predicted one in Shweta leaves under shade drying

Shade drying

In case of shade drying for variety Purple Guava, the drying data was best explained by Page model, with highest R^2 value 0.983 and lowest SSE value of 0.044 (Fig 4a). The value of constants K and n in Page model were 0.0004 and 1.2769. The high value of R^2 towards Page model indicates non-linear drying kinetics of guava leaves. It is an empirical modification of the Newton model, introducing the exponent n for flexibility. The value of n >1 (1.2769) suggests an increasing rate of moisture loss initially, possibly indicating a falling rate period dominated by internal moisture diffusion. Similarly, the low value of K=0.0004 suggests a slow drying rate, which is typical for shade drying due to lower energy input (no direct heat).

In Shweta, variety the drying data was best explained by Verma et al. model, with highest R^2 value 0.985 and lowest SSE value of 0.0433 captures the drying dynamics effectively. The value of constants a, K and g in Verma et al. model were 0.416, 0.321 and 0.002, respectively. The constant a=0.416 denotes the partitioning of moisture into two exponential decay processes (Fig4b). The relatively large difference between K=0.321 and g=0.002 suggests a fast initial moisture loss phase followed by a slower, sustained drying phase. This "two-term exponential" behavior is consistent with empirical observations in leaf drying, where moisture removal dynamics often shift from rapid surface evaporation to slower internal diffusion.This elucidated of drying behaviour is in line with drying of different crops by various researchers (Verma et al., 1985, Erbay and Icier, 2009; Akpinar et al., 2006; Doymaz, 2005; Resende et al., 2009; Lahsasni et al., 2004; Lopez et al., 2009; Yaldiz et al., 2001; Sacilik and Unal, 2005 and Zenoozian et al., 2008).

Tray drying

Under tray drying conditions, each temperature tested yielded a different best-fit model among the selected set (Table 4). For Shweta variety, out of selected models evaluated, the drying data was best explained by Modified Page model at 50˚C; Modified Handerson and Pabis model at 60˚C. This model extends the simple Henderson and Pabis model by incorporating three exponential terms to capture moisture loss at different drying stages—beginning, middle, and end—hence improving fitting accuracy and Jena and Das model at 70˚C, with highest R^2 value 0.960, 0.981 and 0.998 and lowest SSE value of 0.0561, respectively. This model combines two exponential terms, with exponent values set to 1 and 0.5 for simplicity. It is effective for capturing the full drying curve profile. For 50˚C, tray drying, the value of constants K and n in Modified Page model were 0.017 and 1.656. For drying at 60˚C, the value of constants a, K, b, g, c and h in Modified Henderson and Pabis model were 0.365, 0.036, 0.319, 0.036, 0.323 and 0.036 respectively (Table 3). Notably, as temperature increased from 50 °C to 70 °C for Shweta leaves, the drying rate constant (K) also rose from 0.017 to 0.036 to 0.096—indicating a clear acceleration in drying kinetics with higher temperature (Fig 5a).

Table 4. Summary of best fit drying models under tray drying of guava leaves at selected temperatures

Variety	Temperature (°C)	Best Model	Key Parameters	R^2	SSE	Observation
Shweta	50	Modified Page	K = 0.017, n = 1.656	0.960	0.0561	
	60	Modified Henderson & Pabis	K=0.036, a=0.365, ,b=0.319, g=0.036, c=0.323, h=0.036	0.981	0.00	K increases with temp
	70	Jena & Das	K= 0.096, a=1.577, b=0.589, C=-0.045	0.983	0.070	
Purple Guava	50	Alibas	K=0.096, n=0.872, a=0.962, b=0.087, g=0.962, E- 019.62	0.997	0.00	K decreases with temp
	60	Midilli & Kucuk	a=1.000, K=0.050, n=0.891, b=-0.001	1.00	0.00	
	70	Midilli & Kucuk	a=1.001, K=0.002, n=1.786, b=0.002	0.997	0.395	

In case of Purple Guava, variety the drying data was best explained by Alibas model for 50˚C which is known to integrate a term like bt within the exponential, allowing a nuanced fit; Midilli and Kucuk model indicating a decaying exponential plus a linear time term making it highly adaptable across various drying kinetics scenarios at 60˚C and 70˚C. This marks a decrease in the rate constant K (from 0.050 to 0.002) with temperature rise from 60 °C to 70 °C, an interesting deviation from the trend observed in Shweta leaves. This could point to structural, cellular, or moisture binding differences in the leaves compared to Shweta, warranting further investigation. The Midilli et al. model was successfully used in various studies on the drying characteristics of agricultural products (Arslan and Ozcan, 2012; Zang. 2015; Izli et al., 2017; Ertekin and Yaldiz, 2004). Two-Term Exponentia model is also tested earlier (Midilli and Kucuk, 2003; Doymaz, 2008; Lee and Kim, 2009). With increase in temperature from 50°C to 70°C, the drying rate constant 'K' decreased i.e from 4.803 to 0.051 to 0.003 was recorded in drying of Purple Guava leaves. With increase in temperature from 50°C to 70°C, the drying rate constant 'K' increased i.e from 0.017 to 0.036 to 0.096 was recorded in drying of Shweta leaves.

Microwave Drying

For Shweta, variety out of all the models evaluated, the drying data was best explained by Logarthmic model at 360 W; Modified Handerson and Pabis model at 540 W and Diffusion Approach model at 720 W, with highest R^2 value 0.994, 0.995 and 0.993 and lowest SSE value of 0.014, 0.021, 0.026 respectively. For 360 W microwave drying, the value of constants a, K and c in Logarithmic model were 0.592, 0.011 and 0.428 respectively. For 540 W microwave drying, the value of constants a, K, b, g, c and h in Modified Henderson and Pabis model were 0.157, 0.001, -0.099, 3.800. 0.942 and 0.023, respectively.

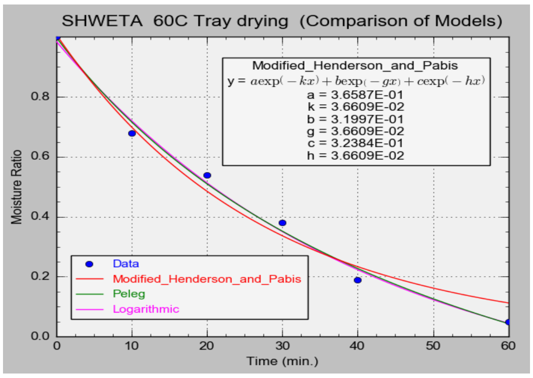

Fig. 5a. Experimental curve with the predicted one in Shweta leaves under tray drying at 60˚C

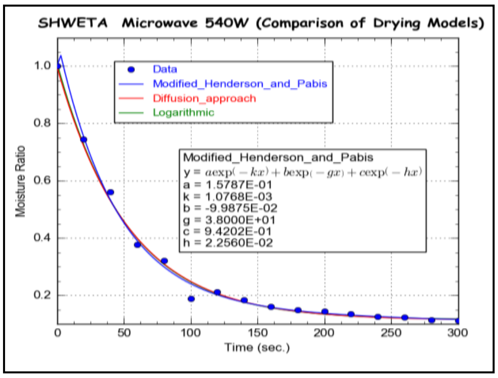

Fig. 5b. Experimental curve with predicted one in Shweta leaves under microwave drying at 540 W

For 540 W microwave drying, the value of constants a, K and b in Diffusion Approach model were 0.355, 0.003 and 6.499 (Fig 5b). For 720 W microwave drying, the value of constants a, K, n and b in Midilli and Kucuk model were 0.999, 0.002, 1.486 and -0.002. The Midilli model was successfully used in studying the drying characteristics by different scientists (Arslan and Ozcan, 2012; Demirhan and Ozbek, 2010; Zang F. 2015; Izli N. et al., 2017 and Ertekin and Yaldiz, 2004) in various crops. In Shade dried leaves of Shweta, the initial drying rate was much higher i.e 0.27 g H_2O/g DM/min than Purple Guava variety 0.07 g H_2O/g DM/min. In case of tray drying, the highest drying rate i.e 0.61 g H_2O/g DM/min was noted at 50° C, followed by 0.21 g H_2O/g DM/min for 60°C and 0.16 g H_2O/g DM/min for 70°C in Purple Guava leaves. The first falling rate period was highest for 70°C at 0.25 g H_2O/g DM/min, followed by 0.15 g H_2O/g DM/min for 60°C and 0.03 g H_2O/g DM/min for 50°C in Shweta tray dried leaves. For Microwave dried leaves of both varieties, the drying rate decreased with decrease in microwave power. For Purple Guava the values were 0.12, 0.1, 0.07 g H_2O/g DM/sec and for Shweta variety the noted values were 0.19, 0.12, 0.04 g H_2O/g DM/sec for 720 W, 540 W and 360 W, respectively.

Effect of Drying on Guava Leaf Colour

In both guava varieties, the *L*, *a*, and b* colour values were best in fresh leaves** and declined following all three drying methods — shade drying, tray drying**,** and microwave drying. This indicates that drying negatively impacts visual quality, particularly in terms of brightness and chromatic attributes. Thus, drying leads to a reduction in these values regardless of the method of drying used, indicating visual degradation.

Tray Drying Effects

Purple Guava

As tray drying temperature increased from 50°C to 70°C, the *L value** (lightness) increased slightly from 43.98 to 44.98, and the *b value** (yellowness) rose from 10.05 to 10.85. This suggests a slight enhancement in brightness and yellow colour at higher temperatures. There has been slight increase in brightness and yellow hue at higher drying temperatures, possibly due to surface drying or colour stabilization at elevated heat. This indicates better colour retention at higher temperatures for the variety.

Shweta

With the same temperature increase (50°C to 70°C), *L decreased from 50.98 to 49.70**, a decreased from -0.35 to -0.70*, *and* b decreased from 17.77 to 15.40*. These changes indicate a loss in brightness and yellowness, and a slight shift toward green colouration (more negative a*). There is decline in brightness, yellowness, and shift further toward green. This suggests that higher drying temperatures degrade visual quality in Shweta, possibly due to pigment breakdown or moisture loss.

Drying reduces visual quality in guava leaves, but the extent varies by variety and method (Table 5). Purple guava responds better to higher tray drying temperatures as there is slight improvement in lightness and yellowness. Shweta is more sensitive as it showed overall colour degradation with higher drying temperatures. So optimization is variety-specific and drying method & air temperature should be tailored per cultivar to preserve colour and thus market value. These findings align with earlier observations by Balasubramanian et al. (2011), where *L and b* values tended to increase** and *a values decreased** as drying air temperature rose from 50°C to 70°C. He also noticed that colour values remained consistently higher for cabinet dryers compared to tunnel dryers, suggesting that dryer type also influences colour retention during the drying process. Thus, drying temperature and method significantly impact the colour attributes of guava leaves, with Purple guava generally showing *increased L and b* values** at higher drying temperatures, while Shweta exhibited a decrease across all colour parameters. This highlights the importance of variety-specific and method-specific optimization to preserve desirable visual qualities in dried leaf products.

Table 5. Leaf Colour values for Purple Guava and Shweta variety.

Varieties	Purple Guava					Shweta				
	L	a	b	c	α	L	a	b	c	α
Fresh Leaves	36.93 ± 2.310	-2.53 ± 2.419	14.33 ± 2.062	14.55	79.98	41.46 ± 2.214	-6.56 ± 1.790	17.5 ± 3.180	18.69	-69.47
Shade Drying	44.03 ± 1.490	-1 ± 0.660	10.6 ± 0.777	10.65	84.61	50.27 ± 1.451	-0.03 ± 0.677	16.97 ± 1.981	16.97	-88.88
Tray Drying										
50°C	43.98 ± 0.618	-0.7 ± 0.908	10.05 ± 0.782	10.07	86.02	50.98 ± 0.749	-0.35 ± 0.565	17.77 ± 0.493	17.77	-88.87
60°C	44.1 ± 0.856	-1.03 ± 0.350	10.55 ± 0.892	10.60	84.42	50.8 ± 0.860	-0.72 ± 0.462	16.38 ± 0.417	16.40	-87.48
70°C	44.98 ± 1.005	-0.82 ± 0.204	10.85 ± 0.458	10.88	85.67	49.7 ± 1.183	-0.7 ± 0.810	15.4 ± 0.787	15.42	-87.48
Microwave Drying										
360 W	43.45 ± 0.497	-1.77 ± 0.532	10.02 ± 0.585	10.18	79.98	46.43 ± 0.979	-0.77 ± 0.186	12.75 ± 0.771	12.77	-86.54
540 W	42.73 ± 0.981	-1.82 ± 0.331	9.97 ± 0.650	10.13	79.66	45.3 ± 0.899	-0.75 ± 0.501	11.88 ± 0.454	11.90	-86.39
720 W	42.5 ± 0.84	-2.15 ± 1.320	9.82 ± 0.542	10.05	77.66	47.08 ± 0.850	-0.17 ± 0.344	14.32 ± 0.534	14.32	-89.32

The Chroma C and hue angle varied with the method of drying and the varieties. Irrespective of the guava varieties the maximum Chroma was obtained in fresh leaves in comparison to the shade, tray and microwave drying methods. In Purple Guava and Shweta, the Chroma was 14.55 and 18.69, respectively. In Purple Guava, the Chroma was lowest (10.05) in microwave at 720 W, while in Shweta it was lowest (11.90) in microwave at 540 W. The hue angle was maximum (-69.47) in fresh Shweta leaves among all drying methods, while in Purple Guava such trend was observed only for shade and tray drying, but not for microwave drying as the readings were comparable. Hence, we conclude that chroma declines across all drying methods, most sharply with microwave drying (Fig. 6). Fresh leaves retain the most vibrant and saturated colour, important for visual and commercial appeal. Hue angle shifts indicate a move away from natural green/yellow hues, with microwave drying affecting hue stability the most. Drying method and intensity must be optimized not only for L*, a*, b* but also for C* and h° to maintain the authentic visual characteristics of guava leaves. Shweta exhibits higher Chroma and hue angle in the fresh state than Purple Guava, suggesting inherent varietal differences in pigment composition.

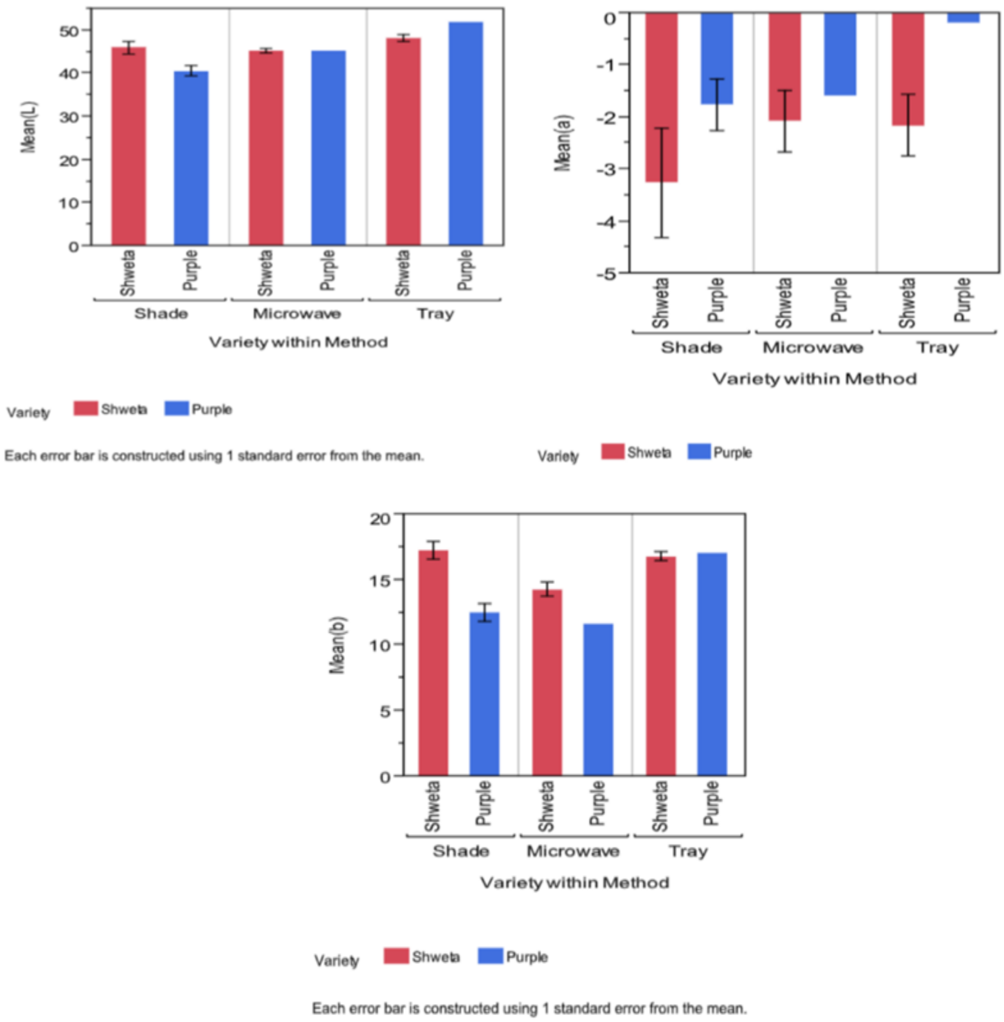

Fig. 6. The average colour values of L, a & b of guava leaves under different drying conditions

Table 6. Optimization of drying parameters for extraction of Flavonoid content from Purple Guava and Shweta varieties

Drying Method	Flavonoid Content (mg QE/ mg dry weight)	
	Purple	**Shweta**
Fresh	49.81 ± 8.742	31.71 ± 8.051
Shade Drying	121.52 ± 42.211	55.92 ± 2.972
Tray Drying		
50˚C	**208.62** ± 16.645	**84.79** ± 10.046
60 ˚C	184.77 ± 41.387	74.95 ± 4.562
70˚C	148.17 ± 19.604	66.52 ± 5.234
Microwave Drying		
250 W	88.56 ± 4.400	46.489 ± 8.912
540 W	98.56 ± 38.450	46.94 ± 1.736
720 W	107.90 ± 26.090	56.78 ± 4.895

Flavonoid Content in Guava Leaves

Fresh Leaves (mg QE/mg dry weight) have been worked out as Purple Guava: 49.81 & Shweta: 31.71**.** Drying increases flavonoid content significantly**,** especially in Purple Guava (2–3x increase). Highest flavonoid content was observed in Purple Guava: 208.62 (Tray drying at 50°C). On comparison, it is observed that tray drying (50°C) is most effective for maximizing flavonoid content while Shade drying gives moderate results and the lowest flavonoid retention among dried samples using microwave drying (Table 6). However, despite lower TFC, microwave drying retains similar antioxidant activity (e.g., in Broccoli studies). No significant interaction between Purple Guava and Shweta varieties under shade and microwave drying conditions. So it can be concluded that Tray drying at 50°C is the optimal method for preserving maximum flavonoid content in both Purple Guava and Shweta varieties and Fresh leaves have the lowest flavonoid content**,** and drying enhances bioactive compound concentration.

Conclusion

For shade drying of leaves *Verma* (Shweta) and *Page* models (Purple guava) respectively, were best fit. For tray drying modified *Henderson & Page*, *Jena & Das* and *Modified Page* (Shweta), while *Alibas* and *Midilli & Kucuk* (Purple guava) were best fit. For microwave drying *Diffusion approach, modified Henderson & Page* and *Logarithmic* models were best fit. Flavonoid content was almost double in variety Purple guava as compared to Shweta. Irrespective of drying method chosen, the phenol content in variety Shweta tends to increase, particularly due to concentration of phenol during removal of moisture from leaves, but for Shweta variety it decreases from fresh. The drying of both varieties is highly recommended to retain maximum flavonoid content. Comparison among various drying method shows that the flavonoid content was highest in Tray drying followed by shade and microwave drying, respectively. This helps to conclude that Tray drying is preferred for both the guava leaf varieties, especially when the leaves are heated at 50°C using tray dryer.

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Author Contributions

IK: Conducted work, Initial drafting of the paper; VO: Proofreading of draft; MK: Major advisor; MISG: Conceived the concept, and all authors approved the manuscript

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