

EFFECT OF LOADING DENSITY AND HOT AIR TEMPERATURE ON DRYING CHARACTERISTICS AND QUALITY OF STEVIA LEAVES DRIED UNDER SOLAR ASSISTED MECHANICAL TRAY DRYER

Gundeep Kaur*, S R Sharma, T C Mittal and M S Alam

¹Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana-141 004, India

ABSTRACT

A study was conducted to analyze the drying behavior of *Stevia rebaudiana* Bertoni leaves dried under open sun and in solar assisted mechanical tray dryer. The effect of drying methods on the quality characteristics of stevia leaves was also studied. The drying was done at different loading densities of 1.17, 2.34 and 3.51 kg/m² in open sun drying and in case of solar assisted mechanical tray dryer, drying air temperatures also varied as 45, 55 and 65°C along with loading densities. The quality assessment in terms of color change, stevioside content, flavonoid content, protein content and crude fiber content proved drying of stevia leaves in solar assisted mechanical tray dryer was better as it also took less time as compared to open sun drying. Also, 55°C temperature and 2.34 kg/m² loading density of leaves was found to be the best combination in terms of drying behavior and quality of dried leaves.

Keywords: Flavonoid content, Protein content, Stevia, Stevioside content, Sun drying

Stevia, (*Stevia rebaudiana* Bertoni) is a sweet herb so known as *Madhu Tulsi*. The leaves of stevia are the source of sweet glycosides. In the food and beverage industry, it is mainly used as a sweetening agent and a flavor enhancer. The chemical compound in stevia is the best and safe alternative source of sugar especially for people suffering from diabetes because the blood sugar levels are not affected by it. More importantly, stevia contains a high percentage of flavonoids, phenols, and antioxidants. Besides this, it contains good amount of protein, magnesium, zinc, chromium, phosphorus, calcium, niacin and riboflavin. It can be used very safely as a sweetener in home-made sweets in India.

The steviosides increase the insulin secretion and, thus, decrease glucose level in the blood due to its insulin tropic effects in pancreatic beta cells. Stevia can be used in all the three forms, i.e. fresh leaves, powder and liquid extract (Hossain *et al.*, 2017).

Fresh stevia leaves are perishable in nature which leads to its easy spoilage due to climatic factors, handling, microorganisms, and structural and chemical changes during storage. To preserve the quality of the product and its storage life, the moisture content needs to be reduced to a level that is safe for storage. Drying is, therefore, an important process to get rid of the excess product moisture. Drying methods have a significant effect on the quality of the product (Gasmalla *et al.*, 2014). Drying of stevia needs to be done as soon as the crop is harvested to protect it from any kind of infestation. Drying for a longer time can lead to

reduction in the stevioside content of the final product. Thus, there is a need to identify most suitable drying method with minimal nutrition losses.

The conventional methods of drying stevia are open sun drying, solar drying and mechanical dryers. But, due to the lack of a proper handling system, open sun drying presents a lot of disadvantages especially in the quality of dried product (Bansal, 2012). The disadvantage with the open sun drying is that the drying can be done only during sunshine hours, and this gives intermittent drying of the product which requires longer duration of drying and yields lower quality product. So, drying would give best results if it is done continuously. Also, temperature cannot be controlled in sun drying. Some medicinal herbs require low temperature to prevent the removal of active volatile essential ingredients. This can be accomplished by using solar assisted mechanical tray dryer which uses solar energy during sunshine hours and back up energy from biomass, electricity or other fuels during non-sunshine hours. During the daytime, the solar energy controls the temperature inside the dryer and dries the product and after the sun set it functions as a regular mechanical tray dryer where the product is spread in trays at an optimum thickness for uniform drying of the product. A solar assisted mechanical dryer consists of drying chamber, solar air collector, blower, and heaters. The auxiliary heaters have an on/off controller. This enables the user to control and maintain the temperature inside the drying chamber. The product is protected from insects, pests, birds etc. in the dryer and moisture addition is also prevented. Keeping all these points in view, the present study was planned to study the drying behavior of stevia leaves.

*Corresponding author: gundeepkaur1996@gmail.com
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MATERIALS AND METHODS

Procurement and preparation of sample

The fresh stevia leaves were procured from local farms and were cleaned to remove dust and leaf stalks were separated. Then these leaves were dried in open sun and solar assisted mechanical tray dryer to evaluate the drying behaviour. The drying experiments were carried out in Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana. The samples were put in rectangular wire mesh containers with varying thickness of material as 2.5 cm, 5.0 cm and 7.5 cm. The respective weights of samples were 400, 800 and 1200g having loading densities as 1.17, 2.34 and 3.51 kg/m², respectively.

Drying of stevia leaves

The stevia leaves were dried under open sun as well as in solar assisted mechanical tray dryer. The samples were spread out in the rectangular wire mesh containers at three different loading densities as 1.17, 2.34 and 3.51 kg/m² and were kept in the open sun. In the solar assisted mechanical tray dryer, the leaves were spread in the wire mesh containers and then placed in the dryer where they were dried by means of hot circulation of air obtained from solar drying system and/or the mechanical drying system. The drying was done at three different loading densities as 1.17, 2.34 and 3.51 kg/m² and three temperatures viz. 45, 55 and 65°C maintained by means of four heaters installed in the dryer. The change in weight was measured at an interval of 1 hour and it was dried till weight loss became zero. Ambient temperature and humidity of inside as well as outside the dryer was recorded using a hygrometer.

Drying kinetics

The drying kinetics of stevia leaves and physio-chemical parameters of dried stevia leaves were assessed using procedures described as follows:

Moisture content (%)

The moisture content in fresh and dried stevia leaves was estimated by standard hot oven method (AOAC, 2000). The sample (5 g) was weighed and dried at 103±2°C till constant weight is achieved in uncovered pre-weighed Petri dishes. The moisture content was calculated using the following formula:

$$\text{Moisture content (\% db)} = \left(\frac{\text{Initial weight} - \text{Final weight}}{\text{Final weight}} \right) \times 100$$

Moisture ratio

Moisture ratio was estimated as per Brooker *et al.* (1997) as:

$$MR = \frac{M - M_e}{M_0 - M_e}$$

where:

M=Moisture content of sample at any time (% db)

M₀=Initial moisture content (% db); M_e=Equilibrium moisture content (%db)

Drying rate

Drying rate was calculated as per method given by Brooker *et al.* (1997) as:

$$\frac{dM}{dt} = \frac{M_i - M_{i+1}}{(t_{i+1} - t_i)}$$

where, dM/dt=Drying rate; t_i=Initial time (minutes)

t_{i+1}=Time corresponding to next moisture content (minutes) M_i=Moisture content at time t_i (%db);

M_{i+1}=Moisture content at time t_{i+1} (%db)

Mathematical modeling

Regression analysis was conducted to fit the mathematical models by the statistical package for social sciences (SPSS version 11.5). The goodness of fit was determined by various statistical parameters like determination coefficient (R²), reduced chi-square (χ²), mean bias error (MBE), root mean square error (RMSE) and mean deviation modulus (P) and were defined by the given equations (Gomez and Gomez, 1983).

$$R^2 = \frac{\sum_{i=1}^n (MR_i - MR_{pre,i}) \cdot \sum_{i=1}^n (MR_i - MR_{exp,i})}{\sqrt{\left[\sum_{i=1}^n (MR_i - MR_{pre,i})^2 \right] \cdot \left[\sum_{i=1}^n (MR_i - MR_{exp,i})^2 \right]}}$$

$$\chi^2 = \frac{\sum_{i=1}^n (MR_{exp,i} - MR_{pre,i})^2}{N - n}$$

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

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

where, MR_{exp,i} and MR_{pre,i} are experimental and predicted dimensionless moisture ratios, respectively and N is number of observations.

$$P(\%) = \frac{100}{N} \sum_{i=1}^N \left| \frac{\text{Experimental value} - \text{predicted value}}{\text{Experimental value}} \right|$$

Table 1. List of different drying models

Sr. No.	Model name	Model Equation	Reference
1	Newton	$MR = \exp(-kt)$	Lewis (1921)
2	Two term	$MR = a \exp(-k_0t) + b \exp(k_1t)$	Henderson (1974)
3	Henderson & Pabis	$MR = a \exp(-kt)$	Pabis and Henderson (1961)
4	Two-term exponential	$MR = a \exp(-kt) + (1 - a) \exp(-k_1t)$	Sharaf-Eldeen <i>et al.</i> (1980)
5	Logarithmic	$MR = a \exp(-kt) + b$	Yaldiz <i>et al.</i> (2001)

Quality analysis of dried stevia leaves- Physiochemical parameters

Color

The color measurements were made by using Hunter Lab Miniscan XE-Plus Colorimeter. Color was measured in terms of L, a and b values and overall color change was calculated by using the following equation:

The comparison was made with initial values of the fresh leaves.

$$\Delta E = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)}$$

Stevioside content

The stevioside content in the stevia extract was estimated by method described by Kaur (2009). After heating the stevia extract in water in a specific ratio of 1: 15 (weight to volume), it was hydrolyzed with 5N HCl at 70°C for 1 hour. Upon hydrolysis with 5% phenol and 95% sulphuric acid (H₂SO₄), the glucose units liberated from the stevioside. The orange, brown color intensity was observed at 490 nm. To calculate stevioside content, the glucose concentration was measured against glucose standard and multiplied by a factor of 25.714 (based on molecular weight).

Flavonoid content

The powdered dried stevia leaves (400 mg) were refluxed with 80% aqueous methanol for 1 h. Refluxed material was then filtered through Whatman's filter paper no. 1 and volume was made to 10 mL by washing with 80% methanol.

The flavonoid content was determined by method given by Balbaa *et al.* (1974). The methanolic extract (3 ml) prepared as discussed was completely evaporated. The residue left was dissolved in 10 ml of 0.1 M methanolic solution of aluminium chloride. Intensity of yellow color was read at 420 nm against blank. Total soluble flavonoids concentration was determined from standard curve prepared using rutin (40-200 µg/ml).

Protein content

Protein content was determined as per Lowry *et al.* (1951). 0.1 ml of the supernatant of stevia extract was placed in a test tube and a volume of 0.5 ml was

obtained by adding distilled water. Then, 5ml mixture of 2% sodium carbonate in 0.1N sodium hydroxide and 0.5% copper sulphate in 1% sodium potassium tartrate was added to the test tube and vortex edit. After 10 minutes, 0.5ml of reagent prepared by mixing Folin & Ciocalteu's phenol reagent and distilled water in the proportion of 1: 1 was added to it and again vortexed properly. The absorbance of the developed color was read at 520 nm using the spectrophotometer. A standard curve of Bovine Serum Albumin (BSA) at different concentrations ranging from 20-100 µg was prepared to measure the protein concentration.

Crude fibre content

Two grams of dried sample of stevia was first digested by boiling with 200 ml of 0.225 N sulphuric acid for 30 minutes. To remove the traces of acid, the mixture was filtered and washed with hot water. After this, alkali digestion was done with 200 ml of 0.313 N sodium hydroxide for 30 minutes and the mixture was filtered and washed. The weight of dried residue was measured. It was ignited at 600°C for 3 hours in muffle furnace and its weight was taken after cooling. For estimation of crude fibre content in the sample, the equation was used as under:

$$\text{Crude Fibre Content} = \left(\frac{W_1 - W_2}{W} \right) \times 100$$

where, W₁=Crucible weight containing of and sample before ashing (g)

W₂=Weight of crucible and sample after ashing (g)

W=Dry sample weight (g) (AOAC, 1980)

RESULTS AND DISCUSSION

Drying kinetics

Moisture content

In all cases, the moisture content of stevia leaves decreased non-linearly with drying time. Open sun-dried stevia leaves showed higher drying time due to uncontrolled ambient temperature and amount of solar radiations throughout the day. Stevia leaves kept at 1.17, 2.34 and 3.51 kg/m² loading densities in open sun took 18, 26 and 27 hours, respectively to attain the equilibrium moisture content (Fig. 1).

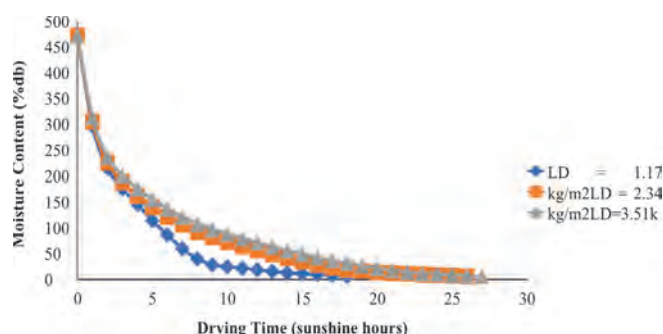


Fig. 1. Effect of loading densities on moisture content of stevia leaves in open sun drying

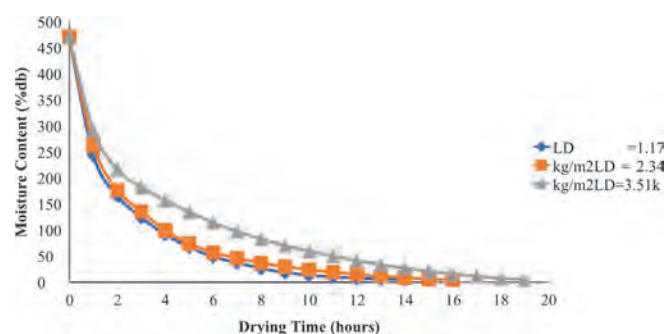


Fig. 2(a). Effect of loading densities on moisture content of stevia leaves at 45°C in solar assisted mechanical tray drying

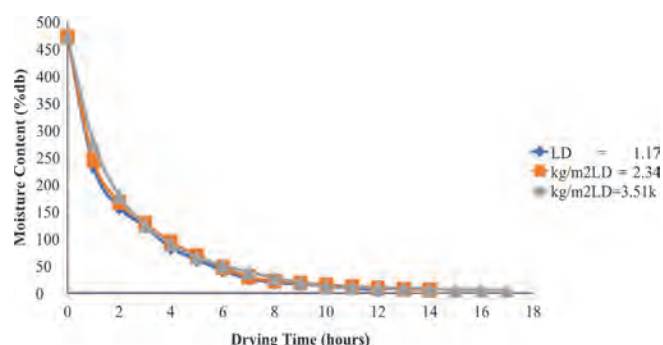


Fig. 2(b). Effect of loading densities on moisture content of stevia leaves at 55°C in solar assisted mechanical tray drying

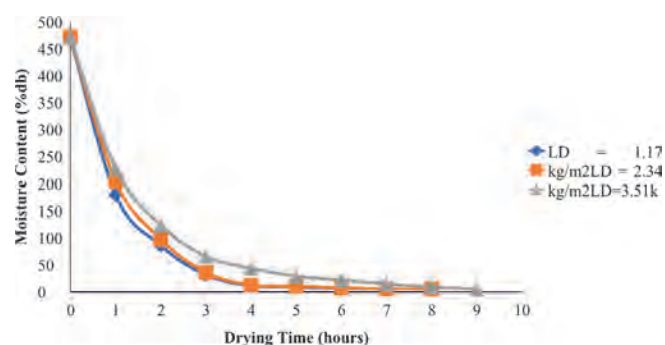


Fig. 2(c). Effect of loading densities on moisture content of stevia leaves at 65°C in solar assisted mechanical tray drying

In case of drying in solar assisted mechanical tray dryer, the time of drying taken by stevia leaves to attain the equilibrium moisture content kept at 45, 55 and 65°C was found to be 14-19, 12-17 and 7-9 hours, respectively. The rate of decrease of moisture content was rapid in the beginning and gradually decreased with time. This was because migration of moisture from inside of the product to the surface and evaporation rate from surface to the air decreased with decrease of moisture content in the product. The samples dried at 45°C took maximum drying time while stevia leaves dried at 65°C took minimum drying time as shown in Fig. 2(a), (b) and (c).

The initial moisture content of stevia leaves was 471.43% db (82.50% wb), whereas, the final moisture content ranged from 5.20% to 5.72% db. The maximum final moisture content was recorded for open sun drying for loading density of 3.51 kg/m², while, the least value of moisture content was recorded for solar assisted mechanical tray drying at 65°C for loading density of 1.17 kg/m². The reason for this could be that, out of the total, less surface area of leaves was in contact with same volume of drying air for 3.51 kg/m² as compared to 1.17 kg/m² and 2.34 kg/m² and, thus it took more time to dry.

Moisture ratio

All the samples showed non-linear decrease in moisture ratio with drying time. Open sun drying showed gradual decrease in moisture ratio throughout the drying process (Fig. 3). On the other hand, in solar assisted mechanical tray drying, the decrease in moisture ratio was very sharp in the beginning and became gradual afterwards due to the slow rate of moisture evaporation with passage of time as shown in Fig. 4(a), (b) and (c), respectively.

The reduction in moisture ratio for loading density of 1.17 kg/m² of dried stevia leaves with increase in temperature may be due to increase in vapour pressure within the product, which resulted in faster migration of moisture to the product surface (Pal *et al.*, 2008). Similar inferences were drawn for loading densities of 2.34 kg/m² and 3.51 kg/m² of dried stevia leaves.

Like the temperature influenced the process; the loading density also affected the kinetics of the dried stevia leaves. In general, greater loading density of leaves led to slow decrease in moisture ratio due to increased distance travelled by moisture to the surface. Similar trends were observed in the present study, where 1.17 kg/m² loading density of stevia

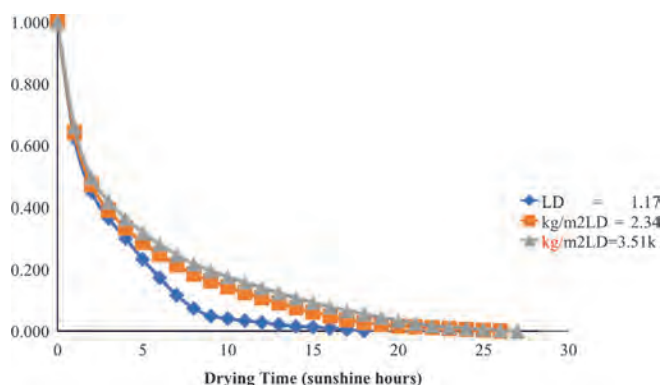


Fig. 3. Effect of loading densities on moisture ratio of stevia leaves in open sun drying

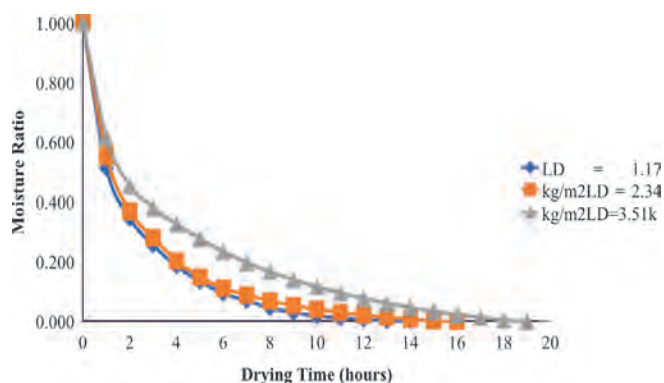


Fig. 4(a). Effect of loading densities on moisture ratio of stevia leaves at 45°C in solar assisted mechanical tray drying

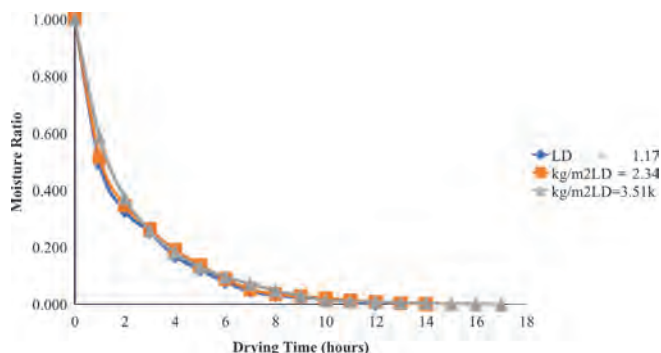


Fig. 4(b). Effect of loading densities on moisture ratio of stevia leaves at 55°C in solar assisted mechanical tray drying

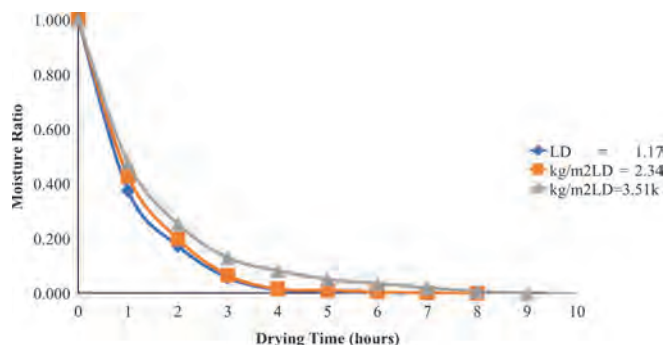


Fig. 4(c). Effect of loading densities on moisture ratio of stevia leaves at 65°C in solar assisted mechanical tray drying

leaves showed minimum values of moisture ratio as compared to the loading densities of 2.34 and 3.51 kg/m². Overall, the reduction in moisture ratio of the stevia leaves depended on both the drying temperature and loading density. The major saving in drying time can be made by drying the stevia leaves at 65°C temperature as compared to sun drying, keeping loading density of 1.17 kg/m².

Drying rate

The drying curves showing drying rate, is defined as kg of water removed per kg from bone dry weight of sample in a specific time interval, were drawn for different drying methods *viz.* sun drying (Fig. 5) and solar assisted mechanical tray drying at 45°, 55° and 65°C at different loading densities *i.e.* 1.17, 2.34 and 3.51 kg/m² (Fig. 6(a), (b) and (c), respectively). It can be seen from the curve that the drying rate followed

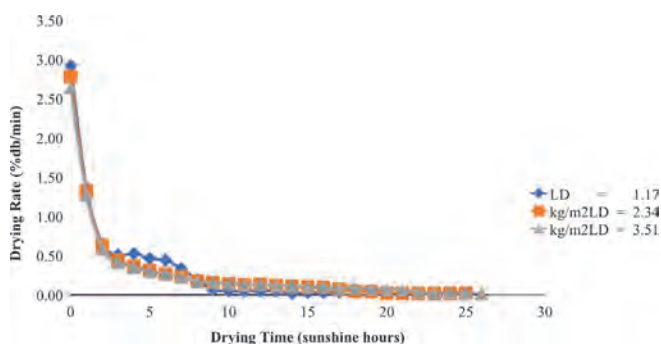


Fig. 5. Effect of loading densities on drying rate of stevia leaves in open sun drying

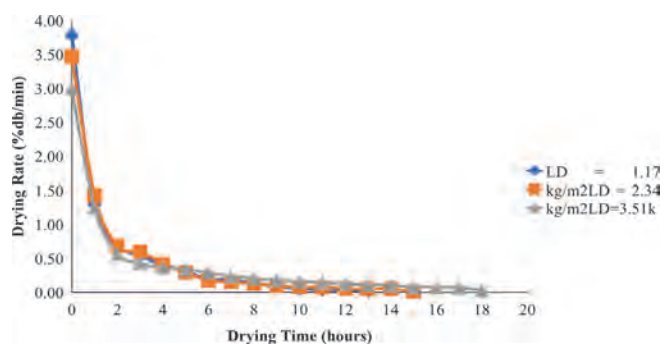


Fig. 6(a). Effect of loading densities on drying rate of stevia leaves at 45°C in solar assisted mechanical tray drying

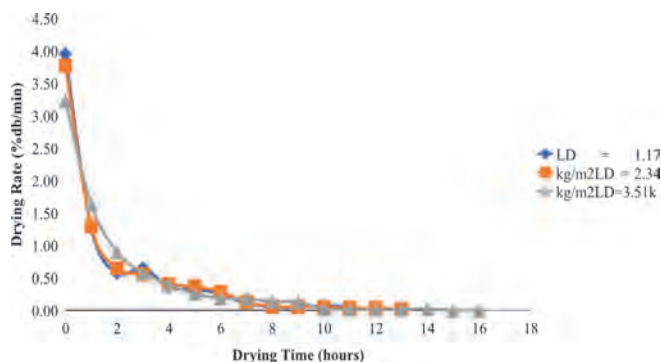


Fig. 6(b). Effect of loading densities on drying rate of stevia leaves at 55°C in solar assisted mechanical tray drying

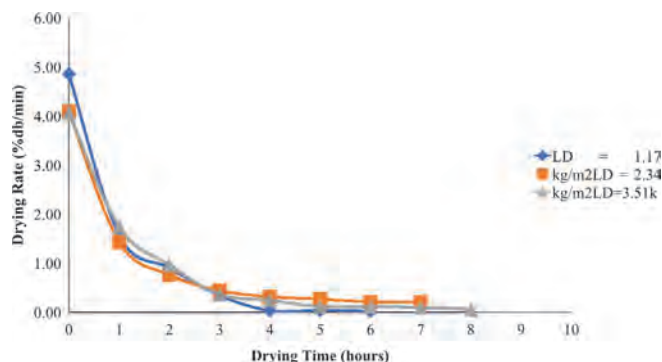


Fig. 6(c). Effect of loading densities on drying rate of stevia leaves at 65°C in solar assisted mechanical tray drying

a nonlinear decreasing trend. The sun drying curve showed some variation because of change in intensity of solar radiations and thus variable drying.

In case of solar assisted mechanical tray drying, it was observed that the drying rate decreased with increase in drying time. This decrease was more rapid in the initial stages as compared to the later stages of drying when the availability of moisture was reduced. The initial high drying rates can be attributed to the fact that initially high surface temperature and high surface moisture was available for removal. The drying rates were lowest in case of sun drying for all loading densities of stevia leaves.

Total drying time

The drying time taken to bring the final moisture content to 8% (db) has been compared for different drying methods and presented in table 2 and fig. 7.

The drying time was the maximum for all the loading densities under open sundrying. Under solar assisted mechanical tray drying, as the temperature of drying air increased, drying time decreased for all the loading densities. The decrease in drying time at 65°C was very high as compared to 55°C. For the same drying air temperature, as the loading density increased, the time taken to dry stevia leaves also increased.

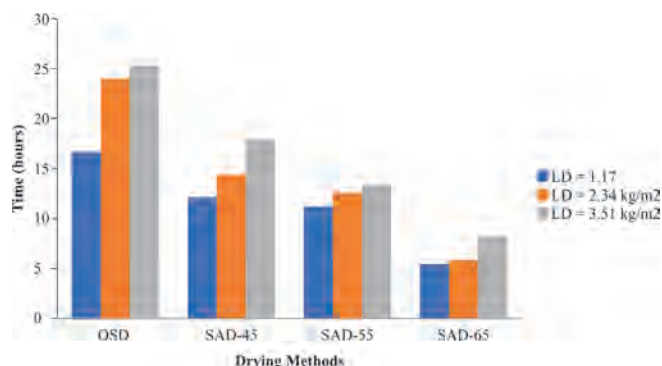


Fig. 7. Effect of loading densities and drying methods on total time to attain moisture content of 8% (db)

Validation of drying models

In case of open sun dried stevia leaves, the value of k_1 either decreased or remained constant with increasing loading density for all drying models. The value of R^2 of all fitted models showed decrease with increase in loading density. Since, there was not any particular trend in the value of MBE, RMSE, Chi square and P values among different models, so average values were compared and presented in table 3. In case of open sun drying, the least average MBE value was found for logarithmic model followed by Henderson & Pabis model and two term model as -149.81, -0.025

Table 2. Drying time taken to achieve moisture content of 8% (db) by different drying methods

Sr. No.	Drying Method	Temperature	Total Time (hours) Loading Density		
			1.17 kg/m ²	2.34 kg/m ²	3.51 kg/m ²
1	Open sun drying (OSD)	16-27°C	16.64	23.98	25.29
2	Solar assisted mechanical tray drying (SAD)	45°C	12.11	14.32	17.88
		55°C	11.20	12.53	13.34
		65°C	5.43	5.84	8.21

Table 3. Average value data for model coefficients and statistical parameters for different models

Drying	Models	MBE	RMSE	χ^2	P(%)
Sun drying	Newton Model	0.008	0.110	0.078	0.089
	Henderson and Pabis Model	-0.025	0.129	0.017	0.052
	Logarithmic Model	-49.81	176.0	0.016	0.063
	Two term Model	-0.016	0.102	-0.016	0.043
	Two term exponential Model	0.006	0.110	0.012	65.840
Solar assisted mechanical drying	Newton Model	-0.110	0.123	0.091	1.025
	Henderson and Pabis Model	-0.001	0.025	0.001	4.371
	Logarithmic Model	0.000	0.024	0.000	3.671

and -0.016, respectively. The least average RMSE value for open sun drying was obtained as 0.102 for two term model followed by 0.110 for both Newton and two term exponential model. It was observed that χ^2 value (-0.016) was the least for two term model. Also, the minimum average value of P% of stevia leaves dried under open sun was observed as 0.043 for two term model.

In case of solar assisted mechanical tray drying, the value of k1 for Newton, Henderson and Pabis, two-term and two-term exponential models decreased with increase in loading density. However, logarithmic model did not show any particular trend. Table 3 showed that the least average MBE value for stevia leaves dried in solar assisted mechanical tray dryer was observed as -0.110 for Newton model. The least average RMSE value was 0.021 for two term model. It was observed that the average error term (χ^2) value (-0.062) was the least for two-term model among all fitted models when samples were dried in solar assisted mechanical tray dryer. The minimum average value of P% was observed

as 1.025 for Newton model.

Therefore, it was concluded that the two-term and Newton model showed higher adequacy of fit between experimental and predicted data for stevia leaves dried in solar assisted mechanical tray dryer.

Quality assessment of dried stevia leaves

It was observed that drying temperature had significant effect ($p < 0.05$) on all quality parameters viz. color change, stevioside content, flavonoid content, protein content and crude fibre content. However, loading density had significant effect ($p < 0.05$) on all other quality parameters except stevioside and flavonoid content. Interaction of loading density and temperature also had significant effect ($p < 0.05$) on all quality parameters except color change (Table 4).

The quality assessment in case of stevia leaves dried in open sun drying (OSD) showed that the stevioside content, flavonoid content, protein content, crude fibre content were observed to have the least

Table 4. ANOVA for quality assessment of dried stevia leaves after drying by different methods

Statistical Parameters	Color Change	Stevioside Content	Flavonoid Content	Protein Content	Crude Fibre Content
	F value (P)	F value (P)	F value (P)	F value (P)	F value (P)
Corrected Model	17.43 (0.231)	19.26 (0.345)	17.67 (0.251)	21.21 (0.382)	16.28 (0.394)
Intercept	1.90 (0.165)	1.90 (0.173)	1.90 (0.173)	1.82 (0.193)	1.90 (0.258)
A-Loading Density	10.51 (0.001)*	10.23 (0.132)	9.78 (0.167)	11.42 (0.006)*	10.26 (0.040)*
B-Temperature	1.66 (0.003)*	1.32 (0.003)*	1.67 (0.001)*	1.54 (0.003)*	1.32 (0.012)*
AB	0.38 (0.008)	0.31 (0.002)*	0.27 (0.014)*	0.31 (0.018)*	0.32 (0.002)*
Error	0.23 (0.992)	0.27 (0.943)	0.24 (0.894)	0.27 (0.396)	0.23 (0.982)
Total Error	0.15	0.15	0.13	0.15	0.15

values, while color change was having higher values as compared to solar assisted mechanical tray drying at 45°C and 55°C (Table 5). On the other hand, in solar assisted mechanical tray dryer (SAD), the drying was done at three temperatures of 45, 55 and 65°C. The quality assessment of dried stevia leaves showed that the leaves dried in solar assisted mechanical tray dryer at 45°C (SAD-45) were found as best quality leaves in terms of color change, stevioside content, flavonoid content, protein content and crude fiber content. For 55°C (SAD-55), the quality was comparable with that of 45°C. In case of 65°C (SAD-65), although the time taken for drying was minimum, but the quality degraded due to high temperature. Moreover, at each temperature, the effect of loading density was observed and it was found that for 1.17 kg/m² and 2.34 kg/m², the quality parameters were comparable, however, for 3.51 kg/m², there was appreciable decrease in all quality parameters. It can be concluded that drying in solar assisted mechanical tray dryer was considered better as it took less time as compared to open sun drying. Also, 55°C temperature and 2.34 kg/m² loading density of stevia leaves was found to be the best combination in terms of drying behaviour and quality parameters. Drying of stevia leaves below this temperature led to longer hours of drying, while, drying above this temperature, led to deterioration in quality of dried product.

Authors' contribution:

Conceptualization and designing of the research work (GK, SR, TC); Execution of field experiments and data collection (GK, SR); Analysis of data and interpretation (GK, SR, TC, MS); Preparation of manuscript (GK, SR, TC, MS).

Declaration: The authors declare that they do not have any conflict of interest.

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