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Selected Engineering Properties and Drying Behavior of Tendu (*Diospyros Melanoxylon Roxb.*) Fruit

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Abstract

In this study, the selected engineering properties of tendu fruit (ripe and unripe) and drying of behavior of tendu fruit slices in different dryers at two temperature levels were investigated. The drying was conducted at 50°C and 60°C for the slices of 1cm, 2cm, and 3 cm in tray dryer, vacuum dryer, and freeze dryer, respectively. The moisture ratio using modified page equation was used to study the drying behavior. The engineering properties such as bulk density, true density, Carr's compressibility index, surface area, unit volume, angle of repose, and the coefficient of static friction were studied for tendu fruits , results showed a slight variation in values of ripe and unripe fruit. The porosity and Carr's compressibility index for ripe and unripe tendu fruits were found (26.12% and 24.89 %) and (6.64 and 7.67), respectively. Whereas the proximate analysis did not found major differences in the ash, crude fat, crude fiber, and protein content values. The drying ratio for vacuum drying was found better results when compared to tray drying for all thickness of fruit slices. The tendu fruit slices of 1cm thickness at 60°C found better result in vacuum drying compared to tray drying and the best fit for modeling on the basis of X2, R^2 and RSME also proved it. Freeze drying as a continuous drying process found the best quality of dried slices for all thicknesses with the final product moisture content between 7-10% (wet basis, wb).

Article History

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Keywords

Drying Rate;
Densities;
Tendu.

Introduction

Tendu (*Diospyros melanoxylon Roxb.*) is generally grown in India, Sri Lanka, China, Phillippines, and Thailand. It is commonly known as Tendu by tribes of the Indian subcontinent. Every part of the tendu plant is beneficial, either for medicinal value or, commercial purposes. The fruit is round in shape with 1.25 inch in diameter with sweet taste when

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fully matured.[22] Fruit contains 4 to 6 seeds and are oblong in shape. Tendu fruit has various health benefits as it can be used for stomach aid, fruit (dried) powder can be used in case of urinary and skin problems. As the tendu fruit is generally grown in the tribal region and is handled by tribes; proper handling and processing techniques are lacking and the masses are not aware of its nutritional benefits. Selected properties of tendu fruit will be benefit to the scientists and manufacturers for designing of machines for this underutilized fruit.

Drying process involves in heat and mass transfer criteria for the preservation of fruits, when an appropriate method of drying is used. Although removal of moisture is defined, but the safe moisture level for fruit preservation is between 9-12%. Through the literature study it has been found that the fruit dehydration process retards the microbial growth and increases the shelf life of fruits.[5] Slices fruits (dried) have good nutritional content and are convenient to use as they require less packaging and storage space. They can be an instant source of energy in a compact form.[14] This research works also emphasize on better utilization of fruits by drying the slices of fruits. Drying studies on different food products conducted by researchers such as Doymaz *et al.,* for green beans,[8] Wang *et al.,* for flax seed,[11] Pandian *et al.,* for tamarind,[9] Jangam *et al.,* for sapota,[16] Mohite *et al.,* for Lima beans.[14]

Like other seasonal fruit, the shelf life of the tendu fruit is poor and being utilized during the harvesting season only. Tribal or Adivasi or forest dwellers that are considered as the poorest in the country are engaged in the collection of this fruit are not aware of the post- harvest loss of the fruit and how to preserve and use it during off seasons. Consequently, the fruit is at present being sold as raw and the tribal people earn their livelihood, even after making much effort during the collection of the fruit. Research on processing and preservation of tendu fruit are found very few. Therefore the research work was undertaken to study the selected engineering properties of ripe and unripe tendu fruit and the drying behavior of tendu fruit slices using different drying systems and conditions were studied.

Materials and Methods

Freshly harvested ripe and unripe tendu fruits were procured from the tribal selling in the local market of Ranchi, India. Fruits were cleaned manually to remove all the impurities on them.

Engineering Properties of Tendu Ripe and Unripe Fruit

The difference in densities is an important parameter for quality analysis of tendu fruit. For modelling of heat and mass phenomenon surface area and specific volumes of fruits are needed during the drying process. The porosity of tendu fruit can be a factor for influencing airstream restriction in solid materials. The porosity affects the resistance to airflow through bulk solids. The coefficient of friction and angle of repose is required for hoppers and material handling machinery.

Bulk Density

Bulk density of tendu fruit was determined using the standard method of filling a cylinder of 1000 ml with the tendu fruit with a height of 45 cm.[13]

True Density

The water displacement method was used to determine the true density of tendu fruits. The weight of the sample to the weight of water displaces, gives the density, only when the sample is not soluble in water. True density of tendu fruit was calculated as the weight of fruits to the weight of liquid removed during the fruit immersed in water. True density of the tendu fruits was determined using average values of three replications.[7]

Porosity

The ratio of void space left out when place in a measuring cylinder on known volume gives porosity. It is given by true density to a bulk density of tendu fruits.[17]

Carr's Compressibility Index

This property deals with the compressibility and flow behavior of the tendu fruit. Carr's compressibility index is an index to indicate the level of compressibility.[10]

$$CI = 100 \times \left(\frac{TD - BD}{TD} \right) \quad ...(1)$$

Angle of Repose

The angle of repose for tendu fruit was studied using the method given by Barnwal *et al.,*[4] It is calculated as the tan inverse of twice the height (sample piled up) divided by the diameter (sample rested).

Coefficient of Static Friction

The coefficient of static friction apparatus consists of a frame box attached with frictionless pulley, weight loading pan with three surfaces *viz*. Wooden ply, Stainless steel, and Aluminium. The frame box is filled with the samples, simultaneously the weight loading pan is filled with known weighs as the sample just slides due to weight, and the coefficient of static friction is calculated as the friction force to actual force.[19]

Average Size

For the determination of the average size of tendu fruit, 100 tendu fruit (ripe and unripe separately) was randomly selected for measuring the dimensions (length, breadth and thickness) using Vernier caliper of ±0.01mm accuracy (M/s Mitutoyo, Japan).

Geometric Mean Diameter (GMD) and Sphericity (ϕ)

The geometric mean diameter, Dg and sphericity, ϕ of ripe and unripe separately tendu fruit was calculated by using the following relationships (5).

$$GMD = \left\{\frac{xyz}{x}\right\}^{1/3} \quad ...(2)$$

$$\phi = \left\{\frac{(xyz)^{1/3}}{x}\right\}\times 100 \quad ...(3)$$

Unit Volume

The unit volume of 100 individual tendu fruit was calculated from the value of three axial dimensions (major, medium, and minor), invoking the equation proposed by Altuntas *et al.,*[2]

$$V = \frac{\pi xyz}{6} \quad ...(4)$$

Surface Area

The surface area of tendu fruit was studied using the formula given by Altuntas *et al.,*[3]

$$S = \pi(GMD^2) \quad ...(5)$$

Proximate Analysis of Tendu Fruits

Proximate Composition

Proximate composition of the whole fruit, was determined according to AOAC methods 1. The fruit was analyzed by taking the average weight of 20 fruits samples. Ash content was determined in Muffle furnace at 550 ±25°C until grey ash result. Total nitrogen/protein & fat content were deterred based on Kjeldahl method and Soxhlet fat extraction method respectively. For protein content conversion factor of 6.25 was used. Triplicate samples were analyzed for each parameter[12] After the analysis of engineering properties for ripe and unripe tendu fruits, drying behavior of ripe tendu fruit slices were studied.

Drying Behavior of Tendu Fruit Slices

Drying behavior at a constant air velocity was studied in laboratory scale dryers i.e. tray dryer (M/s Universal Engineering, Baroda), freeze dryer (M/s Freeze Drying Systems Pvt. Ltd.), and vacuum dryer (operated at 15psi) in the present research work. The samples kept in the dryers were weighed at hourly intervals till constant weight was obtained.[20]

The moisture content of the tendu fruits was studied using hot air oven AOAC method.[1] The mass balance theory was used for moisture content analysis at the time of drying. Page's equation (modified) was used to obtain the drying ratios of tendu fruits.

$$MoR = \left[\frac{(Mo(t) - Me)}{Mi - Me} = \exp(-k\, t^{n})\right] \quad ...(10)$$

Where, MoR = moisture ratio, Mo (t) = moisture content, % at time, t (db); Mi = initial moisture content, % (db); Me = equilibrium moisture content, % (db); t = drying time (min); and k, n = equation constants 20. Similar modelling studies were carried by Reyes *et al.,*[9]

Drying methods used in the Study

Tray Drying

The Tendu fruit slices of 1 cm, 2cm and 3 cm were placed on trays of the re-circulatory tray dryer (M/s Universal Engineering, Badora). It was operated at 2 m/s constant air flow at 50°C and 60°C temperature. The final moisture content of slices was reached to 7- 8% (w.b) and the drying process was stopped.

The dried slices were cooled and packed in zip lock packs for further studies.

Vacuum Drying

The tendu fruit slices of 1 cm, 2cm and 3 cm, were placed on perforated stainless steel trays in a vacuum dryer at 50°C and 60°C in separate batches. The drying was continued until, 7 to 8 % (wb) moisture content was obtained. The vacuum pressure of 500 mm Hg was kept during the complete experiment.[9] Finally, the sample was allowed to cool in desiccators and packed in zipped polyethylene bags and stored for further study. The dried slices were cooled and packed in zip lock packs for further studies.

Freeze Drying

The tendu fruit slices were initially placed in a deep freeze for 12 hrs at -20°C. Further the slices were uniformly spread on stainless steel tray inside the freeze dryer (M/s Freeze Drying Systems Pvt. Ltd,Vadodara). The freeze-drying of the slices was carried out at -40°C and 10 bar for 16 h. The freeze-drying of tendu fruit was continued until it attained a moisture level of 7 to 8 % (wb), drying was carried out at 50°C and 60°C, respectively.[9] The dried slices were cooled and packed in zip lock packs for further studies.

Model Fitting

Drying studies are essential to predict the loss of moisture at different drying time intervals. Model fitting in this study was conducted to find out best fit which was based on X^2, R^2 and RSME. Root Mean Square Error (RSME) is used to find out the difference between the actual data (during the experiment) and the estimated data. Various researchers found lower values of X^2 and RSME as the best fit during their studies of drying kinetics[9] and.[19] Even though there are various models used in drying behavior of the fruits and vegetables, but the modified page equation has predicted good results for best fit, therefore it was selected for drying of tendu slices in this investigation.

Statistical Analysis

For statistical analysis, Stata software 6.0 was used. Analysis of significant difference was carried out by using the Durbin Watson test method to describe the effect of ripe and unripe tendu fruit ($p \leq 0.05$) on drying behavior and engineering properties.

Table 1: Engineering properties of ripe and unripe tendu fruit

S.No.	Properties	Ripe Fruit	Unripe Fruit
1	Bulk Density (kg/m^3)	1160.21 ±.55^a	1098.55±.87^a
2	True Density (kg/m^3)	1241.76±.05^a	1190.11±.07^a
3	Porosity %	26.12±1.80^b	24.89 ±.85^b
4	Carr's Compressibility Index (CI)	6.64 ±.12^b	7.69 ±.021^b
5	Angle of Repose	27.47 ±.0.27^b	26.55±.0.38^b
6	Coefficient of static friction (Wooden ply)	0.28±0.02^b	0.27±0.01^b
	(Aluminium)	0.24±0.01^b	0.21±0.02^b
	(Stainless Steel)	0.20±0.02^b	0.19±0.01^b
7	Geometric Mean Diameter (GMD)mm	36.9 ±.04^b	35.7±.06^b
8	Sphericity%	0.97±.0.13^c	0.94±0.19^c
9	Unit volume m m^3	543.32± 47^c	506.9 ± 61^c
10	Surface Area mm^2	356.39 ± 39^a	319.32 ± 45^a

Significant difference was ($p \leq 0.05$).

Results and Discussion

Engineering Properties of Tendu Fruit

The engineering properties of tendu ripe and unripe fruit were studied as the average values of three replications. Bulk density and true density values of tendu fruit are represented in the Table 1. From the randomly selected 100 fruits average numbers of fruits were of medium size and as the size of fruit was around 3.5 cm, the difference was found due to the weight of each fruit counted in density calculations.[10] The void ratio (porosity) was found more in ripe fruits due to volumetric expansion of fruits was more compared to unripe fruits.[6] Similarly Carr's compressibility index is related to bulk density and true density and has a direct effect on its values. Angle of repose was found, 27.47 and 26.55 for ripe and unripe fruit. The shape of tendu fruit become closer to sphere, as the fruit reaches towards the end of its maturity stage due to this fact fruit settle on each other and the angle required for sliding was found higher in ripe fruits. The coefficient of static friction values was highest for wooden ply surface, followed by aluminum surface, and SS surface. The results for the coefficient of friction were found at (0.28 and 0.27) for wooden ply (0.24 and 0.21) for aluminum and (0.20 and 0.19) stainless steel surface of ripe and unripe fruits, respectively. Lower values of coefficient of friction indicated the smooth surface finish of stainless steel and aluminum compared to wooden ply surface. Altuntas *et al.,*[3] studied that a continuous increase in coefficient of friction with increasing moisture content in fenugreek seeds.

Surface areas and unit volume were found 356.39 mm^2 and 543.32 mm^3 for ripe fruit, whereas 319.22 mm^2 and 506.9 mm^3 found unripe, respectively. The results for geometric mean diameter and sphericity were found at (36. 9 and 35.7) and (0.97 and 0.94) for ripe and unripe fruit. Although there is a marginal difference in the size of ripe and unripe tendu fruit, but due to non- uniform size (according to sphericity calculation) fruits found the difference in sphericity and GMD. Close results of the present study was found in kendu fruit by Hmar *et al.,*[22] The Table. 1 shows the engineering properties of ripe and unripe tendu fruits were some properties are found significant and for others it was found non-significant ($P \leq 0.05$).

Proximate Analysis

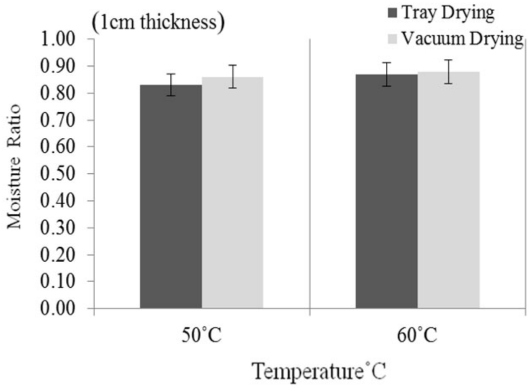
Ash content of ripe tendu fruit was found slightly higher in amount as compared to and unripe fruit. Ash content, crude fat and crude fiber contents of ripe tendu fruit were found as 3.85%, 0.91 %, and 2.83%, respectively. Similarly, for unripe fruits the values were found as 3.15%, 0.82%, and 2.69 %, respectively.[14] The proximate composition was performed to observe a compositional change in tendu fruit due to the difference in harvesting stages of fruit (fruit harvest at fully ripe stage and fruit harvest at unripe stage). But there was a significant difference found in the analysis ($P \leq 0.05$). The higher ash, crude fat and crude fiber content in ripe fruit was due the development of minerals, lipids and fibrous tissues more in fully matured fruit compared to under matured fruit. The protein contents of ripe and unripe fruit were found 0.64% and 0.58%, respectively, as protein synthesis is more in ripe fruit and this is an indication that there is a more protein content development, as the fruit gets fully matured.[15]

Drying Behavior of Tendu Fruit

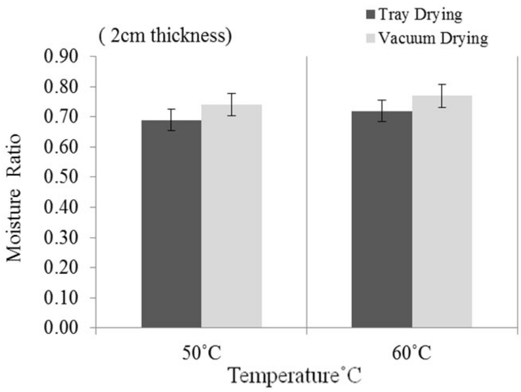
After completion of engineering properties of ripe and unripe tendu fruit, further ripe fruits were chosen for drying characteristics of tendu fruits. Graphical representation of a tray and vacuum drying of tendu fruit slices is given in Figure 1.

Ripe tendu fruits sliced into 1 cm, 2cm, and 3 cm were spread uniformly on tray surfaces of different dryers. Tendu fruit at different dryers took 480-540 min for drying when dried in at 50 to 60°C. A drying graph of Tendu fruit slices exposed to the air at two drying temperatures was studied by a plot of moisture content against temperature[15] and [18]. The results found, clearly indicates that initial drying hours played the important role in re-circulatory tray drying and vacuum drying of tendu slices at both the drying temperatures. The drying rate of fruits and vegetable is more complex during the falling rate period,[14] and [17]. The results showed that the temperature of drying and the drying time was significant ($P \leq 0.05$). The moisture ratios obtain for tendu fruit slices was found at (0.83, 0.69 and 0.47) for 50°C and (0.87, 0.72 and 0.55) for 60°C for tray dryer, respectively. Close trend for moisture removal was found for tamarind.[20]

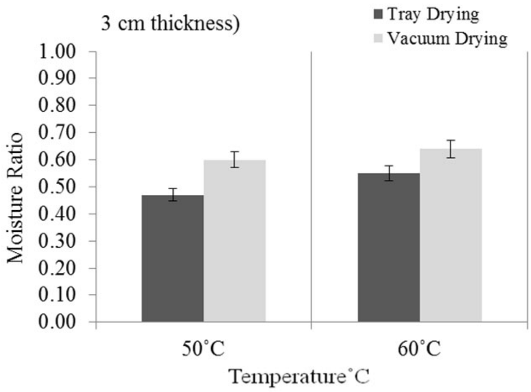
Similarly the values found (0.86, 0.74 and 0.60) for 50°C and (0.88 0.77 and 0.64) for 60°C in a vacuum dryer respectively. Drying at 60°C for 1cm slices, at a constant air velocity showed the best results for tray and vacuum drying process. In case of freeze drying hourly reading was not possible, therefore final drying data was only possible, which was found as (0.93, 0.92 and 0.91)and (0.96, 0.94 and 0.90), for 50°C and 60°C, respectively. Close agreement of results was founded with studies conducted on freeze drying of strawberries slices at 30°C, 40°C, 50°C and 60°C by Shishehgarha *et al.,*[23] Drying at 60°C in vacuum drying showed satisfactory results when compared with tray dryer for 1cm, 2 cm and 3 cm thickness. Freeze drying process is a continuous drying process where an hourly reading of samples was not possible, therefore only the final reading as recorded. The results finding found best quality of dried slices for all thickness with the best moisture ratio (0.93 and 0.96) and the final product moisture content between 7-8% (wb).



(a)



(b)



(c)

Fig. 1: Drying behavior of tendu fruit slices of thickness 1 cm (a), 2 cm (b) 3 cm (c)

Table 2: Model fitting parameters at different drying methods and temperatures

Drying Methos	Temperature°C	X^2	R^2	RMSE
Tray Drying				
	50	0.023	0.95	0.0554
	60	0.025	0.97	0.053
Vacuum Drying				
	50	0.001	0.97	0.0027
	60	0.002	0.99	0.0047
Freeze Drying				
	50	0.003	0.96	0.0025
	60	0.007	0.98	0.0023

Model Fitting

A modified page equation was used as drying model in this study. Non-linear regression was selected for the present study to obtain the values. Table.2 represents the results obtained from the model fitting. The higher values of R^2 and lower values of X^2 and RSME is an indicator for the goodness of fit. During the analysis, it was found all the R^2 values were found above 0.95 which shows a good possibility of curve fitting. X^2 and RSME values were found in the range of (0.23 to 0.001) and (0.0023 to 0.0554) respectively. The best fit was found for 60°C drying for vacuum drying as R^2 (0.99), X^2 (0.002) and RSME (0.0047), respectively.

Conclusions

The research work was based on the analysis of engineering properties of tendu fruit (ripe and unripe) and drying behaviour ripe fruit slices, the following are conclusions drawn.

1. The engineering properties such as bulk density, tap density, coefficient of friction and angle of repose found slight difference in ripe and unripe fruits values.
2. Proximate analysis, such as ash content, crude fiber, crude fat and protein found slight differences in values for ripe and unripe fruits ($P \leq 0.05$).
3. Drying at 60°C was best suited for tendu fruit slices of 1 cm thickness in vacuum drying when compared to tray drying this was also validated by R^2 and X^2 and RSME.
4. The quality of final tendu fruit slices of 1cm thickness found best for freeze drying when compared to tray and vacuum drying system.
5. As freeze drying is a continuous process and the final product found was better in terms of quality when compared to other drying process.

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Conflict of Interest

The authors do not have any conflict of interest with any person or organization in publishing this article.

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