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RESEARCH ARTICLE

Design and Development of a Belt Type Dryer for Drying Tamarind

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ABSTRACT

Tamarind pulp is the most valuable and commonly used part, which is acidic and is mostly used in Indian cuisines. After harvesting the tamarind fruit, it is dried under the open sun or by mechanical methods, which helps separate the outer hull and seeds manually or mechanically. The stickiness of the tamarind fruit is a major problem observed during deseeding, and it is done manually by beating the fruits with sticks. A belt conveyor type dryer was developed to reduce the moisture content of dehulled tamarind fruit to an optimal level for deseeding the fruits. The dehulled tamarind fruit was dried at three different temperatures (50, 60, & 70 ^{o}C), three different feed rates (5, 7.5 & 10 kg h^{-1}) with an airflow rate of 1.5 m s^{-1}. The optimized temperature, airflow rate, and feed rate were 60 ^{o}C, 1.5 m s^{-1} and 5 kg h^{-1}, respectively. The moisture content of the tamarind fruit was reduced from 19 (% d.b.) to 11.35 (% d.b.) at the end of the drying process.

Keywords: *Tamarind fruit; Belt conveyor; Dryer; Design; Engineering properties*

INTRODUCTION

Tamarind is found abundantly in Indian states of Karnataka (87,000 tonnes), Tamil Nadu (53,000 tonnes), Kerala (20,000 tonnes), Andhra Pradesh (12,640 tonnes), Maharastra (11,400 tonnes), and Telangana (3740 tonnes) during the year 2019-20 (Spice Board, India, 2020). Almost all tree parts find some use in food, chemical, pharmaceutical, textile industries, and as fodder, timber, and fuel (Dagar *et al*.,1995). India is also an exporter of fresh tamarind, mainly to Europe and Arab countries and lately to the United States where over 10,000 tonnes are exported annually (Jarimopas & Jaisin, 2008).

A typical tamarind pod contains about 55% pulp, 34% seed, and 11% hull and fiber (Pandian and Rajkumar, 2016). Tamarind pulp has excellent keeping quality when dried properly and cured with salt. The pods are allowed to ripen on the tree until the outer hull is dry and thereafter harvested, and the hulls are removed manually. The pulp is then separated from the seeds and fibers and dried in the sun to reduce its moisture level. Then it is packed in palm leaf mats, gunny bags, or polythene bags and stored in a cool dry place (Pandian and Rajkumar, 2018).

Tamarind processing commonly includes the unit operations of drying pods, dehulling, deseeding, pressing into cakes, and storage. The dehulling process is carried out to remove outer hull portion of the tamarind fruit. After dehulling, the tamarind fruits have to be dried, before deseeding operations. To deseed the tamarind fruits effectively, the moisture content has to be reduced to 12 % dry basis. Drying food products is the oldest post-harvest operation for preserving food products (Moneo *et al*., 2010). For processing and preserving the tamarind, several drying methods are employed. One of the traditional methods to dry the tamarind fruit is sun drying (Okilya *et al*., 2010). This involves spreading the tamarind fruit on the concrete floor or a raised platform under the sun immediately after the harvest. These fruits are stirred manually to provide even drying. Sun-drying has many disadvantages such as uncontrolled drying process, poor quality, longer drying time, risks for contaminations (such as rain, storm, windborne dirt and infestation by insects, rodents) and insufficient drying (spoilages) due to less sunshine.

Mechanical drying has a lot of advantages compared to the sun drying method. The hot air for drying can be generated through electricity or burning fuel. The hot air temperature required for drying can be controlled using a thermostat. Therefore, the drying process is uniform. The total time required for drying under mechanical drying is comparatively lesser than sun drying. Also, the losses in sun-drying are more when compared to mechanical drying (Karthickumar *et al*., 2015).

Though many drying methods are available for the continuous operations of deseeding, a mechanical conveying type dryer is ideally suitable. For deseeding operation, the dried tamarind fruit is to be continuously fed to avoid stickiness during deseeding. The existing deseeding operation is not perfect due to the stickiness of the tamarind fruit. This can be avoided by feeding dried tamarind fruits in a continuous manner using a mechanical conveyor type dryer. Keeping this in mind, a study was undertaken to design and develop a mechanical conveying type dryer and to optimize the required drying conditions for deseeding the tamarind fruits.

MATERIAL AND METHODS

Engineering Properties of Tamarind

The dimensions of the tamarind fruit, namely, length (L), breadth (B), and thickness (T) were measured using a Vernier caliper. The average values were reported in cm. The Geometric mean diameter (D_g) and Sphericity index (Φ) of the fruit were calculated by using the formula as referred by (Felix Uba *et al*., 2020). The bulk density of tamarind fruit was determined using a cube box with a volume of 1000 cm^3. The samples were filled in a box of standard size, and the top surface was leveled off. Then the samples were weighed using an electronic weighing balance. The bulk density (kg m^{-3}) was determined based on the formula as adopted by Li *et al*. (2011). The static co-efficient of friction of tamarind fruit was determined against four different surface materials: rubber, plywood, mild steel, and aluminium sheet. The static angle of friction was calculated when the tamarind fruits just began to slide over a plane surface as per the formula used by Altuntas and Sekeroglu (2008). The angle of repose is the angle between the base and slope of the cone formed on a free vertical fall of the tamarind fruits to a horizontal plane. It was found by measuring the height and diameter of the fruits heaped in natural piles by using the expression as adopted by Kabas and Ozmerzi (2008).

Design of the Tamarind Dryer

The dimension of the drying chamber was determined with the assumptions that the configuration is horizontal and the mass of tamarind fed at the rate of 5, 7.5 and 10 kg h^{-1}. The angle of surcharge of a material is the angle to the horizontal, which the surface of the material assumes while the material is at rest on a moving conveyor belt. For tamarind fruit, the angle of surcharge (β) was found to be 6-7°. In this design, the flat belt with a troughing angle is taken as 0° and since the troughing angle for the flat belt is zero, the belt width is taken as 35 cm. The lump height was assumed as 40 mm for the ease of conveying without clogging dehulled tamarind. Hence, the total belt width was taken as 400 mm. Based on the belt speed, belt material, belt width and lump size of the tamarind fruit, the conveyor was allowed to run at 0.002 m s^{-1} (Visweswarao *et al.*, 2013).

Belt capacity is the product of speed and belt cross-sectional area. The power required at the drive pulley can be calculated from the belt tension and speed value and it was found as 0.0132 kW. The motor power is calculated from the ratio of absorbed power to the overall efficiency and estimated as 0.74. Hence, 1 hp (0.745 kW) motor was chosen for the better performance of the dryer. Considering all the resistances (including Wrap & bearing resistances), the torque can be assumed as 1.42 Nm based on the experimental trials. The shaft material is made of mild steel, and the safe shear stress is assumed to be 420 kg/cm^2. The diameter of the shaft (d) was determined by using the values of torque and the maximum permissible stress on shaft; therefore, the diameter of the shaft was selected as 5 cm for the conveyor type dryer. The drying unit was a conveying type model, which helps to dry the tamarind fruit uniformly. The tamarind dryer consists of a feed hopper, conveying unit, blower unit (heating coil and blower), motor with gear box, frame, rotor and cylindrical shaft, variable auto transformer, power transmission system and recirculation unit. The conveyor is driven by a motor (Fig.1).

A rectangular-shaped hopper having a size of 75 x 40 cm, made up of mild steel plate was fixed at an angle of 40^o to the horizontal surface. The conveying unit consisted of an endless wire mesh of 35 cm width, rolling over two end pulleys, kept at a distance of 250 cm. The wire mesh was connected with chains on both sides to avoid slippage. A strip of 37 numbers as fitted for the uniform conveying and drying of dehulled tamarind fruit. The drying chamber was enclosed fully with a galvanized iron sheet to cover the entire drying chamber to avoid heat loss. The blower unit is comprised of a centrifugal fan, and the air velocity can be controlled by the adjustment provided in the blower ranging from 0.1 to 2.0 m s^{-1}. The blower case housed a centrifugal fan that blew ambient air to the heating coil of 4 numbers of 1000 Watts, which was fitted at the sides of the drying chamber. A 0.15 hp single phase electric centrifugal fan motor of 2880 rpm was used to operate the blower. The conveying unit was connected to a variable speed motor. Required horsepower of one hp single phase electrical motor was selected and was connected to the speed reducer for adjusting the rpm of the belt conveyor. A frame was made up of L-angle section of size 4.0 x 4.0 x 0.6 cm. The size of the frame at the top was 300 x 46 cm. The height of the frame was 90 cm. The frame was fabricated with a provision to mount and support other parts of the dryer and to withstand the minimal vibrations during drying operations. The rotor shaft is covered by a hollow cylinder of size 50 cm in length and 2.54 cm in diameter with each end connected to a chain sprocket with one end coupled to the power transmission unit. The continuously variable autotransformer regulates the input current of the heating coil by adjusting the power supply. It ranges from 0 to 240 V as per the requirement.

Drying Operation

Five kilogram of whole tamarind fruit was taken for the sun drying study. To remove the hull, it was spread on a polythene sheet for open sun drying for three consecutive days. For mechanical drying, the dryer was adjusted to a preset temperature for about half an hour prior to the experiment to achieve the steady state. The experiments were carried out to dry dehulled tamarind fruits at three temperatures of 50, 60 and 70 ^{o}C.The air velocity of the blower was kept as 1.5 m s^{-1} with the feed rates of 5, 7.5 and 10 kg h^{-1}. Initially, the dehulled tamarind fruit sample was taken at 19 (% d.b.) moisture content. The weight loss was taken at every ten-minute interval with three replications of temperatures and feed rate.

Moisture content

The moisture content of tamarind fruits was determined as per the standards of the American Society of Agricultural Engineers (Ali *et al*., 2014) using the formula (Eqn.1):

$$M.C. = \frac{(W_i \quad W_f)}{W_f} x100 \qquad \text{.........................} (1)$$

where,

M.C. is the moisture content in (% d.b.); W_i is the Initial weight of sample in g; W_f is the final weight of sample in g

Evaluation of Drying Rate

The length of time needed to dry a product from initial moisture content to final moisture content and also the rate is to be known. The drying rate is calculated as expressed in Eqn. 2 (Isabel *et al*., 2000).

$$D_R = \frac{m_i - m_f}{t} \qquad \text{.........................} (2)$$

where,

D_R is the drying rate in kg h^{-1}, t is the total time in h, m_i is the initial mass of tamarind samples in kg and m_f is the final mass of tamarind samples in kg.

Evaluation of Dryer Efficiency

This indicates the ratio of Energy utilized for heating the product for moisture evaporation to the total consumed Energy. The efficiency of the machine used for drying the tamarind sample can be calculated as per the Eqn. (3) as referred by Adamade and Olaoye (2014).

$$\eta\ (\%) = [\text{Energy utilized by the dryer} / \text{Energy supplied to the dryer}] \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Statistical Analysis

Experiments were performed in triplicate. The data were analyzed by one-way analysis of variance (ANOVA), using SPSS Statistics Version 20 (USA), and presented as mean plus/minus standard deviation. The least-squares difference (LSD) test was employed to determine the statistical significance of the differences between the means ($p \leq 0.05$).

RESULTS AND DISCUSSION

Engineering Properties of Tamarind Fruit

The average length, width and thickness of the dehulled tamarind fruits were recorded as 112.59 ± 10.52 mm, 25.84 ± 3.73 mm and 15.20 ± 1.75 mm respectively. The mean values of sphericity index, surface area, bulk density and geometric mean diameter were found to be 0.32 ± 0.04, 1391.46 ± 25.42 mm^2, 611.3 ± 3.06 kg m^{-3} and 25.12 ± 3.16 mm respectively. The average value of angle of repose for dehulled tamarind fruit was found to be 44.84 ± 7.46°. These physical properties such as size, shape, bulk density, angle of repose are important in designing the tamarind processing equipment (Zare *et al*., 2012).

The maximum static co-efficient of friction was noted on rubber (0.82 ± 0.03) and plywood (0.78 ± 0.03) surfaces, followed by mild steel sheet (0.60 ±.0.02). The lowest co-efficient of friction of tamarind fruit was obtained for stainless steel surface (0.42 ± 0.01), followed by aluminium sheet (0.50 ± 0.01) due to their surface smoothness compared to other surfaces. The data showed that frictional properties vary significantly among the surfaces of materials (Ozguven & Vursavus, 2005).

Sun Drying

The time required to dry tamarind from an initial moisture content of 19.00 (% d.b.) to a final moisture content of 11.91 (% d.b.) was 24 h and the moisture content was recorded from 9.00 am to 17.00 pm at one hour interval (An *et al*., 2016). The entire sun drying process was observed to follow in the falling rate period of drying (Zielinska & Michalska, 2016). The drying rate on the first day was initially found to be 0.0389 kg of water removal per kg of dry matter and reached the final value of 0.0259 kg of moisture removal per kg of dry matter on the third day of drying. Kumar *et al*., (1997), reported similar results for drying the tamarind fruit. It is obvious that there was a reduction of moisture content while drying time was increased under sun drying.

Effect of Moisture Content and Drying Rate on Dehulled Tamarind Fruit at Different Temperatures and Feed Rate

Drying Characteristics of dehulled tamarind fruit at 50 °C

The drying characteristic curves of tamarind fruit dried at 50 °C with a combination of feed rates namely 5, 7.5 and 10 kg h^{-1} are shown in Figs. 2 and 3. From the Fig. 2, it is seen that the final moisture content was 11.57 (% d.b.), which was reduced from an initial moisture content of 19 % (d.b.) in eighty minutes (Pandiarajan *et al*., 2021). The drying process recorded a drying rate value of 0.0581 kg of moisture removal per kg of dry matter at the end of the drying process. The average drying rate values recorded at ten, twenty, thirty, forty, fifty, sixty and seventy minutes of drying were 0.0986, 0.0884, 0.0845, 0.0798, 0.0724, 0.0684 and 0.0634 kg of moisture removal per kg of dry matter, respectively and then reached an equilibrium moisture content after one hour of drying. The average drying rates for the feed rates of 7.5 and 10 kg h^{-1} were found to be 0.09874, 0.09236, 0.08751, 0.08298, 0.07524, 0.07298 and 0.06986; 0.09914, 0.09521, 0.08722, 0.08124, 0.07845, 0.07423 and 0.07157 kg of moisture removal per kg of dry matter, respectively. Based on these results, it is evident that as the feed rate increased, the drying rate decreased during the drying process. Similar drying characteristics results were reported in mushrooms with a maximum drying rate of 2.3 kg/(kg min) and 3.6 kg/(kg min) using hot air and infrared dryer by Wang *et al.* (2019).

Drying Characteristics of dehulled tamarind Fruit at 60 °C

The relationship between the moisture content of tamarind fruit against drying time with the air velocity of 1.5 m s^{-1} and different feed rateswas plotted and presented in the Figs. 4 and 5. The initial moisture content of tamarind fruit at the beginning of the drying process was 19 (% d.b.) and then reached the equilibrium moisture content at the end of the drying process as 11.35 (% d.b.) in 60 minutes. Similarly, Ozgen and Celik, 2019 obtained a final moisture content of 10 (% d.b.) in 360 min at 45 ^{o}C from an initial moisture content of 80 (% d.b.). Initially, the drying rate was at 0.0987 kg of per kg of dry matter and after drying at the temperature of 60 ^{o}C with the air velocity of 1.5 m s^{-1} and by feeding the dehulled tamarind fruit at 5 kg h^{-1} continuously, the final drying rate obtained was 0.0566 kg of per kg of dry matter. At the feed rates of 7.5 and 10 kg h^{-1}, the drying rate decreased gradually at the end of the drying process and it was found to be 0.09712 to 0.05661 and 0.0987 to 0.07257, respectively. It is difficult to remove moisture at increased feed rate levels, particularly bound moisture due to the thickness of the tamarind fruits passed in the conveyor belt. Pandian and Rajkumar (2016) reported a similar reduction in drying rate of tamarind fruit during drying.

Drying Characteristics of dehulled tamarind fruit at 70 ^{o}C

The relationship between the moisture content of tamarind fruit against drying time is shown in Fig. 6. At the beginning of the drying period, the initial moisture content was 19.00 (% d.b.) and at the end of the drying period, it was 11.14 (% d.b.) in 60 min. Pandiarajan *et al*., (2021) reported that the moisture content of the tamarind fruit decreased drastically, as the temperature and air flow rate of the hot air increased inside the dryer. From the Fig.7, it is seen that after one hour of drying, the drying process recorded a drying rate value of 0.0547 kg of moisture removal per kg of dry matter at the feed rate of 5 kg h^{-1}. After ten, twenty, thirty, forty and fifty minutes of drying, the average drying rates were found to be 0.0951, 0.0821, 0.0716, 0.0611 and 0.0564 kg of moisture removal per kg of dry matter, respectively and then reached an equilibrium moisture. Similarly, the average drying rate for the feed rates of 7.5 and 10 kg h^{-1}, were found to be 0.0978, 0.0844, 0.0774, 0.0647 and 0.0582, 0.0987, 0.0865, 0.0775, 0.0683 and 0.0618, respectively. The drying rate is found to be higher at the feed rate of 5 kg h^{-1} due to less thickness of the material over the belt dryer.

Dryer Efficiency

It was observed from Fig. 8 that the drying temperature of the dryer had significant effects on the efficiency of the dryer. For this type of tamarind fruits, the sample dried at

50 ^{o}C had the lowest efficiency for all the quantity dried. It was also observed that at 60 ^{o}C, 5 kg h^{-1} feed rate, the highest drying efficiency of 88.21 % was obtained and reduced for the feed rates of 7.5 kg h^{-1} and 10 kg h^{-1}. This might be due to the fact that tamarind fruit has more moisture so at reduced weight, it dried faster. Also, the tamarind fruit dried at 70 ^{o}C recorded no significant differences in feed rates at 5 and 7.5 kg h^{-1} compared to the feed rate of 10 kg h^{-1}. The efficiency increased with an increase in drying temperature and drying time. This confirms the finding of Olalusi *et al*. (2006).

CONCLUSION

The performance of the tamarind dryer was tested by drying at three different temperatures viz., 50 ^{o}C, 60 ^{o}C and 70 ^{o}C, three different feed rates viz., 5 kg h^{-1}, 7.5 kg h^{-1} and 10 kg h^{-1} and with the airflow rate of 1.5 m s^{-1} for optimizing the maximum efficiency of the dryer. The developed dryer was run at the speed of 0.002 m s^{-1}. Among the treatments tested, the treatment (10 kg h^{-1} at 50 ^{o}C) was considered poor in removing the moisture content of tamarind, which took a longer time for drying in the dryer. Among the combination of treatments, it was observed that the drying efficiency was found to be maximum at the feed rate of 5 kg h^{-1} dried at 60 ^{o}C. At this combination, the moisture content of the dried tamarind fruit was found to be 11 (% d.b.). The color retention was also found to be comparatively higher. Hence, this combination was considered the best treatment for drying dehulled tamarind fruits that were suitable for deseeding considerably.

FUTURE WORK

it is required to connect the dryer between dehuller and deseeder and exposing the dried tamarind to dehumidified air for increasing tamarind brittleness for effective deseeding in a continuous manner.

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CONSENT FOR PUBLICATION

All the authors agreed to publish the content.

Ethics Statement

Specific permits were not required for the above studies because no human or animal subjects were involved in this research.

Originality and plagiarism

The authors declare that the work carried out in this research paper is the original work carried out and has not been published earlier or sent for publication to other research journals.

Competing interests

The authors declare that they have no competing interests.

Data Availability

All the data of this manuscript are included in the manuscript. No separate external data source is required.

Author's contribution

Dr.P.Rajkumar performed the idea of this article. Er. S.Idhayavarman carried out the experiment. Dr.J.Deepa wrote the manuscript. Dr.C.Indu Rani encouraged to investigate and supervised the findings of this work. Dr.P.Sudha verified the analytical methods. Dr.Arulmari developed the theory and performed the computations. Dr.G.Amuthaselvi contributed to the interpretation of the results.The authors wish to akcknowledge the AICRP on PHET scheme for the financial support

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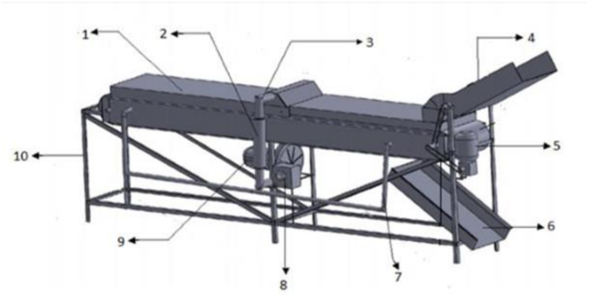

1. Drying chamber 2. Heating coil 3. Heating coil connection to chamber 4. Inlet-Feed hopper 5. Motor (1.0 hp) 6. Outlet 7. Air recirculating pipe 8. Temperature controller 9. Air Blower 10. Frame

Fig. 1 Isometric view of belt conveyor type dryer for dehulled tamarind fruit

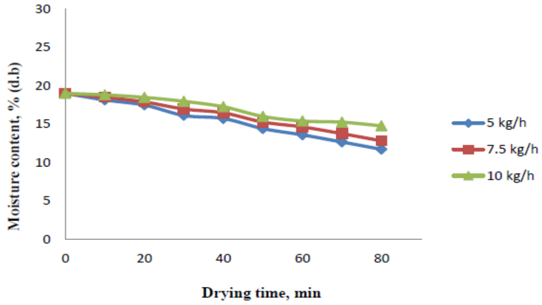

Fig. 2 Moisture content of tamarind fruit dried at 50° C and at different feed rates

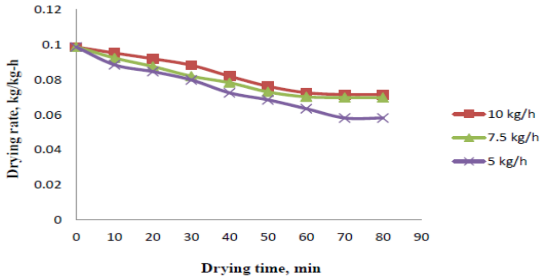

Fig. 3 Drying rate of tamarind at 50 °C and at different feed rates

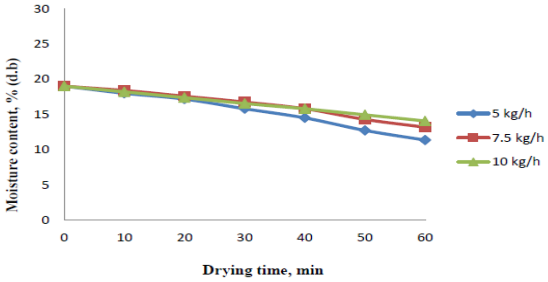

Fig. 4 Moisture content of tamarind fruit dried at 60 °C with different feed rates

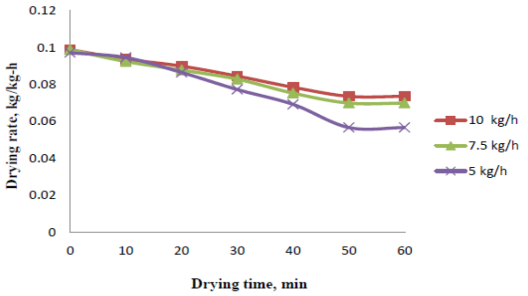

Fig. 5 Drying rate of tamarind at 60 °C with different feed rates

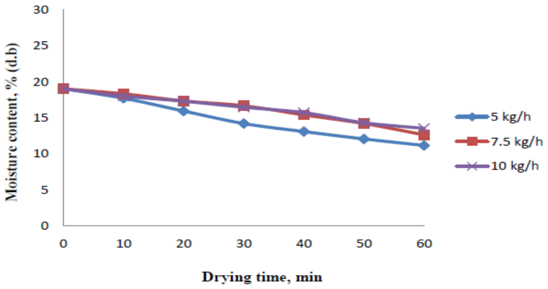

Fig. 6 Moisture content of tamarind fruit dried at 70 °C at different feed rates

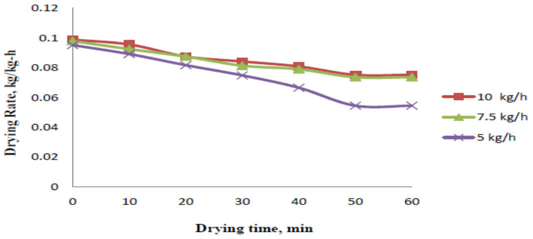

Fig. 7 Drying rate of tamarind at 70°C at different feed rates

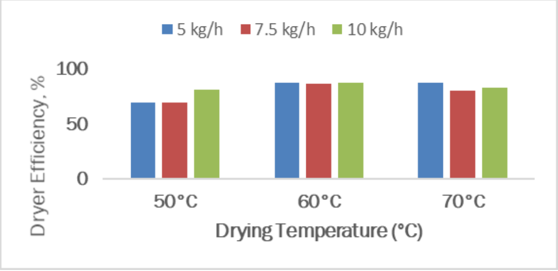

Fig. 8 The effects of drying temperature and feed rate on dryer efficiency