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FULL-LENGTH RESEARCH ARTICLE

Effect of Different Grinding Processes on Powder Characteristics of Tamarind Seeds

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Abstract Tamarind seed powder (TSP) is a natural hydrocolloid source with an intended vast application in food industry. Different milling processes and moisture content found to affect the grinding properties of tamarind seeds. The present study was conducted to understand the grinding characteristics of tamarind seed powders prepared using attrition and hammer mills at different moisture levels. The average particle size and fineness modulus were found in the range of 0.99–1.36 and 0.39–0.45 for attrition and hammer mills, respectively, in moisture content range 5–15%. The values of Rittinger's constant and Kick's constant were found to be 1.6–1.9 and 0.8–1.5 for attrition mill, and 0.5–0.80 and 0.6–1.1 for hammer mill, respectively. Colour indicator, i.e. whiteness index (WI), found better values (82.29–81.11) for hammer-milled in comparison with (80.96–77.18) attrition-milled samples. Thermal conductivity values of hammer-milled samples were in the range of 0.046–0.069 W/m °C and 0.058–0.075, W/m °C for attrition-milled samples. Through the present analysis, hammer mill was found to be highly suitable for making TSP, whereas attrition mill did not give desirable results.

Keywords Tamarind seed powder · Attrition mill · Hammer mill · Grinding and colour

Introduction

In the last century, there was a tremendous growth in the science of nutrition and food industry, and a new concept of functional food has been introduced. A class of foods, conventional and/or modified, that included additional health benefits beyond basic nutrition is named as functional food. Hydrocolloids are used extensively as food because of their quality to reform rheological properties of food. Hydrocolloids from seeds of locust beans, guar, tara, fenugreek, psyllium, flax, yellow mustard and tamarind have been used as functional food. Polysaccharide hydrocolloids from renewable resources are of extreme interest as replacements for polymers from non-renewable sources. A concise knowledge of rheological properties combing with thermal aspect with other hydrocolloids systems is the need of the time that would eventually lead to several food products with improved physical properties and health benefits.

It is utmost important to study the thermal conductivity of a raw material or hydrocolloid ass it plays an essential role while modelling the thermal processes including cooking, pasteurization, sterilization, chilling and freezing. In case of particulate foods like powders, the thermal conductivities may differ drastically even for the products which are morphologically similar [11].

Tamarind (*Tamarindus indica L*) seed powder is one of the natural hydrocolloid sources. Tamarind seed powder has galactoxyloglucan polysaccharide (55–65%), lipids (6–10%), proteins (18–20%), little amount of fibres, sugar, etc. [17]. Tamarind xyloglucan (TXG) is a galactoxyloglucan, widely used in the food industry as a functional ingredient for rheological control of the aqueous phase. It is intended for use in ice cream, sauces and condiments, dressings and mayonnaise, fruit preserves, desserts, beverages, pickles, tsukudani,

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spreads and fillings, flour products, soup and all other food categories. It forms a gel over a wide pH range. Less sugar is needed to achieve the desired gel strength than in corresponding pectin gels. It can be used in jams, jellies, marmalades and mayonnaise production cited by Mishra and Malhotra [18]. The gels exhibit only a low syneresis phenomenon. The addition of xyloglucan (XG) affects bread quality as it increases the stability of the dough and improves the loaf and softness. XG increases the water activity of the dough, and therefore, the gluten matrix of dough becomes strong and uniform [18].

The size reduction of food raw materials is primarily used for the conservation of energy by increasing surface area, pore size of the material and number of contact points in the compaction process [12]. Vitality utilization of ground biomass relies upon size of particles, moisture content of product, its properties and machine factors. Economically accessible machines that are used for creating small size of particles are usually hammer mills [15]. Product is reducing down in size when a continuous impact forces are applied on it in a confined casing. The sieve at the bottom of the grinder outlet majorly influences shape and particle size of the product [14]. Commonly hammer mills are used for medium- to hard-to-mill products for grinding process. Tamarind seed is a hard-to-mill material; even some of its seeds may damage the grinding zone of mills. Its seed with higher moisture content may stick inside the grinding zone if the mill is run for longer period. The knowledge of the raw material (tamarind seeds) characteristics like initial moisture content, temperature of grinding and grinding method used for obtaining tamarind seed powder will be useful for millers and manufacturer in selecting appropriate TSP for application in food products. It will drastically reduce the chances of error in contrast to hit-and-trial method which is presently used by millers and manufacturer. Barnwal et al. 2015 [2] studied the grinding characteristics of fenugreek at cryogenic and ambient conditions. The authors in this study are reporting the grinding characteristics of tamarind seed at different moisture contents, using attrition and hammer mill to determine the appropriate milling process.

Materials and Methods

Tamarind was procured from the local market of Noida, India. The raw pods of tamarind were broken manually, and the pulp was separated from the seeds. Seeds were washed and cleaned, and packed in polythene pouches before use. After splitting the tamarind seed, the initial moisture content was determined by Barnwal et al. [2] and was found to be 10.55% on dry basis (db). Tamarind seeds were regulated at 5%, 10% and 15% (db) moisture levels. To achieve desired 5% moisture level, samples were dried at re-circulatory tray dryer. For 10 and 15% (db) moisture content, the samples were added with calculated amount of distilled water as per method given by Balasubramanian and Viswanathan [3]. The moisture content attained after treatment was ensured by hot air oven method according to (AOAC, 1995). Tamarind seeds were grinded in attrition mill (M/s Ganesh Agro Pvt. Ltd, India) for 10 min at temperature of ground powder (final product) in the range of 51–54 °C. The mill had single-phase AC motor operated at 1 HP and 1440 rpm with the diameter of attrition disc of 60 cm. Seeds ground in hammer mill (Sanco India Pvt. Ltd, India) were operated for 10 min, and the temperature of ground powder was in the range of 42–44 °C. The hammer mill also had single-phase AC motor operated at 1 HP and 1440 rpm.

Physical Properties of Tamarind Seed Powder

Bulk density (BD) of powdered sample was determined using the method described by [21], and the average of three replications was reported. Tap density (TD) was determined by tapping filled measuring cylinder of 100 ml with ground tamarind powder until no further volume could be added then the sample was weighed [8].

Carr's compressibility index (CI) and Hausner ratio are the important properties which are fast methods to predict the powder flow characteristics. Hausner ratio is not an absolute property of a powder; it is a property of a material with a given particle size, its distribution and its shape of particle depending upon the particular processing method [13]. It can be used to compare different processing methods for same product. Therefore, it can be used as an indicator for the compressibility which relates to Carr's compressibility index of a particular powder. Carr's compressibility index (CI) is the ability to get compressed, whereas Hausner ratio is given as tap density to bulk density of sample [19].

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

Angle of repose for seed powder was determined by using a tapering hopper, made of mild steel with top and bottom having a dimension of 250 mm × 250 mm × 250 mm and 20 mm × 20 mm hole in the bottom, respectively [24]. A circular disc (100 mm) was placed below the hopper bottom which allows the powder to flow through during the test. The angle of repose was calculated as

$$\vartheta = \tan^{-1}\left(\frac{2H}{D}\right) \tag{2}$$

where θ is the angle of repose, H is the height of the cone (cm) and D is the diameter of disc (cm).

The apparatus used for determining the static coefficient of friction consisted of a frictionless pulley, rectangular box with open ends, loading pan and test surfaces of plywood, stainless steel and mild steel [16]. The rectangular box was placed on the experimental surface which was filled with known quantity of sample, and on the other side, weights were put till the rectangular box just slides. Ratio of frictional force (weight added, *f*) to normal force (sample weight, n) was used to calculate coefficient of static friction as given by [3].

The particle size was determined by sieve analysis methods using BSS standard sieve series of 10, 14, 20, 30, 50, 60, 85, 100 and pan. About 250 g of tamarind seed powder was placed on the top of sieves set (1.676, 1201, 0.894, 0.500, 0.295, 0.251, 0.177, 0.157 and 0.124 mm opening) and shaken until it reaches equilibrium, by inspecting and weighing at 5-min intervals after an initial sieving time of 10 min [9]. The material obtained on particular sieve was weighed accurately in digital balance with least count: 0.001 g (Citizen Scale Pvt. Ltd, New Delhi) samples were packed in zip lock polythene pouches for future analysis accuracy of ± 0.001.

Characterization of Tamarind Seed Powder on Grinding Characteristics

The samples were characterized on the basis of formulae given by [9].

Fineness modulus (FM) is calculated by adding the total percentages of a sample of the aggregate retained on each of a specified series of sieves and dividing by 100.

$$\text{Fineness Modulus} = \frac{\text{Total \% retained on sieve}}{100} \tag{3}$$

Using value of FM, average particle size (D_p) was calculated using the following equation:

$$\text{Average particle size } (\mathrm{D}_2) = 0.135 \times \left(1.366^{\mathrm{FM}}\right) \tag{4}$$

$$\text{Weight of one particle} = (4/3)\,\pi (D_m/2)^3 \rho \tag{5}$$

$$\text{Average number of particles per grain} = \frac{\text{weight of one grain}}{\text{weight of one ground particle}} \tag{6}$$

Using the above formula, the number of particles per gram was calculated by dividing with one gram.

$$\text{Volume Surface Mean Diameter, } D_{vs} = \frac{1}{\sum_{i=1}^{n}\left(\frac{m_i}{D_{pi}}\right)} \tag{7}$$

where m_i, and D_{pi} are mass retained and mean diameter in each increment, respectively.

$$\text{Mass Mean Diameter}, D_m = \sum_{i=1}^{n} (m_i D_{pi}) \tag{8}$$

$$\text{Volume Mean Diameter, } D_v = \left[\frac{1}{\sum\limits_{i=1}^{n}\left(\frac{m_i}{D_{p_i}^3}\right)}\right]^{\frac{1}{3}} \tag{9}$$

Energy required for grinding process per unit mass (E, kWh/kg) was calculated as energy required by attrition and hammer mill with feed rate and time required for grinding [5]. Based on the particle size (initial and final) and energy required to grind a unit weight of material, Kick's constant (K_K) and Rittinger's constant were calculated. Rittinger's constant (C) was determined using Rittinger's law [9] as given below:

$$\text{Kicks law} \qquad E = K_K \ln(D_1/D_2) \tag{10}$$

$$\text{Rittingers constant} \qquad E = C\left(\frac{1}{X_\mathrm{p}} - \frac{1}{X_\mathrm{f}}\right) \tag{11}$$

where D_1 and D_2 are the diameter of product and feed at 80% passes from sieve.

X_f and X_p are the diameters of feed and product, respectively. E is the amount of work required to reduce a unit mass of feed from X_f to X_p, and C is Rittinger's constant.

Ratio of weight of sample (feed) to time utilized during process of grinding

$$\text{Feed rate } (f),\ \text{kg/h} = \frac{M_s}{t} \tag{12}$$

Energy consumption during grinding operation (ΔW) was calculated by the following expression

$$\Delta W = W_{OL} - W_{NL} = V \times (I_{OL} - I_{NL}) \tag{13}$$

where V is voltage during operation and I_{OL} and I_{NL} at load recorded at machine in loaded condition and load recorded at machine in no load condition.

Specific energy consumption (ΔE) was determined by using the following equation:

$$\Delta E = \frac{\Delta W \times 3.6}{f} \tag{14}$$

Thermal Conduction Analysis of Tamarind Seed Powder

Thermal conductivity of foods lies on composition and structure of the product; it is one of the important parameters utilized during modelling of various thermal processes such as drying, chilling, freezing and pasteurization, and such parameters can be optimized to the enhance quality of the product. Thermal conduction was measured by employing a digital thermal conductivity meter (model: KD-2 Devices, Inc. USA), and the instrument was calibrated using glycerine. Samples prepared under standard conditions offered little resistance to the needle probe, which was inserted to full depth of the needles into the tamarind seed powder. To minimize the potential for bending or breaking the sensor, holes of a slightly smaller diameter than the sensor needles were pre-drilled into the sample powder. The needles contain a heating element, and energy was supplied to the heating needle in the form of heat, which was then transferred into the medium between the needles to be measured by the thermocouple.

The powdered samples was crammed into 50 cc beaker and tapped; then, the beakers were coated with aluminium foils and kept in a deep freezer (model: U 410-86, New Brunswick Scientific, England) at − 35 °C to get the values of thermal conduction below 0 °C. For the upper temperature, i.e. above 55 °C, the samples were place in recirculatory kind of drier (BTPL, Kolkata, India) at 60 °C for 5 hour. A particular sample was taken out of freezer; then, the probe needle (KS-1, 1.3 metric linear unit diameter × sixty metric linear unit long) was inserted into the sample, the probe was connected to thermal conductivity meter and the required information was recorded at interval time of per degree Celsius [6].

Colour Analysis of Tamarind Seed Powder

In tamarind seed powders, colour analysis was performed using handhold portable Hunter colorimeter (Hunter lab, Reston, USA); instrument was calibrated using white and black plate, and the sample values were obtained in terms of L*, *a* * and b*. Chroma values were calculated to obtain the particular departure degree from grey colour to its lightness, and hue values represent the quality attribute by which colour analysis can be understand [1]. Whiteness index (WI) indicates the fairness in colour analysis. Hue and chroma values were calculated after obtaining L^*, a^* and b^* values; it gives a clear understanding of change in colour that occurs after grinding.

$$\text{Chroma} = \sqrt{(a^2 + b^2)} \tag{15}$$

$$\text{Hue} = \tan^{-1}(b/a) \tag{16}$$

$$\text{Whiteness index (WI)} = \sqrt{(10 - L^* + a^{*2} + b^{*2})} \tag{17}$$

Statistical Analysis

Statistical analysis was performed by using Durbin–Watson distance method using Statistica software 6.0 to evaluate the effect of different moisture levels on grinding characteristics, energy constants and thermal conductivity.

Results and Discussion

Physical Properties of Tamarind Seed Powder

The bulk density of the seed powder prepared by hammer mill having moisture content from 5 to 15% decreased linearly from 484 to 384 kg/m^3. Similar trend was seen for the samples prepared by attrition mill. The bulk density was in the range of 690–640 kg/m^3 for the same moisture content range. This may be due to more expansion in volume of samples with higher moisture content leading to the formation of larger particles. The sample with larger particle size would have more interstitial space between the particles resulting in expanded volume, whereas the finer particles would occupy less volume because of compressed interstitial spaces between the particles. Tap density of tamarind powder shows a linear decreasing trend in moisture content range of 5–15% (db) for attrition- (820–728 kg/m^3) and hammer-milled (648–534 kg/m^3) samples. The powder with higher moisture content have larger particles on grinding resulting in less compact organization of particles in the final product [10]. This may be the reason for the decrease in tap density with the increase in moisture content. Results found by Mohite et al. [20] for physico-chemical properties of tamarind seeds showed similar trends.

Carr's compressibility index (CI) values were found as 15.85–12.08 for hammer-milled and 25.17–27.22 for attrition-milled samples of 5–15% (db) moisture content. Hausner ratio for both the grinding processes found different trends as 1.18, 1.16, 1.13 and 1.33, 1.338, 1.37 for hammer- and attrition-milled samples, respectively. Although a clear indication of the decrease in values of CI and Hausner ratio was found in hammer-milled samples which show better flowability of powder, the increase in Hausner ratio represents poor flow properties of attrition-milled samples. Angle of repose values was found to be 23.74 24.12 and 26.56 for hammer mill and 32.61, 33.83 and 34.99 for attrition mill in the moisture content level 5%, 10% and 15%, respectively. Very good flow properties were represented hammer-milled and fair by attrition-milled samples as per [11]. The samples of attrition mill found coefficient of static friction increased linearly with the increase in moisture content of the samples. It was found to be the highest values for plywood sheet followed by mild steel and stainless steel sheet for attrition milling process. The values of coefficient of friction increased polynomially. The values increase from 0.29, 0.35, 0.38 for mild steel, 0.43, 0.48, 0.50 for plywood and 0.18, 0.23, 0.28 for stainless steel surface for moisture content 5%, 10% and 15%, respectively. Similarly, for hammer-milled samples, the values were also increased from 0.57 to 0.75 for mild steel, 0.62 to 0.72 for plywood and 0.23 to 0.29 for stainless steel surface. Several researchers found similar trends such as Barnwal et al. [7] for turmeric powder, Balasubramanian and Viswanathan [3] for minor millets, and Mohite and Sharma [19] for lima beans.

Grinding Characteristics of Tamarind Seed Powder

The ground samples by attrition mill and hammer mill were further subjected to grinding characteristic analysis. It was observed that in all the samples, particle size was found to be increasing with increasing moisture levels as shown in Table 1. Attrition mill and hammer mill showed the similar results. The properties such as volume mean diameter (Dv) vary from 0.29, 0.32 and 0.35 with the moisture content 5%, 10% and 15%, respectively. The volume surface mean diameter (Dvs) varies from 0.31, 0.34 to 0.37, and the mass mean diameter (Dm) varies from 0.33 to 0.36 to 0.39 with 5%, 10% and 15%, respectively, for hammer-milled samples. The volume mean diameter (Dv) varies from 0.60, 0.81 to 0.86, volume surface mean diameter (Dvs) varies from 0.55, 0.61 to 0.67 and the mass mean diameter (Dm) varies from 0.54, 0.58 and 0.84 for attrition-milled samples at same moisture contents. It can be concluded that the mass mean diameter and volume mean diameter of two grinding process were significantly different ($P \leq 0.05$).

Figure 1 shows the values of average number of particles per grain and number of particles per gram. Particle/grain varied from 66,521 to 54,529 and number of particles per gram varied from 49,533 to 33,402 at the same moisture content for hammer mill grinding. And for attrition mill grinding values were in the decreasing order from 5128 to 1380 particles/grain and number of particles per gram, 3528 to 1027. From the ANOVA table, it can be defined that the particular surface of blend and number of particles per gram of ambient and hammer mill grinding

Table 1 Grinding properties at different moisture contents and milling processes for tamarind seed powder

Type of mill	M.C. (%)	Average particle size (mm)	Volume surface mean diameter (mm)	Mass mean diameter (mm)	Volume mean diameter (mm)	Fineness modulus	Average no. of particles per grain	No. of particles per gram
Hammer	5	0.39 ± 0.02	0.31 ± 0.02	0.33 ± 0.01	0.29 ± 0.02	3.41 ± 0.03	66521 ± 79.6	49533 ± 59.1
	10	0.42 ± 0.02	0.34 ± 0.01	0.36 ± 0.02	0.32 ± 0.02	3.68 ± 0.02	53929 ± 84.1	37552 ± 180.1
	15	0.45 ± 0.01	0.37 ± 0.02	0.39 ± 0.01	0.35 ± 0.01	3.88 ± 0.01	54529 ± 4.01	33402 ± 98.3
Attrition	5	0.99 ± 0.02	0.55 ± 0.03	0.54 ± 0.02	0.60 ± 0.02	6.40 ± 0.05	5128 ± 113.3	3528 ± 9.84
	10	1.33 ± 0.01	0.61 ± 0.03	0.58 ± 0.01	0.81 ± 0.02	7.34 ± 0.02	1699 ± 25.6	1169 ± 11.5
	15	1.36 ± 0.05	0.67 ± 0.04	0.84 ± 0.03	0.80 ± 0.01	7.42 ± 0.04	1380 ± 41.6	1027 ± 14.1

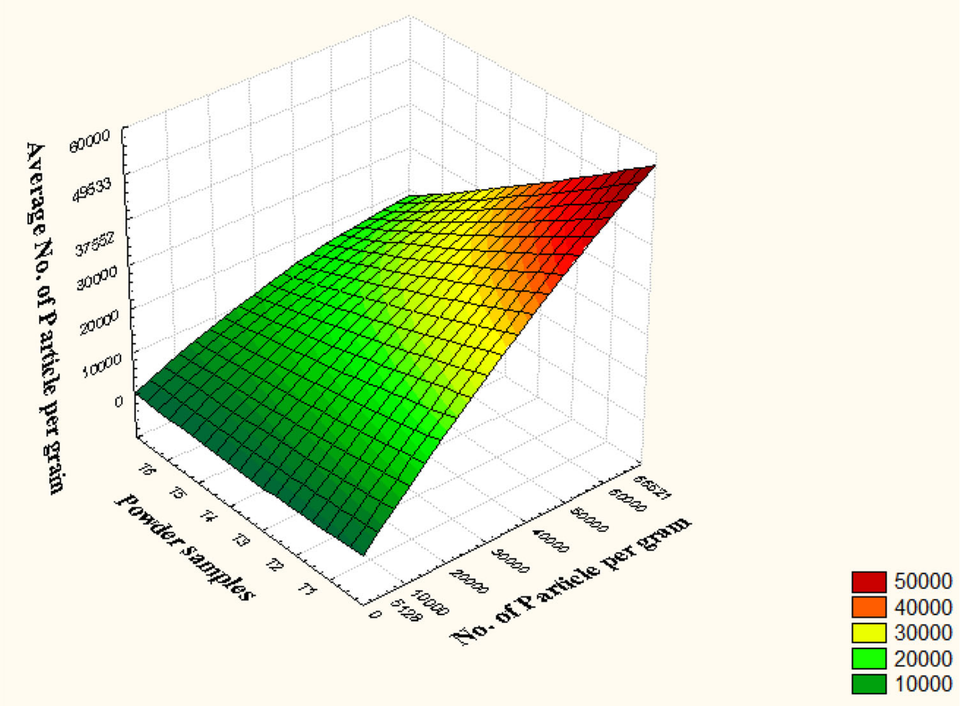

Fig. 1 Average number of particles per grain and number of particles per gram of tamarind seed powder at hammer and attrition milling

Table 2 Energy values for tamarind seed powder at different moisture contents and milling processes

Type of mill	M.C. (%)	Rittinger's constant	Kick's constant	Specific energy consumption (kWh/t)
Hammer	5	0.80 ± 0.01	0.6 ± 0.02	1.96 ± 0.01
	10	1.1 ± 0.02	0.8 ± 0.01	2.58 ± 0.01
	15	1.5 ± 0.01	1.1 ± 0.03	3.23 ± 0.05
Attrition	5	1.6 ± 0.03	0.5 ± 0.03	1.03 ± 0.01
	10	1.8 ± 0.02	0.6 ± 0.01	1.21 ± 0.02
	15	1.9 ± 0.01	0.8 ± 0.02	1.60 ± 0.01

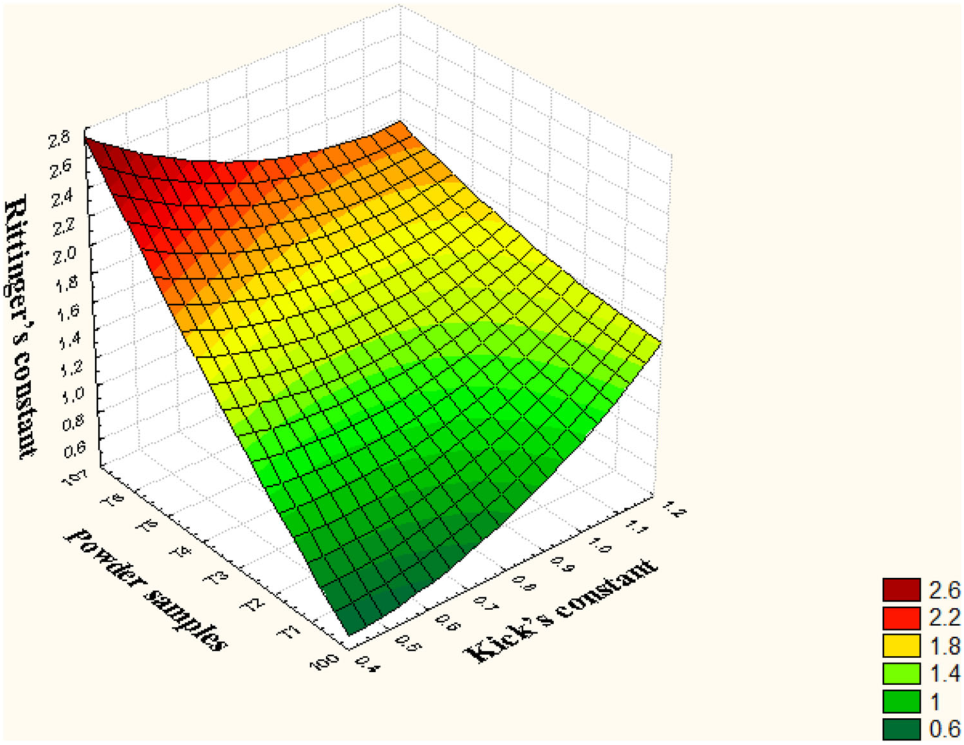

Fig. 2 Rittinger's constant and Kick's constant of tamarind seed powder at hammer and attrition milling

were essentially significant ($P \leq 0.05$). It was observed that the values of particles/g in hammer mill grinding were found to be higher as compared to that of attrition mill grinding. This finding may be due to fineness of ground samples done in hammer mill [9].

The Kick's constant and Rittinger's constant were used to measure the energy consumed, and their values are given in Table 2. Energy consumed decreased with increasing moisture content in hammer mill grinding. Comparable results were found for attrition mill. Rittinger's and Kick's constant values increased continuously with increasing moisture content. The values of Kick's and Rittinger's (kWh/t) constant increased with the moisture content of the sample for samples done in attrition and hammer mill, respectively (Fig. 2). Table 3 shows that Rittinger's and Kick's constant estimations of attrition and hammer milling process of tamarind seed powder tests were fundamentally non-significant ($P > 0.05$).

Thermal Conductivity of Tamarind Seed Powders

The thermal conductivity was investigated in the temperature range of − 35 to 55 °C. The values of thermal conductivity for attrition-milled samples increased from 0.046 to 0.063, and for hammer-milled samples increased from 0.058 to 0.074 at 5% (db) moisture content. Similar results were found for 10% and 15% (db.) moisture content samples. Figure 3 shows that the thermal conductivity increases with the increase in moisture content. The data analysis shows each temperature and moisture content have considerably affected the thermal conductivity at 5° temperature interval. The similar results have been reported by Singh et al. [22] for cumin seed, Subramanian and Viswanathan [25] for millet grains and Balasubramanian et al. [4] for coriander seeds.

Table 3 ANOVAs for different grinding characteristics of powder samples

Source	Average particle size (mm)	Volume surface mean diameter (mm)	Mass mean diameter (mm)	Volume mean diameter (mm)	Average number of particles/grain	Rittinger's constant	Kick's constant	Specific energy consumption (kWh/t)
Intercept	101.353	98.901	99.872	106.614	106.210	97.262	103.31	105.70
Std error estimate	0.70	0.54	0.91	0.67	0.80	0.48	2.08	1.79
Std error predicted	0.63	0.74	0.73	0.71	0.48	0.76	3.28	1.98
R^2	0.94	0.96	0.93	0.94	0.92	0.97	0.49	0.51
F	31.28*	62.22*	28.47*	34.94*	22.92*	70.58*	0.98**	1.43**
P	0.005	0.001	0.005	0.0041	0.008	0.001	0.92	0.29

*Significant at 5%, **non-significant

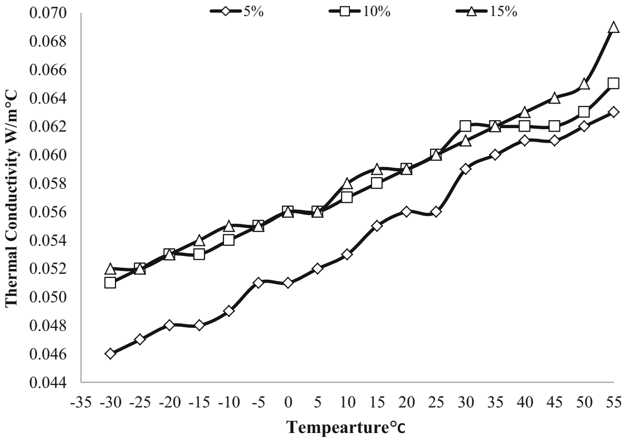

Fig. 3 Thermal conductivity values at different moisture contents for hammer-milled samples

Colour Analysis of Tamarind Seed Powders

Results for colour analysis found *L**, *a** and *b** variation at different moisture contents in both grinding processes. *L** values found decreasing trend with the increasing moisture levels, but the *a** values found increasing values with increasing moisture content. In case of *b** values, variation was observed in both milling process. The shade criteria (hue), chroma and WI were found to differ with moisture content at both grinding processes; however, hue and chroma values did not demonstrate a specific pattern with reference to moisture content at attrition milling, in spite of the fact that hammer milling process found decreasing trends with increasing moisture content, i.e. 81.86–80.17. Chroma values found for hammer-milled samples were 12.22, 14.12 and 11.67 for attrition mill, respectively, as given in Table 4. Whiteness index (WI) values found for hammer-milled and attrition-milled samples were 82.29–80.96 and 80.96–77.18 for moisture level of 5–5%, respectively. Furthermore, from statistical analysis it was found that hue, chroma and WI were influenced by moisture content and grinding processes. Similarly trends were found by Singh et al. [23] on king chilli powder and Barnwal et al. [9] on fenugreek powder.

Conclusions

The average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found lower in hammer mill as compared to attrition milling process. Energy values such as Rittinger's, Kick's constants and specific energy consumption were found as 0.80 and 1.6, 0.6 and 0.5, and 1.96 and 1.03 kWh/tonne for hammer-milled and attrition-milled samples, respectively. It was due to its high impact strength of hammer mill which easily ground the material and converted it into powdered form. Result showed that attrition mill required less

Table 4 Colour analysis of tamarind seed powder at hammer and attrition milling process

Type of mill	M.C. (%)	*L**	*a**	*b**	Chroma	Hue angle	WI
Hammer	5	87.18	1.73	12.09	12.22	81.86	82.29
	10	84.96	1.94	11.5	11.67	80.42	80.96
	15	86.02	1.80	14.02	14.12	83.16	80.17
Attrition	5	84.04	1.78	12.72	12.84	82.03	79.51
	10	84.96	1.94	11.5	11.67	80.42	81.11
	15	81.32	2.24	12.91	13.1	80.17	77.18

specific energy consumption for milling process; these was due to the sample had more space to escape from discs. Colour index finding indicated better whiteness index, i.e. 82.29–81.11 for hammer-milled and 80.96–77.18 for attrition-milled samples. From the study, it may be concluded that attrition mill was not appropriate for making the tamarind seed powder, while hammer mill was the most suited.

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