Drying behaviour and engineering properties of lima beans

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Abstract: In this research, selected engineering properties and drying behaviour of lima beans using different dryers were studied. The results for geometric mean diameter and sphericity were found as 8.82 and 0.66.Bulk, tap and true densities were found as 568.1, 625.8 and 769 respectively. Arithmetic mean diameter, equivalent mean diameter and square mean diameter values were found to be 4.84, 24.89 and 8.08 mm. Values for static coefficient of friction was highest on plywood surface followed by mild sheet and stainless steel. Ash content, crude fat and fibre content was found as 3.85%, 20.11% and 4.23% for lima beans. The drying behaviour of beans at three temperatures 40°C, 60°C and 80°C at constant air velocity of 2 m s^{-1} was investigated using tray, recirculatory tray and vacuum dryer. The effect of drying air temperature on drying time was significant and drying at 80°C in recirculatory dryer showed satisfactory results.

Keywords: beans, drying rate, density

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1 Introduction

Lima beans originate from Lima city of Peru. *Phaseolus lunatus L.* is also the botanical name of the lima beans. It belongs to the family Fabaceae and also known by the names butter bean, Burma bean, duffin bean, Rangoon bean (English), *Semphalee* (Hindi). The green seed in particular is eaten nowadays. In Asia the young plants or young leaves are also consumed. There is a wide variation in the glucoside content in the beans, and potential for improvement with types of less than 5 mg L^{-1}, without any correlation with the colour of the tegument. The evaluation of cultivars to determine the glucoside content will make it possible to establish many materials in traditional areas of cultivation and consumption. Its toughness and extensive production may be advantageous in adverse conditions where other leguminous vegetables do not prosper, concluded by Hernández Bermejo et al. (1994). It is the richest source of protein among beans. It is well known that, animal sources of protein are costly and it is difficult for vegetarian population to accept it. Legumes are cheaper source of protein with higher nutritional values.

The quality differences in lima beans can often be detected by differences in densities. Volumes and surface areas of beans must be known for accurate modelling of heat and mass transfer during cooling and drying. The porosity affects the resistance to airflow through bulk solids. The static coefficient of friction and angle of repose are necessary to design conveying machine and hoppers which are used in planter machines (Mollazade et al. 2010).

Engineering properties of lima beans can have a significant effect on processing, storage and transportations. The drying behaviour of beans using different dryers and varying range of temperatures will help processors to make important decisions in drying process. The present investigation was carried out with the objective to study the drying behaviour of lima beans using different dryers and selected engineering properties of beans.

2 Material and methods

Lima bean (*Var. udit*) was procured from local market of Greater Noida (India). Beans were separated from the pod manually. The beans were cleaned and undesired

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materials namely broken, foreign matter, split and deformed seeds were discarded before the samples wereprepared for the experiment (Jha and Sharma, 2010). Initial moisture content of beans, was determined by hot air oven method at 105°C (AOAC, 1995). The beans were allowed to equilibrate at room temperature prior to experimentation.

2.1 Engineering properties of lima bean

2.1.1 Bulk density

Bulk density of lima bean was determined as a ratio of mass to volume. It was determined using the standard method by filling a measuring cylinder of 100 mL with the lima beans from a constant height (Singh and Goswami, 1998). Average of three replications was reported.

$$\rho_b = \frac{m}{v} \qquad (1)$$

where, m is mass (kg) and v is volume (m^3).

2.1.2 Tap density

Tap density was determined using tapping method by filling a measuring cylinder of 100 mL with lima beans and taking care that a level surface of the seeds is formed and then tapped it until no further decrease in volume. Levelled the surface and then weighed the sample. It was calculated as the ratio of weight of beans to volume of container.

2.1.3 True density

True density was determined by liquid displacement method at 25°C. It is the weight of the solid material divided by the weight of the liquid it displaces. The weight ($W1$) of the clean, dry 50 mL density bottle was determined. The bottle was filled with water and the top of the bottle was dried with filter paper and weighed as $W2$. The procedure was repeated using benzene, obtaining the weight of the bottle plus benzene ($W3$). Benzene was used as the displacement liquid. About 3 g of the lima beans were transferred to dried density bottle and weighed as $W4$. The bottle was filled with benzene and the weight ($W5$) was measured. The density of the benzene used was calculated using the formula.

$$\text{Density of benzene } (\rho) = \frac{(W3 - W1)0.9971}{W2 - W1} \qquad (2)$$

Density of benzene (ρ) = (Density of water at 25°C = 0.9971 g cm^{-3}).

The true density of beans was calculated from the following formula,

$$\text{Density of sample} = \frac{W4 - W1}{\left(\frac{W3 - W1}{\rho}\right) - \left(\frac{W5 - W4}{\rho}\right)} \qquad (3)$$

2.1.4 Porosity (ε)

The porosity is the fraction of the space in the bulk seeds which is not occupied by the beans. The porosity of bulk beans was calculated from the values of true density and bulk density using the relationship (Coşkuner and Karababa 2007) as follows:

$$\varepsilon = \frac{\rho_t - p_b}{\rho_t} \times 100 \qquad (4)$$

where, ρ_t and ρ_b are true density and bulk density of beans respectively (kg m^{-3}).

2.1.5 Compressibility index

This property deals with the compressibility of the beans. The property has no direct connection with relative flow rate, cohesiveness and particle size but it is indirectly related to it. The compressibility index was given by the formula of Hausner Ratio.

Hausner Ratio= Tapped bulk density/Loose bulk density

2.1.6 Angle of repose

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

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \qquad (5)$$

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

2.1.7 Coefficient of static friction

Apparatus used for determining static coefficient of friction consisted of a frictionless pulley, rectangular box with ends opened, loading pan and test surfaces viz. plywood, stainless steel (SS) and mild steel (MS). The rectangular box was placed on the experimental surface which was filled with known quantity of sample and on the other side weights were added to the pan till the rectangular box just slides. The experiment was conducted for lima beans of different moisture contents. The coefficient of static friction was calculated as the ratio of weights added (frictional force) and material mass (normal force) (Balasubramaniam et al., 2012).

2.1.8 Average size

For the determination of average size of beans, 100 beans were randomly selected for measuring their axial dimensions (major, medium and minor) using digital vernier calliper (±0.01 mm accuracy).

2.1.9 Geometric mean diameter (D_g) and sphericity (ϕ)

The geometric mean diameter (D_g) and sphericity (ϕ) of lima beans were calculated by using the following equations (Altuntas et al., 2005).

$$D_g = \left\{\frac{abc}{a}\right\}^{x/3} \quad (6)$$

$$\phi = \left\{\frac{(abc)^{1/3}}{a}\right\} \times 100 \quad (7)$$

2.1.10 Unit volume

The unit volume of 100 individual beans was calculated from the value of three axial dimensions (major, medium and minor), invoking the equation proposed by Murthy and Bhattacharya (1998).

$$V = \frac{nabc}{6} \quad (8)$$

2.1.11 Surface area

The surface area of beans was found by analogy with a sphere of same geometric mean diameter, using expression cited by Sacilik et al. (2003).

$$S = \pi(D_g^2) \quad (9)$$

where, D_g is the geometric mean diameter in mm.

For the determination of geometric, gravimetric and frictional properties, the experiment was repeated three times. The geometric mean diameter (D_g), sphericity (φ), arithmetic mean diameter (*AMD*), square mean diameter (*SMD*), equivalent diameter (*EQD*), aspect ratio (*AR*) were determined using the following equations given by Balasubramanian et al. (2012).

$$D_g = \sqrt[3]{abc} \quad (10)$$

$$\text{AMD} = \frac{a*b*c}{3} \quad (11)$$

$$\text{SMD} = \sqrt{ab*bc*ca} \quad (12)$$

$$\text{EQD} = \frac{AMD + GMD + SMD}{3} \quad (13)$$

$$\text{AR} = \frac{b}{a} \quad (14)$$

where, *a* is major; *b* is medium and *c* is minor axis.

2.2 Proximate analysis of lima bean

2.2.1 Ash (%)

Five gram sample was weighed into a previously weighed silica crucible. It was then turned to carbonised form when silica crucible was burn at about 550°C for six hours in the muffle furnace to get complete white colour ash and then allowed it to cool in the furnace. The crucible was transferred to desiccator and weighed as possible to prevent moisture absorption process cited by Mohite et al. (2016b).

$$\text{\% Ash (\%)} = \frac{\text{Wt of crucible with ash (g)} - \text{Wt of crucible (g)}}{\text{Wt of sample (g)}} \times 100 \quad (15)$$

2.2.2 Crude fat (%)

Fat content in the sample was estimated by Soxhlet extraction method. Moisture free sample was transferred to thimble which was then fixed into a stand and transferred to a pre-weighed Soxhlet beaker. The beaker was filled with petroleum ether. The beaker was then attached to Soxhlet apparatus and the sample was extracted for two hours at 60°C. At the same temperature the ether was evaporated for two hours after extraction. At the end of four hours the ether left was dried in hot oven at 100°C for 30 minutes. The beaker was then cooled in desiccator and weighed. It gave the amount of ether soluble fat present in the sample.

$$\text{Crude fat (\%)} = \frac{\text{Weight of fat (g)}}{\text{Weight of sample (g)}} \times 100 \quad (16)$$

2.2.3 Crude fibre (%)

Fat free samples were used for determination of crude fibre. Crude fibre is the organic residue which remains after the food sample has been treated under standardized condition with petroleum sprit, boiling dilute sulphuric acid, boiling dilute hydroxide solution and alcohol. About 3 g fat free residue was taken and then transferred to the digestion flask. 200 mL boiling sulphuric acid was added and immediately the flask was connected to condenser. Heated the flask and boiled it by frequently rotating for

30 min, maintained the volume with hot water. Then filtered through filter cloth in a fluted funnel. The residue was washed on cloth with hot water or potassium sulphate solution, and returned the residue to digestion flask by washing with hot water, 200 mL boiling sodium hydroxide was added and boiled for 30 min. The volume was adjusted with boiling water, filtered it through the muslin cloth and the residue free of alkali was washed. The residue was transferred into crucible and washed with 15 mL alcohol and the crucible was dried at 130°C for 2 h. The crucible was cooled in desiccator and weighed. The crucible was ignited in the furnace at 600°C for 30 min then cooled and weighed. The loss in weight represented the crude fibre as cited by Mohite et al. (2016b).

2.3 Drying behaviour of lima beans

Drying behaviour at 40°C, 60°C, and 80°C using constant air velocity of 2 m s^{-1} was studied at laboratory scale dryers. Tray dryer, recirculatory dryer and vacuum dryer (operated at 15psi) were used in the present research work. Fifty-gram sample of freshly harvested lima beans with initial moisture contents of 19.17% (d.b.) were kept in petri dishes for three different dryers. The samples kept in the dryers were weighed at hourly intervals till constant weight was obtained (Mohite et al., 2016a).

The moisture content of the samples during drying was computed using mass balance equation. Modified Page's equation was tested for predicting the drying rates of lima beans.

$$MR = [(M(t) - Me)/(Mo - Me)] = \exp(-K t^n) \quad (17)$$

where, MR = moisture ratio, dimensionless; $M(t)$ = moisture content, % at time, t (db); Mo = initial moisture content, % (db); Me = equilibrium moisture content, % (db); t = drying time (min); and K, n = equation constants.

2.4 Statistical analysis

Statistical analysis was performed using Statistica software 6.0 to evaluate the effect of different engineering properties on lime beans.

3 Results and discussion

3.1 Engineering properties of lima beans

The experimental analysis of engineering properties of lima beans was represented as the average values of three replications. The geometric mean diameter and sphericity were found be 8.82 mm and 0.66 decimal respectively. Bulk, tap and true densities were found to be 568.1, 625.8 and 769 kg m^{-3} respectively. Whereas, arithmetic mean diameter, equivalent mean diameter and square mean diameter values were found to be 4.84, 24.89 and 8.08 mm. Surface area and aspect ratio was found 244.39 mm^2 and 0.68 respectively. The porosity and compressibility were found to be 26.12% and 1.101% respectively.

Angle of repose was 41.65°, whereas coefficient of static frictions values was found to be highest for plywood followed by MS sheet and SS sheet. The values of coefficient of friction were 0.60 for plywood, 0.57 for mild steel and 0.52 for stainless steel surface for 5%-15% moisture content respectively. Altuntas et al. (2005) reported a linear increase in coefficient of friction with moisture content. From the Table 1, it clearly reflected that the engineering properties for lima beans were found significant for most of the properties except for unit volume and surface area it was found non-significant ($P \leq 0.05$).

Table 1 ANOVAs for engineering properties of lima bean

Source	Bulk density (kg m^{-3})	Tap density (kg m^{-3})	True density (kg m^{-3})	Porosity	Compressibility ratio	Angle of repose (°)	GMD (mm)	Unit volume (mm^3)	Surface area (mm^2)
Intercept	516.37	731.63	792.88	12.82	28.40	0.76	12.80	459.28	267.22
Std Error Estimate	0.70	0.54	0.91	0.67	0.69	0.08	0.48	2.08	1.79
Std Error Predicted	0.63	0.74	0.73	0.71	0.91	0.04	0.76	3.28	1.98
R^2	0.94	0.96	0.93	0.94	0.94	0.92	0.97	0.49	0.51
F	31.28*	62.22*	28.47*	34.94*	32.47*	22.92*	70.58*	0.98**	1.43**
P	0.005	0.001	0.005	0.0041	0.004	0.008	0.001	0.92	0.29

Note: * Significant at 5%, ** Non Significant.

3.2 Proximate analysis

Ash content for lima beans was found slightly higher in amount as compared to other properties. Ash content, crude fat and crude fibre content were found as 3.85%, 20.11% and 4.23% for lima beans. The proximate composition was determined for different varieties change but no significant change was found in this analysis.

3.3 Drying behaviour of lima beans

Tray, recirculatory and vacuum dryers were used for drying of lima beans. Initially moisture absorption process was maximum for all three dryers in the first hour as the low resistance to moisture lost was offered by the beans but as the drying progressed the more energy was required to remove the moisture from the beans. Lima beans at different dryers took 220-300 min for drying when dried in range of 40^{o}C to 80^{o}C. Tray dryer took 220 min, recirculatory dryer took 265 min and vacuum dryer took 300 min. Drying graph of lima beans fully exposed to the air stream at different drying air temperature was obtained by plotting moisture content versus different temperature. Prediction of drying rate of biological material is more complicated during falling rate period. A modified drying equation described by Page's was fitted to predict the drying rate of beans (Basunia and Abe, 2005).

Effect of temperature on drying time was significant (p≤0.01). A systematic trend in the variation of modified Page's model constants 'K' and 'n' with drying air temperature for beans was observed. The drying rate i.e moisture ratio obtain for beans were found for 40^{o}C was (0.83, 0.59 and 0.37) and (0.91, 0.78 and 0.65) for 60^{o}C and (0.97, 0.84 and 0.71) for 80^{o}C for recirculatory, tray and vacuum dryer, respectively (Figure 1 and 2). It can be stated from the results, that drying behaviour is a function of time and temperature. Drying at 80^{o}C air temperature at constant air velocity showed best results for all three dryers for lima beans as higher temperature at initial stage removed surface moisture very quickly and speeded up the drying process (Figure 1). The effect of drying air temperature on drying time was significant and drying at 80^{o}C in recirculatory dryer showed best results whereas tray dryer showed next best results. Vacuum dryer took longer period to dry beans with lower moisture ratio.

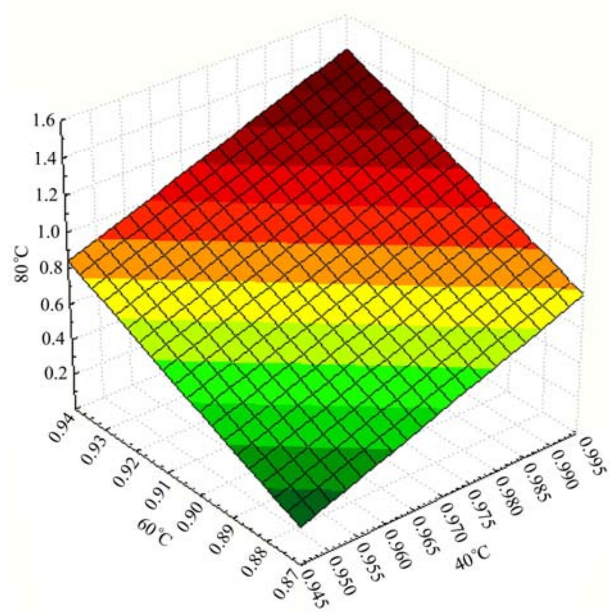

Figure 1 Drying behaviour of lima bean in Recirculatory tray dryer

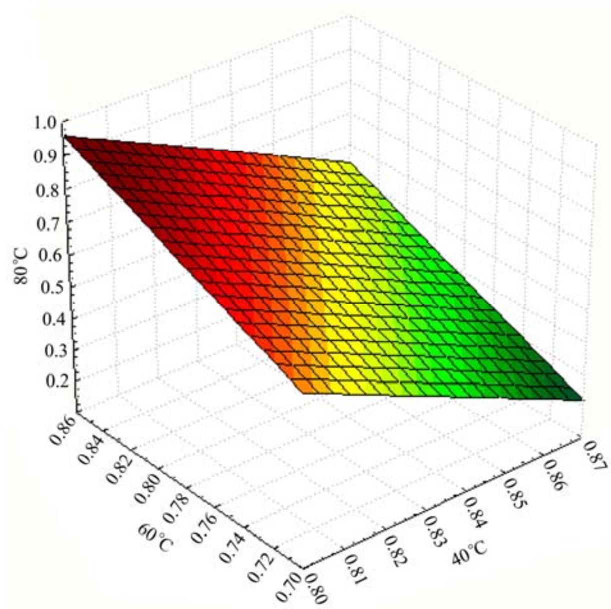

Figure 2 Drying behaviour of lima bean in tray dryer

4 Conclusions

The conclusions for the investigation are as follows. Engineering properties such as bulk density, tap density, coefficient of friction and angle of repose found significant values whereas, proximate analysis values found to be slightly higher values due to varietal differences. Drying at 80^{o}C was best suitable drying temperature using recirculatory dryer for lima beans compared to tray and vacuum dryer, as tray and vacuum dryers took more drying time compared to recirculatory dryer.

References

Altuntas, E., E. Özgöz, and Ö. F. Taser. 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. *Journal of Food Engineering*, 71(1): 37–43.

AOAC. 1995. Official methods of analysis. In *Association of Offical Analytical Chemists*, ed. Williams, S. Arlington, Virginia: AOAC.

Balasubramanian, S., A. M. Mohite, K. Singh. T. J. Zachariah, and T. Anand. 2012. Physical properties of turmeric (*Curcuma longa* L.). *Journal of Spices and Aromatic Crops*, 21(2): 178–181.

Basunia, M. A., and T. Abe. 2005. Adsorption isotherms of barley at low and high temperatures. *Journal of Food Engineering*, 66(1): 129–136.

Coşkuner, Y., and E. Karababa. 2007. Physical properties of coriander seeds (*Coriandrum sativum* L.). *Journal of Food Engineering*, 80(2): 408–416.

Hernández Bermejo, J. E., and J. León, 1994. Neglected crops: 1492 from a different perspective. Plant Production and Protection Series No. 26, FAO, Italy, Rome.

Jha, S. N., and R. Sharma. 2010. Physical, gravimetric and functional characterization of various milling fractions of popped gorgon nut (*Euryale ferox*). *Journal of Food Science and Technolog*, 47(5): 564–570.

Mollazade, K., H. Ahmadi, Khorshidi, J., Rajabipour, A. and S.S. Mohtasebi. 2009. Moisture dependent physical and mechanical properties of cumin (*Cuminum cyminum* L.) seed. *International Journal of Agricultural and Biological Engineering,* 2(2): 49–56.

Mohite, A. M., A. Mishra, and N. Sharma. 2016a. Equilibrium moisture content and drying behaviour of tamarind seed under thin layer condition. *International Journal of Seed Spices*, 6(2): 18–22.

Mohite, A. M., N. Sharma, and A. Mishra. 2016b. Physico-chemical and phytochemical properties of tamarind seed at varying moisture content. *Journal of Nutritional Ecology and Food Research*, 3(1): 10–14.

Murthy, C. T., and S. Bhattacharya. 1998. Moisture dependent physical and uniaxial compression properties of black pepper. *Journal of Food Engineering*, 37(2): 193–205.

Sacilik, K., R. Özturk, and R. Keskin. 2003. Some physical properties of hemp seed. *Biosystems Engineering*, 86(2): 191–198.

Singh, K. K., and T. K. Goswami. 1998. Mechanical properties of cumin seeds (*Cuminum cyminum* Linn.) under compressive loading. *Journal of Food Engineering*, 36(3): 311–321.