Engineering properties of Oilseeds

Kirti Jalgaonkar, Manoj Kumar Mahawar, Bhushan Bibwe, Kalyani Sharma
HCP Division, ICAR-CIPHET, Abohar

Introduction

Biological materials especially that are consumed as food or feed undergo various unit operations right from the pre-harvest to post harvest processing, primary, secondary and tertiary processing, formulation, preservation, packaging, storage distribution, retailing, domestic storage and finally consumption. Scientists and engineers need to know and understand the characteristics of the material to be processed, preserved and consumed to solve the problems while designing and selecting the means and modes of preservation, packaging, processing, storage, marketing, and consumption. Each of these unit operations has unique characteristics and need special tools and equipments. Designing and selecting such food processes, tools as well as equipments requires knowledge of the properties of food materials. Influence of these properties is even greater in problems of conceptual design, in which a wrong estimation of a property can lead to an infeasible design plan. Not only the knowledge of properties aids in engineering design and control but also gives information about the product quality, its acceptability by the consumer of different groups and its behaviour post production, during storage, during consumption and post consumption.

There are many classifications of properties of biological materials, which can generally be grouped under physical properties, mechanical properties, rheological properties, textural properties, electrical and dielectric properties, optical properties, acoustic properties, chemical and nutritional properties etc.

Physical properties

The knowledge of some important physical properties such as shape, size, volume, surface area, thousand grain weights, density and porosity of different grains has great implication in deciding the equipment for screening, separation, handling, storage and drying systems. The size and shape are important in their electrostatic separation from undesirable materials and in the development of sizing and grading machinery. Bulk density, true density, and porosity can be useful in sizing grain hoppers and storage facilities; they can also affect the rate of heat and mass transfer of moisture during aeration and drying processes. Density values are used to separate materials with different densities or specific gravities. Separation of properly matured seeds can be separated from the immature and infected ones by water flotation methods. Cereal grain densities have been of interest in breakage susceptibility and hardness studies. It plays an important role in other applications that include the design of silos and storage bins and the maturity and quality of paddy, which are essential to grain marketing. The resistance of bulk grain to airflow is in part a function of the porosity and the kernel size.

Geometric properties

Seed dimensions are usually computed by measuring three linear dimensions, specified as length (L), width (W) and thickness (T) using digital vernier callipers (Mitutoyo (Japan), least count 0.01mm). Geometric mean diameter, GMD (D_p) and sphericity (Φ_s) of the seeds were also calculated using the following relationship given by Mohsenin (1970).

$$\text{Geometric Mean Diameter } (D_p) = (L \times W \times T)^{1/3}$$

$$\text{Sphericity } (\Phi_s) = \frac{(LWT)\ 1/3}{L}$$

Likewise, surface area is important in investigation related to spray coverage, respiration rate, light reflectance, color evaluation and heat transfer studies. It can be calculated by keeping the equivalence with a sphere having identical geometric mean diameter, using following relationship as described by McCabe et al. (1986).

$$S = \pi D_p^2$$

Where, S is the surface area (mm^2); D_p is the geometric mean diameter (mm).

Density

Quality of food materials can be assessed by measuring their densities. Density data is required in separation process, such as centrifugation, sedimentation, hydraulic transport, for liquid, pumping power calculation.

Bulk Density

It is the density of material when stacked or packed in bulk. Bulk density of the material can be determined by dividing the material volume inclusive of voids to weight of product. The bulk density is an important in packaging requirement and is often 2-20 % of true density.

$$\text{Bulk density} = \frac{\text{Mass}}{\text{Bulk volume}}$$

True density

True density is determined using toluene displacement method in which volume of toluene displaced was estimated by immersing the weighed quantity of seed in toluene (Mohsenin 1970).

Solid/substance density

Density of a material measured when the material has been broken into pieces small enough to be sure that no closed pores remain.

Grains	Bulk Density	Particle density
Wheat	850	1480-1410
Paddy	575	1411-1342
Parboiled rice	522-566	1405-1346
Rice	507-565	946-991
Bean	750	
Oat grain		1380.0

Porosity

It is the measure of void `space between the materials. It is defined on the percentage of volume of inter grain space to the total volume of grain bulk. Porosity depends on shape, dimension/size and roughness of grain surface. Porosity of the grain mass determines the resistance to airflow during aeration and drying operation (Kachru et al. 1994). It is calculated using the relationship given by Mohsenin (1970) as follows:

$$\mathcal{E} = 100(\frac{1-\rho b}{\rho t})$$

Where ε is porosity (%), ρ_b is bulk density (g cm^{-3}) and ρ_t is true density (g cm^{-3}).

Test weight

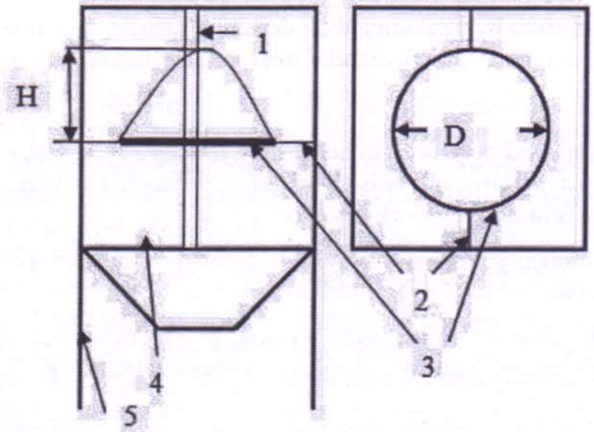
Test weight can be measured using an electronic balance with least count 0.001g. The weight of 100 seeds from the bulk sample can be taken and extrapolated further to the weight of 1000 seeds.

Frictional Properties

Frictional properties are useful in designing discharge and conveying devices. Properties such as angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures and the angle of internal friction between seed and wall in the prediction of seed pressure on walls. The coefficient of static friction plays also an important role in loading and unloading of grains while storage. Coefficient of friction is important in designing storage bins, hoppers, chutes, screw conveyors, forage harvesters and threshers. The frictional losses are one of the factors, which must be overcome by providing additional power to the machine. Hence, the knowledge of coefficient of friction of the agricultural commodities is necessary.

Angle of Repose

The angle of repose is measured with a square box, which is filled to the top and then removing lid, by allowing the granular material to fall freely, resulting in a conical shape of the sample.



$$\theta = \tan - 1\frac{2(Ha - Hb)}{Db}$$

Where, H_a, H_b and D_b are height of the cone, height of the platform and diameter of the platform, respectively.

Mechanical Properties

Mechanical properties may be defined as those which affect the behaviour of the agricultural material under the applied force. Properties such as hardness, compressive strength, impact and shear resistance and the rheological properties affect the various operations of agricultural processing. Data on these properties are useful for application in designing equipment for milling, handling, storage, transportation and food processing etc. The mechanical damage to grain and seed in threshing and handling operations causes reduction in germination power and viability of seeds, increases the chances of insect and pest infestation and also affect the final product quality. The hardness of grain effects the milling characteristics and it is also useful to live stock feeders and plant breeders. The impact and shear resistance are important for size reduction of food grains. Such king of information is useful in determination of the appropriate methods of crushing, breaking or grinding the grains. These properties also play important roles towards seed resistance to cracking under harvesting and threshing conditions.

Aero and Hydro-Dynamic Properties

The aerodynamic properties and hydrodynamic properties like terminal velocity and drag coefficient of agricultural products are important and required for the designing of air/ hydro conveying systems and the separation equipment. The physical properties, such as density, shape, size, etc., are required for calculating the terminal velocity and drag coefficient of the agricultural produce. In the handling and processing of agricultural products, air is often used as a carrier for transport or for separating the desirable products from unwanted materials, therefore the aerodynamic properties, such as terminal velocity and drag coefficient, are needed for air conveying and pneumatic separation of materials. As the air velocity, greater than terminal velocity, lifts the particles to allow greater fall of a particle, the air velocity could be adjusted to a point just below the terminal velocity. The fluidization velocity for granular material and settling velocity are also calculated for the body immersed in viscous fluid.

Drag coefficient

It is used to quantify drag or resistance of an object is a fluid environment such as air or water. It is a dimensionless quantity. Drag coeّfficient is always associated with surface area:

Terminal velocity

In free fall, the object will attain a constant terminal velocity V_t at which, where acceleration will be zero. Net gravitational accelerating net upward equals to the sum of buoyant force and drag force. It can be measured using air column. The terminal velocity (m/s) of common grains are: Wheat: 9-11.5, Barley: 8.5-10.5, Small oats: 19.3, Corn: 34.9, Soybean: 44.3, Rye: 8.5-10.0, Oats: 8.0-9.0

Thermal Properties

These properties are involved in almost every food processing operation. Knowledge of the thermal properties of foods is essential in the analysis and design of various food processes and food processing equipment involved in heat transport, with respect to heat transfer or energy use, such as in extrusion cooking, drying, sterilization, cooking etc. The most important thermal properties in food processing such as, specific heat capacity (Cp), thermal conductivity(k), and thermal diffusivity(a). Specific heat has an important role in determination of energy cost and for the dimensions of machinery and equipment that are needed in thermal processes. Furthermore, specific heat (Cp) of food materials changes according to their physical and chemical properties. The thermal conductivity (k) of food determines how fast heat can be evenly transferred to the entire food mass, which in turn affects the quality of the final product. When heating and cooling of materials involves unsteady state or transient heat conduction, the material temperature changes with time and knowledge of the thermal diffusivity (a) is required for predicting temperature in these processes.

Specific heat

It may be defined as the amount of heat in kilocalories that must be added to or removed from 1kg of substance to change its temperature by 1°C. The specific heat of wet material is the sum of specific heats of bone dry material and its moisture content.

$$\boldsymbol{Specific\ heat\ (C) = Cw\left(\frac{m}{100}\right) + \left(\frac{100-m}{100}\right) Cd, kcal/kg°C}$$

Where, C_d and C_w are the specific heats of bone dry material and water, respectively and 'm' is the moisture content of the material in wet basis.

The above relationship exists above 8% moisture content of the grain only. The specific heat of bone dry grain varies from 0.35-0.45 kcal/kg °C.

Thermal conductivity

The thermal conductivity of food determines how fast heat can be evenly transferred to the entire food mass, which in turn affects the quality of the final product. Thermal conductivity depends strongly on moisture, temperature and structure of the material. In porous materials the void fraction and the pore structure and distribution affect thermal conductivity significantly. It may be defined as the rate of heat flow through unit thickness of material per unit area normal to the direction of heat flow and per unit time for unit temperature difference. The thermal conductivity can be expressed by the following equation:

$$Q = KA\Delta T$$

Where, Q is amount of heat flow, kcal; A is area, m^2; Δ T is temperature difference in the direction of heat flow, °C; K is Thermal conductivity, kcal/m. h. °C

Enthalpy

It is the total heat content or energy level of a material. The enthalpy data are required for frozen foods that freeze over a range of temperature below 0°C. It can be estimated using the following expression:

$$h2 - h1 = mCp\ (T2 - T1) + m\ XwL$$

Where, h_2 - h_1: Enthalpy difference; m: mass of product; Cp: Specific heat of the product; X_w: water fraction; T_2- T_1: temperature difference; L: latent heat of fusion of water

Thermal diffusivity

It is important in determination of heat transfer rated in solid food materials of any shape. It shows the relationship between the ability of material to conduct heat and its ability to store heat. It may be calculated as:

$$\mu = \frac{K}{\rho Cp}$$

Where, μ: Thermal diffusivity; K: Thermal conductivity; ρ: Mass density; Cp: Specific heat

The common method of determination of thermal diffusivity is to calculate from experimentally measured values of K, ρ and Cp.

Textural Properties

Texture is one of the most important quality characteristics of foods. The textural properties of a food are the 'group of physical characteristics that arise from the structural elements of the food sensed by the feeling of touch, are related to the deformation, disintegration and flow of the food under a force, and are measured objectively by the functions of mass, time and distance' (Bourne 1982). The differences in the textural properties are caused by inherent differences due to the variety, maturity and method of processing. Food texture can be evaluated by sensory or instrumental methods. Sensory methods need a taste panel containing trained panelists. It is hard to repeat the results. Instrumental methods are less expensive and less time consuming as compared to sensory methods. In practice, texture is used primarily with reference to solid or semi-solid foods rather than liquids.

Elasticity, harness, plasticity and brittleness are important mechanical properties for food materials. These properties are described in terms of force or stress that the material must withstand and how these are resisted. Common types of stress are compression, tension, shear, torsion, impact or a combination of these stresses, such as fatigue.

Compressive stresses develop within a material when force compress or crush the material. When a food material is placed between two plates and plates are move towards each other, the food material is under compression. Tensile stresses develop when a material is subject to a pulling load. Tensile strength is defined as resistance to longitudinal stress or pull. Shear stresses occur within a material when external forces are applied along parallel lines in opposite directions. Shear forces can separate material by sliding part of it in one direction and the rest in the opposite direction.

When dealing with maximum strength, it is imperative to state the type of loading. A material that is stressed repeatedly usually fails at a point considerably below its maximum strength in tension, compression or shear. For example, noodle can be broken by hand by bending it back and forth several times at a place; however, if the same force is applied in a steady motion (not bent back and forth), the noodle can't be broken. The tendency of a material to fail after repeated bending at the same point is known as fatigue (Vishwakarma et al. 2012).

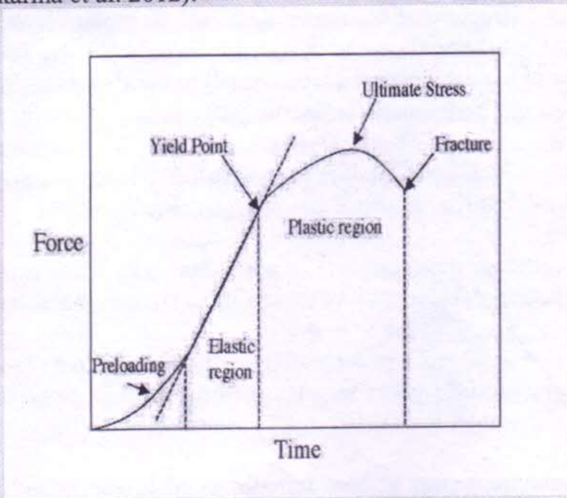


Fig: A typical force- deformation curve showing yield point, ultimate stress and fracture

Table: Physical properties of some Oilseed crops

Crop	Bulk density	True density	Kernel density	Porosity	Angle of repose		Coefficient of static friction
					Filling	Emptying	G.I
Rapeseed	687	744	1129	34	24	26	0.27
Mustard	6852	758	1145	34	25	28	0.25
Flaxseed	669	743	1152	36	24	25	0.42
Sunflower	429	480	1084	56	21	22	0.48
Soyabean	719	774	1258	38	28	29	0.20
Groundnut kernel	590	770	-				0.24

Source: Rapeseed, Mustard, Flaxseed, Sunflower, Soyabean (Muir and Sinha 1987), Groundnut Akcali et al. (2006)

Conclusion

It can be concluded that estimation of engineering properties is a wide knowledge that can be useful in the farming, harvesting and storage or in processing such as drying, freezing and other unit operations. This knowledge is important in the designing of machinery to harvest and in preparation of processing chain from grain to food. Accurate design of machines and processes in the food chain from harvest to table requires an understanding of physical properties of raw material. Considering either bulk or individual units of the agricultural material, it is important to have an accurate estimation of shape, size, volume, density, specific gravity, surface area, and other mechanical characteristics, which may be considered as designing parameters for food production. The measurement techniques allow computation of these parameters, which can than provide information about the effects of processing. Some of characteristics, such as colour, mechanical parameters, rheological properties, thermal and electrical resistance, water content and other physical quantities give excellent description of product quality.

References

- Akcali ID, Ince A, Guzel E (2006). Selected physical properties of Peanuts. International Journal of Food Properties 9(1): 25-37
- Bourne MC (1982). Food texture and viscosity 1st ed. Academic Press. New York
- Kachru RP, Gupta RK, Alam A (1994) Physico-chemical constituents and engineering properties of food crops. 1st ed. Scientific Publishers, Jodhpur, India
- McCabe WL, Smith JC, Harriott P (1986) Unit operations of chemical engineering. New York: McGraw-Hill Book Company
- Mohsenin NN (1970) Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York
- Muir WE, Sinha RN (1987). Physical properties of cereal and oilseed cultivars grown in western Canada. Can. Agric. Eng. 30: 51-55
- Vishwakarma RK, Shivhare US, Nanda SK (2012). Physical properties of guar seeds. Food Bioprocess Technol 5: 1364–1371.