

# Physical Properties of Food Materials

Subjects: Agricultural Engineering

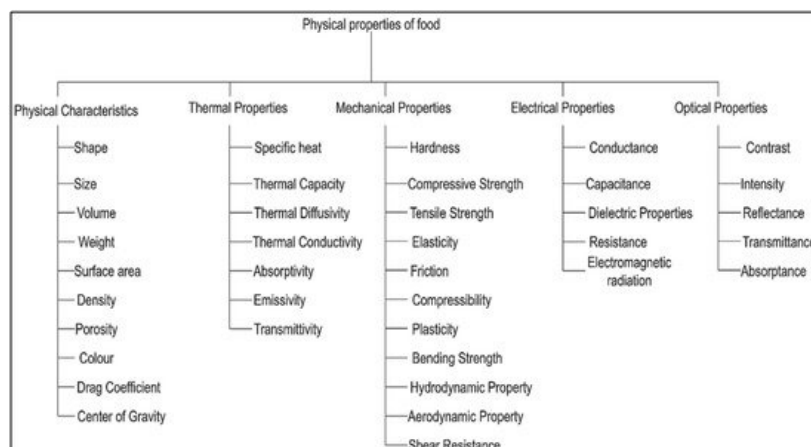
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The physical properties of food materials have defined those properties that can only be measured by physical means rather than chemical means. Food materials are basically naturally occurring biological-originated raw materials that have their own exclusive physical identity that makes them unique in nature. Due to the uniqueness of their physical properties, to properly measure the different physical characteristics of any food materials to get control and understand about the changes in their native physical characteristics with the influence of time-temperature-processing-treatment-exposure, proper measurement techniques for various physical properties of food materials are required with numerous desired outputs.

Keywords: food industry ; food physics

## 1. Importance of Physical Analysis Methods in the Food Industry

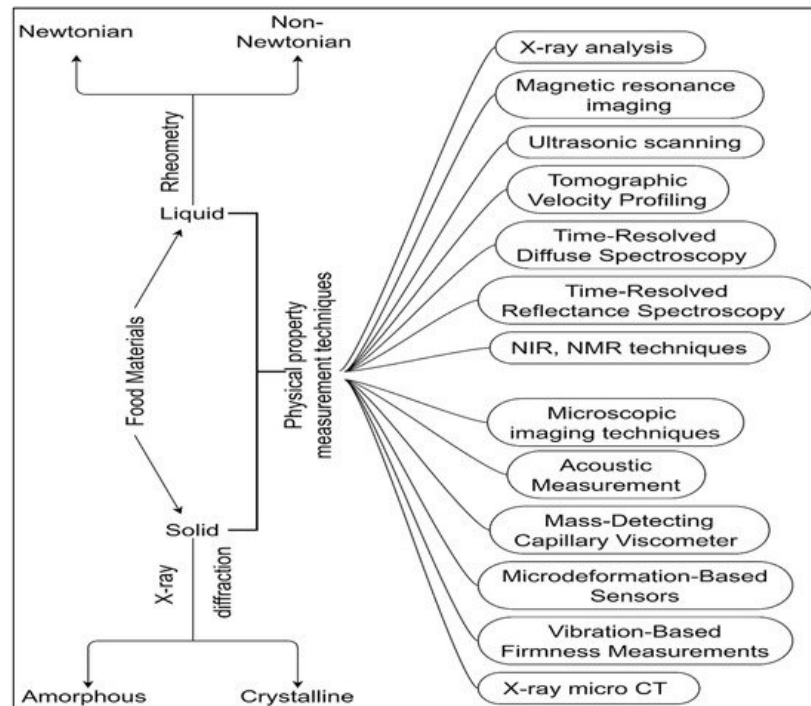
Physical testing in the food industry refers to the methods used to evaluate a food product's varied physical qualities. Color, viscosity, weight, thickness, granulation size, and texture are all common food product attributes examined. Physical testing in the food industry is usually employed as a quality indication, but it can also be used to ensure product consistency. Manufacturers can utilise this to evaluate product value, connect a product to consumer perception, and, in some situations, ensure food safety when a product must be cooked. Unusual physical outcomes could indicate a problem with the shelf life, production, and supply chain. Physical testing has a distinct advantage for businesses in terms of monitoring their suppliers' items and catching problems before customers complain. Furthermore, when physical qualities are assessed in conjunction with consumer research, the physical test specification ranges can be linked to desirable product information. This can help determine preferences in terms of appearance, such as a certain hue, or texture, such as viscosity, firmness, and consistency. Because a product's physical properties impact customer perspective and acceptability, determining optimal physicochemical characteristics can aid product development teams and retailers with knowledge on the part for drawing conclusions. Technologies that help in the physical analysis of food material is a subject of growing interest because of their non-destructive nature (**Figure 1**). Since the last half of the 20th century there has been an increase in the search for new physical analysis methods for the food industry. In Scopus and the Web of Science, a moderate number of papers are being published on this topic, and most of the published articles are research articles. The published works available in the field basically describe the working procedures, results, and validation of some particular methods on specific food products. Keyword searching reveals that the techniques to analyze the physical property of food materials are gaining the interest of researchers from academia, as well as from industry (>25 in 2022 to date, >75 in 2021 and >50 in 2020). Bibliometric analysis has revealed that there are several research papers available on the techniques for analysis of various physical properties of food materials, but there is a need for a concise review of the principles, specific field of applications, merits, and demerits of the techniques to provide an overall view of the rigorously practiced methods.



**Figure 1.** Classification of physical properties of food materials.

## 2. Techniques for Non-Destructive Physical Methods

During recent years, researchers have applied several novel techniques in the field of physical property assessment of different food commodities. Depending on the physical states of the food material, the methods of physical techniques that have been employed are described in **Figure 2**.



**Figure 2.** Novel techniques for assessment of physical properties of food materials.

### 2.1. Ultrasonic Wave-Based Analysis

The ultrasonic frequency is beyond audible to human hearing. These acoustical or mechanical waves have a frequency of  $\geq 20$  kHz. An ultrasonic scanning system can be used for food diagnostic purposes (physicochemical properties like flow rate, structure, composition, and physical state), especially for soybean, honey, cereals, meat, and aerated foods (**Table 1**) [1]. Volume estimation, firmness, maturity of fruits [2][3][4], rheological properties of cereal products [5], determination of fat percentage in meat [6], and defect detection in cheese [7] have been measured or conducted with ultrasound. Ultrasound velocity, attenuation coefficient, signal and wave amplitude, acoustic impedance, and relative delay are the parameters considered for analysis of food materials [8][9]. The techniques provide the following advantages: portable, simple, low power consumption, lower operational cost, adaptability for both liquid and solid foods, and environmentally friendly [8]. The limitations of the techniques are shock wave generation, followed by degradation of products, and radical formation followed by off-flavor formation in the products subject to analysis. Surface characteristics and homogeneity of products may affect test efficiency and the development of mass transfer resistance [1].

### 2.2. Young's Modulus and Poisson's Ratio

The Sitkey technique was applied by researchers to determine the Poisson's ratio as a function of moisture content and Young's modulus as a function of loading rate. A material testing machine was used to perform the test. It found that there is a negative correlation between the Poisson's ratio of the grains and moisture content. On the other hand, the reverse was found for the loading rate. For the grains, Young's modulus is inversely proportional to moisture content and loading rate [10].

### 2.3. Compressibility Analysis through High-Pressure Processing (HPP)

Processing food by applying high pressure is now an impactful technique to preserve different foods. High pressures exhibit bulk compression loading on the food. At high pressure (400–1000 MPa) and adiabatic conditions with a pressure change of 100 MPa, there is a change in water temperature of 3 °C. Pressurization of food material leads to changes in rheological properties, thermodynamic properties, and compression heating [11]. It is a non-destructive green technique,

but the food composition and solute concentration are the limiting factors for the efficacy of the technique. Moreover, it is not suitable for solid food products <sup>[11]</sup>.

### 3. MRI Technique

MRI is the formation of a very weak magnetization field produced by atomic nuclei of body tissue in the presence of another magnetic field. The density of the nuclei is correlated to the magnetization, and hence it shows the nature of the distribution of atoms. In an MRI, mainly hydrogen atoms are observed. Therefore, softer tissue with large water molecules can be studied well in an MRI <sup>[12]</sup>. Fat content ( $40 \pm 23$  mg/g) determined by an MRI demonstrated an association with GC ( $39 \pm 16$  mg/g) in starving fish. For well-fed fish, however, there was no agreement. This could be attributable to non-triglyceride lipid synthesis in well-fed fish and MRI and GC sensitivity differences. It is obvious that the MRI may more precisely depict fat content <sup>[13]</sup>. The non-invasive and non-destructive features of this technique make it attractive for food analysis <sup>[14]</sup>, but for the cost-intensive nature and difficulty in analysis of food materials in the metastable physical state (e.g., subcool materials) <sup>[15]</sup>.

The physical properties, their significance in the food industry, their techniques for measurement, interpretation of the measured results, brief working principle, and the objective of the analysis have been listed in **Table 1**.

**Table 1.** Physical properties of different food commodities.

Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
Water Activity (WA)	Assessment of internal structure of the food, effect on food texture and shelf-life assessment.	-	WA > 0.90 growth of bacteria; WA < 0.70 growth of molds inhibit; WA < 0.60 growth of most of the microorganisms inhibit	Water activity meter.	Ratio of the vapour pressure (VP) of the water in food and the VP of the pure water.	Equilibrium relative humidity	Quality characteristic measurement for Sugar and sugar replacers, Starch powders, Agar gels.	[16][17]
Hygroscopicity	Assessment of a food's ability to absorb moisture.	-	Powdered food with high hygroscopicity likely to be clump formation with simultaneous increase in texture hardening	Hygrometers	Works on the concept of evaporative cooling.	Amount of moisture uptake by a specific fod material	Moisture sorption isotherm modeling for starch and wheat gluten, Corn starch, pepper	[18]
Mass	Measure for inertia and heaviness of a body.	kg/g/mg	-	Weighing balance.	A counteracting force is created to be compared to the unknown mass.	Quantity of matter	To meet product formulation standards and manufacturing specifications	
Density	Mass per unit volume.	kg/m <sup>3</sup>	>1 kg/m <sup>3</sup> (at STP) food material will sink in water	Hydrometer	Displacement of its own weight within a fluid.	Mass and volume	Alcohol concentration of drinks; Solids in sugar syrups; Density, specific gravity and absorption of fine aggregate; Specific gravity of pigments.	[16]

Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
Specific Gravity	Ratio of the absolute density of a food material to the density of a reference material	-	Determines whether the solid food materials will sink or float in liquid medium	Specific gravity bottle	Liquid densities are measured by measuring the weight difference between an empty and filled bottle and dividing by an equal volume of water.	Density of food materials and water		
Bulk Density	Density of powders like food materials which contain hollow spaces or voids filled with gas, normally air.	g/mL	High bulk density is desirable in terms of food transportation and packaging	-	By measuring the volume of a known mass of powder sample that may have been passed through a sieve into a graduated cylinder.		Determination of powdered food characteristics especially for grinding and spray drying process	
Particle Size	Particles with a regular shape are characterized by their linear dimensions (lengths) along their principal axes.	m/cm/mm	Affect the flowability, solubility and reactivity, and the shelf life, processing condition, organoleptic properties and texture of the final product (e.g., sieving considered for >63 micron particles; sedimentation hindered when size <10 nm)	Particle Size Analyzer	The angle of incidence light scattering is inversely proportional to particle size.	Diameter	Texture and organoleptic characterisation of chocolate, fibres of grain, powdered food, and sizing of protein nano-fibres.	
Specific Surface Area (S.A)	Quantification of internal surface area or size of individual particles within a disperse system	m <sup>2</sup> /kg or m <sup>2</sup> /g	Materials with 500–3000 m <sup>2</sup> /g S.A suitable for solute and gas absorption; 200 m <sup>2</sup> /g S.A suitable for catalyst	Brunauer-Emmett-Teller (BET) surface area analysis		Surface area	Mass and heat transfer calculation, gas and moisture permeability through packaging materials	[19][20][21]
Sphericity	Compactness compared with a perfect sphere of same dimension.	-	Sphericity value ≈ 1 (sphere), ≈0.00271 (cube), ≈0.00155 (cylinder)		Ratio of the surface area of an equal-volume sphere to the actual surface area of the particle.	Surface area and volume	Analysis and design of food process equipment	
Sauter Diameter (SD)	Diameter of a hypothetical sphere with the same specific surface as the irregular shaped particle.	m/cm/mm/ μm	Coarse particle (SD > 10 mm); fine particle ≈ 1 mm, ultrafine particle < 0.1 mm	Diameter gauge	Ratio of surface area and volume of particle	Surface area and volume	Grinding characteristics measurement for wheat grain and size reduction characterisation	

Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
Uniaxial Stress	It is caused by a force pushing or pulling the body in a direction perpendicular to the surface of the solid body upon which the force is acting.	Pa	-	Strain gauge hole-drilling method	Deformation around the hole	Deformed area		
Young's Modulus	It is the slope of the linear part of the stress-strain curve for a material under tension or compression.	-	Addition fat reduces the young's modulus i.e., the decrease in rigidity. The harder is the food material the higher is the young's modulus	Oscillating rod	Estimated with the help of stress-strain curve.	Alteration in length, and uniaxial stress	Alginate gel: stress strain behavior and viscoelasticity. Fruit and vegetable puree products: rheological properties. Ketchup: hydrocolloids and flow behaviour. Powders: flow properties, nonflow problems. Wheat flour: rheological properties using farinograph, extensograph, valorigraph, alveograph device.	[22][23][24] [25][26][27]
Bulk Modulus	The relative change in the volume of a body produced by a unit compressive or tensile stress acting uniformly over its surface.	Pa		-	The measure of the ability of a substance to withstand changes in volume when under compression on all sides. It is equal to the quotient of the applied pressure divided by the relative deformation.	Pressure and volume		
Shear Modulus	It is the resulting stress When a force is acting parallel to a surface.	Pa	The higher the shear modulus the higher is the rigidity of the food material	-	-	Pressure and strain		
Newtonian Flow	linear relationship between shear stress (SS) and resulting shear rate (SR).	-	Reynolds no (NR) <2000; viscosity not change with applied force	Ball viscometer		Elapsed time for the ball to fall under gravity	Flow behaviour of liquid food materials for process design, quality measure and flexible container design	
Non-Newtonian Flow	non-linear relationship between SS and SR.	-	NR >2000; viscosity change with applied force	Brookfield viscometer		Torque		
Interfacial Surface Tension (IST)	It is the force of attraction between the molecules at the interface of two fluids.	N/m	Emulsion stability increases with the IST	Force tensiometer	Du Noüy ring method; Wilhelmy plate method	Force and length	Foam stability of ice-cream; Physical properties of chocolate	[28]

Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
Permeability	Quantification of the relative ease with which a transporting substance can pass through the material.	m <sup>2</sup> /s-Pa	Lower the permeability of the packaging material lower will be the shelf life of the food product	Helium Permeability Meter		Pressure, mass		
Conductivity	It can be defined as a measure of electrical conduction.	Siemens per meter (S/m)	Efficiency of pulsed electric and ohmic heat proces is depend on conductivity of food materials	conductivity meter	It is the ability of a material to conduct electric current.	Resistivity	Understanding the moisture transfer phenomenon during drying of fruits; mass tranfer phenomenon in lactose crystallization, Whey-protein-coated plastic films; design of pulse electric and ohmic heat process.	[29][30][31][32]
Resistance	It is a measure of the opposition to current flow in an electrical circuit.	Ohm (Ω)	Juiciness and tenderness of meat products are correlated with the resistance	Ohmmeter	Deflection of pointer to left or right side in ohmmeter due to current passing through it indicate low/high resistance.			

Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
<b>References</b>					The difference in the amount of heat required to increase the temperature of a sample and reference are measured as a function of temperature			
Heat capacity (J/C)	Thermal property that indicates the ability of the material to hold and store heat	Joule per Kelvin (J/K)	Food materials have more mass and take higher cooking time	Differential scanning calorimeter		Constant temperature, heat flow unit time		1. Majid, I.; Nayik, G.A.; Nanda, V. Ultrasonication and food technology: A review. <i>Cogent Food Agric.</i> 2015, 1, 1071022.
								2. Yildiz, F.; Özdemir, A.T.; Uluşık, S. Evaluation of Ultrasonic Testing for Fruit Quality Determination. <i>J. Food Qual.</i> 2019, 19, 6810865.
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					Steady state (when the temperature of the substance			4. Mizrach, A. Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre- and postharvest processes. <i>Postharvest Biol. Technol.</i> 2008, 48, 315–330.
					how it is measured			5. Ross, K.A.; Pyrak-Nolte, L.J.; Campanella, O.H. The use of ultrasonic and shear oscillatory tests to characterize the effect of mixing time on the rheological properties of food. <i>Food Res. Int.</i> 2004, 37, 567–577.
					It dictates how quickly heat may be evenly distributed throughout the mass, affecting the quality of the end product.	Amount of heat transfer, change in temperature, surface area of food material		6. Li, C.; Zheng, Y.; Kwabena, A. Prediction of IMF Performance of Litter Cattle by Using Ultrasound Technologies with High Accuracy. In <i>Proceedings of the 2009 WASE International Conference on Information Engineering</i> , Taiyuan, China, 10–11 July 2009; Volume 2, pp. 474–478.
Thermal conductivity (W/m.K)	Ability of food to transfer heat	Kelvin (W/m.K)		Thermal conductivity measurement techniques: steady-state and non-steady-state, transient, conductivity meters)	Two types of thermal conductivity measurement: constant over time (hot-wire based method), and time domain heating up phase, transient (hot-wire take measurements) techniques.			7. Hægström, E.; Luukkala, M. Ultrasound detection and identification of foreign bodies in food products. <i>Food Control</i> 2001, 12, 37–45.
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Thermal diffusivity (TD)	It is the thermal conductivity divided by density and specific heat capacity at constant pressure.	Square meter per second (m <sup>2</sup> s <sup>-1</sup> )	Most of the food materials lies within the range of 10 <sup>-7</sup> m <sup>2</sup> s <sup>-1</sup> (apple juice) to 10 <sup>-12</sup> m <sup>2</sup> s <sup>-1</sup> (peas).	Discovery of thermal diffusivity measurements		Density, specific heat capacity, thermal conductivity		11. Fauzi, N.A.; Farid, M.M.; Silva, P. An insight on the relationship between food compressibility and microbial inactivation during high pressure processing. <i>J. Food Eng. Technol.</i> 2017, 54, 802–809.
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Calorific value (CV)	Heat generated due to complete combustion of specified quantity at constant pressure under normal conditions.	kJ/kg	4 kcal/g for carbohydrate and protein and 9 kcal/g for fat; higher the CV, higher the energy content of the food	Calorimeter	Energy released by burning a representative sample in a high-pressure oxygen atmosphere used in a pressure vessel or "bomb"	Increase in temperature		14. Ebrahimnejad, H.; Ebrahimnejad, H.; Sedighi, A.; Barghi, H. Use of Magnetic Resonance Imaging in Food Quality Control: A Review. <i>Biomed. Phys. Eng. Online</i> 2013, 8, 127–132.
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Physical Property	Significance in Food Industry	Unit	Interpretation of Measured Data	Measurement Technique	Principle	Measured Property	Objective of Analysis	Reference
Electric polarization	Separation of centre of positive charge and the centre of negative charge in a material with help of high-electric field.	Coulomb per square metre (C·m <sup>-2</sup> )	It influence the dielectric heating of food materials	Polarimeter	-	Dipole moment	Sequential treatment of drinking water with UV and ozone; combined treatment of pulsed light and to inactivate microorganism;pulsed UV treatment of milk; gelling temperature investigation of gelling gels, rheologic and dielectric properties; analytical fingerprinting with spectroscopic techniques for butter and margarine; identifying coffee arabica, robusta and blends by NIRS.	
Refractive index	Ratio of the velocity of light in a vacuum to the velocity of light in a material.	-	Higher refractive index refers to higher total soluble solid content	Refractometer	The concentration of a particular substance within a given solution is measured. It operates based on the principle of refraction. When rays of light pass from one medium into another, they are bent either toward or away from a normal line between the two media.	Angle of refraction	Measure for concentration and purity of food materials	<a href="#">[40]</a> <a href="#">[41]</a> <a href="#">[42]</a> <a href="#">[43]</a> <a href="#">[44]</a>
Colour	Sensory attribute	TCU (True Color Unit)	L = 0 (black), = 100 (white); a = +ve (red) = -ve (green); b = +ve (yellow), = -ve (blue)	Colorimeter	It is based on Beer-Lambert's law, according to which the absorption of light transmitted through the medium is directly proportional to the medium concentration.	Concentration or intensity of colour	standardising and checking of ingredient colour allows them to maintain control over the colour of their final goods and analyse colour changes during manufacturing, transit, and preservation.	