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Physical and textural properties of lemon (*Citrus limon*)

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Abstract
Research was conducted to evaluate some physical and textural properties of lemon (*Citrus limon*). The knowledge of the properties studied in this work will be useful for the design of manufacturing and storage equipment, as well as handling and process operations in lemon sector. The fruit size, sphericity, aspect ratio, true density, bulk density, angle of repose, coefficient of friction, moisture content and cutting force were determined.
Results revealed that the average length, width and thickness of lemon were found to be 34.57 mm, 31.09 mm and 32.77 mm respectively. The average value of geometric mean diameter and sphericity of lemons was 32.75 mm and 0.9482 respectively. The aspect ratio of lemon was 1.08. The bulk density of lemons was 0.6263 g/cm^3 and true density was 0.9533 g/cm^3. Angle of repose was recorded 4.76°. The static coefficient of friction of lemon in stainless steel was 0.63 whereas dynamic coefficient of friction was 0.67. The moisture content in lemons were 92% (w.b). The shear force for cutting the lemon is in the range of 300 ~ 410 N and the corresponding shear stress to be in the range of $352 \times 10^3 \sim 368 \times 10^3$ N/m^2.

Keywords: Moisture content, size, sphericity, bulk density, true density, angle of repose, coefficient of friction

1. Introduction

Citrus fruits as a group of fruits which are in high demand in the world have remarkable economical, social and cultural impacts in our society (Iglesias *et al*., 2007) [2]. Among these fruits, lemon (*Citrus limon*) is the third most important citrus species after orange and mandarin (Perez-Perez *et al*., 2005) [4]. Lemons are favorite fruits for many consumers around the world because of their exceptional flavor and acidity, and also potential application as industrial and value-added food products. They are known to possess nutritive as well as medicinal values, mainly as rich source of vitamin C. They also contain other vitamins such as vitamin B, riboflavin and minerals like calcium, phosphorous, magnesium besides proteins and carbohydrates. Lemons are known to reduce the risk of heart diseases, cancer and also work as antiseptic, astringent, digestive stimulant etc. (Hrishikesh-Tavanandi *et al*., 2013) [1].

The knowledge of physical and textural characteristics of agricultural produce is crucial for proper establishment of standards and design criteria for fabrication of cutting, sorting, grading, conveying, storing, processing and packaging systems. Design of these equipment without putting these physical, mechanical and textural properties into consideration may yield poor results (Oluka *et al*., 2010) [5]. Hence, keeping the above factors in view, a study has been undertaken to found out physical properties of lemon such as fruit size, sphericity, aspect ratio, true density, bulk density, angle of repose, coefficient of friction, moisture content and cutting force.

2. Material and Method

2.1 Sample Collection and Preparation of Samples

The physical and textural properties of lemon fruits were determined as they are very important to optimize the design parameters of processing equipment. Selected physical and textural properties of lemon fruits like size, geometric mean diameter, sphericity, aspect ratio, surface area, volume, density, angle of repose, cutting force required to cut the lemons were determined. The raw material required was collected from local market of Akola district. The experiments were carried out in the laboratory of Department of Agricultural Process Engineering, Dr. PDKV Akola.

Some physical properties of lemon fruits were studied for proper development of a machine.

2.1.1 Moisture Content

The moisture content of fresh lemon was determined by using the hot air oven (Mityutoyo Japan model), which has a thermostat to control the temperature and its operating temperature range between 0 °C to 100 °C. A flat metallic plate of known weight was taken. Nearly 50 g of sample was spread on the dish. The weight of sample plus dish was noted. The hot air oven was maintained at 100 °C. The samples were heated at this temperature to 72 h. After drying the sample was immediately placed into the desiccators for cooling and to avoid moisture gain. After cooling the sample was weighted and the initial moisture content was determined by the following formula.

$$\text{Moisture content (w.b.) \%} = \frac{\text{Initial weight of sample} - \text{Final weight of sample}}{\text{Initial weight of sample}} \times 100 \quad \ldots (3.1)$$

2.1.2 Size

Size is an important physical attribute of food materials and it is used in screening solids to separate foreign materials, grading of fruits and vegetables, and evaluating the quality of food materials. Size is the measure of physical dimension of the object. Measurements on the three major perpendicular axes of the fruit were carried out with a digital vernier calliper to an accuracy of 0.01 mm. Dimension 'L' is the length or (axial diameter), '*W*' is the width or (radial diameter) perpendicular to '*L*' and '*T*' is the thickness or (transverse diameter) perpendicular to 'L' and 'W'. The Geometric mean diameter (Dg) of the fruit was calculated by using the following relationship (Mohsenin, 1980) [3].

$$\text{The Geometric mean diameter } Dg = (LWT)^{1/3} \quad \ldots (3.2)$$

2.1.3 Sphericity

Sphericity is the ratio of geometric mean diameter of the fruit to major diameter (L) of the fruit. It is determined with help of digital vernier calliper to measure Length (L) Width (W) Thickness (T) (Mohsenin, 1980) [3].

$$\text{Sphericity} = \frac{(L\times W\times T)^{\frac{1}{3}}}{L} \quad \ldots (3.3)$$

2.1.4 Aspect ratio (Ra)

It is the term used to express the shape of a material. The aspect ratio is the ratio between the sizes in different directions i.e., Length to Width (Mohsenin, 1980) [3].

$$\text{Aspect ratio, } Ra = L/W \quad \ldots (3.4)$$

2.1.5 True Density

The ratio of mass of sample to the true volume is termed as true density of the sample. It was determined with toluene displacement method. A lemon was submerged in toluene in measuring cylinder having an accuracy of 0.1 ml. The increase in liquid volume due to sample was noted as true volume of sample. Average of three replications was considered as a true density of lemon fruits (Mohsenin, 1986) [6].

$$\text{True Density (kg/m}^3) = \frac{\text{weight of lemon in air,kg}}{\text{volume oflemon,m}^3} \quad \ldots (3.5)$$

2.1.6 Bulk Density

Bulk density of fruit is determined by putting known quantity of lemon in container of known volume. To measure the bulk density of the grain, the method given in IS: 4333 (Part III)-1967 was used which involves filling up standard kettle of 500 ml with lemon from a height of 150 mm and then weighing the contents. Average of three replications was reported as the bulk density of lemon fruits (Mohsenin, 1986) [6]. It is given by following relation (Mohsenin, 1980) [3].

$$\text{Bulk density (kg/m}^3) = \frac{\text{Total weight of lemon,kg}}{\text{volume of container,m}^3} \quad \ldots (3.6)$$

2.1.7 Angle of Repose

Angle of repose is defined as when a material is allowed to flow freely from a point into a pile, the angle, which the side of pile makes with the horizontal plane, is called as angle of repose. For measuring the angle of repose a GI sheet box of 210×210×210 mm size, having funnel with 120 mm circular disc fitted inside discharge gate below the box was fabricated and used for the experimentation. The box filled with lemon fruits will be placed on the floor and discharge gate will quickly be removed allowing the lemon fruits to slide down and assume their natural slope. The angle of repose calculated by using formula:

$$\text{Angle of Repose} = \tan^{-1}(2h/d) \quad \ldots (3.7)$$

Where,
h = Height of piled material.
d = Horizontal distance measured from middle of piled material.

2.1.8 Coefficient of friction

The coefficient of friction is an important property which helps to estimate the lateral pressure in storage silos, design the storage bins and hopper for the gravity discharge. These properties help to know flow ability of the sample in a machine (Mohsenin, 1980) [3].

$$\text{Coefficient of friction, } \mu_i = \frac{W_2 - W_1}{W} \quad \ldots (3.8)$$

Where,
μ_i = Coefficient of friction.
W_1 = Weight placed in load pan which cause sliding of empty box, g.
W_2 = Weight of sample cause sliding of filled box, g.
W= Weight of sample material inside the box, g.

$$\text{Coefficient of dynamic friction } \mu d = \frac{F}{N} \quad \ldots (3.9)$$

Where,
μd = Coefficient of dynamic friction.
F = Frictional Force.
N = Normal force.

2.1.9 Cutting force

The texture analyzer is used for determination of cutting force. Among the various textural properties, the cutting force of lemon was calculated. The total force required to cut the lemon will be calculated by texture analyzer. Total 25 lemons will be randomly tested and average of all the effective cutting force. Cutting force required for lemon will be calculated using the texture analyzer. The cutting force of lemon was measured with the following settings of the texture analyzer.

Table 1: Specifications of texture analyzer

1.	Probe type	HDP/BS (Warner Bratzler)
2.	Load cell	50 kg
3.	Pre-test speed	1 mm/sec
4.	Test speed	5 mm/sec
5.	Post-test speed	10 mm/sec
6.	Distance	50 mm

Results and Discussion

For determining the physical and textural properties, lemons of different size were selected. The properties such as geometric mean diameter, sphericity, aspect ratio, true density, bulk density, angle of repose, coefficient of friction was measured and the results are tabulated below Table 2, Table 3 and Table 4. The average length, width and thickness of lemon were found 34.57 mm, 30.39 mm and 32.77 mm respectively. The maximum geometric mean diameter of lemons was recorded 36.62 mm and minimum geometric mean diameter was 30.93. The geometric mean diameter of lemons was 32.75 mm. The sphericity was found 0.9482 and aspect ratio of lemon was 1.08.

The bulk density of lemons was 0.6263 g/cm^3 and true density was 0.9533 g/cm^3. Angle of repose was found to be 4.76º whereas static coefficient of friction of lemon in stainless steel was 0.63 whereas dynamic coefficient of friction was 0.67.

The moisture content in lemons were 92% (w.b). The shear force for cutting the lemon was recorded 300 ~ 410 N and the corresponding shear stress in the range of $352 \times 10^3 \sim 368 \times 10^3$ N/m^2. The above observations were thrice replicated and average was calculated.

Table 2: Physical properties of lemon

Sr. No.	Length, (mm)	Width, (mm)	Thickness, (mm)	Geometric mean diameter, (mm)	Sphericity	Aspect ratio
1	32.66	29.51	30.78	30.95	0.9775	1.10
2	33.41	30.32	31.25	31.63	0.9467	1.10
3	38.23	35.55	36.16	36.62	0.9578	1.07
4	32.89	29.32	30.69	30.93	0.9404	1.07
5	31.62	33.27	32.14	32.33	0.9438	1.12
6	34.12	28.32	33.37	31.82	0.9325	1.11
7	34.67	30.17	32.27	32.31	0.9319	1.14
8	36.79	31.91	35.00	34.50	0.9377	1.15
9	36.18	30.13	31.52	32.51	0.9449	1.02
10	35.14	32.47	34.61	34.05	0.9689	1.06
Min	31.62	28.32	30.29	30.93	0.9319	1.15
Max	38.23	35.55	36.16	36.62	0.9775	1.07
Mean	34.57	30.39	32.77	32.75	0.9482	1.08

Table 3: Gravimetric properties of lemon

Sr. No.	Bulk density, (g/cc)	True density, (g/cc)
1.	0.613	0.954
2.	0.629	0.949
3.	0.637	0.957
Mean	0.6263	0.9533

Table 4: Various physical properties of lemon

Replications	Static coefficient of friction	Dynamic coefficient of friction	Angle of repose (°)	Cutting Force (N)	Moisture Content (%, w.b.)
1	0.73	0.67	4.7	375	94
2	0.71	0.69	4.8	380	91
3	0.74	0.66	4.8	370	93
Mean	0.7266	0.6733	4.76	375	92.66

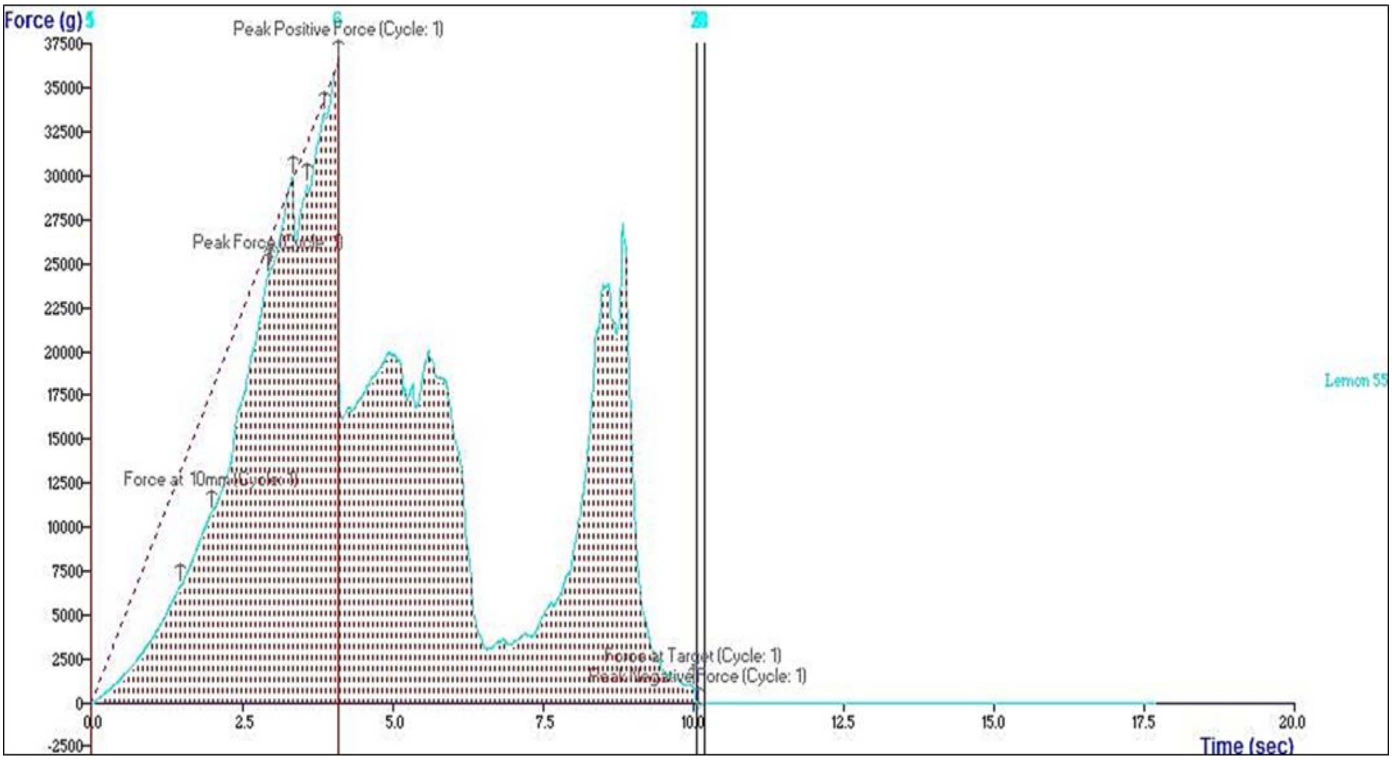

Fig 1: Graph of cutting force of lemon

Conclusion

The present study provides a comprehensive basic information about selected physical and textural properties of lemon fruit such as size, sphericity, aspect ratio, true density, bulk density, angle of repose, coefficient of friction, moisture content and cutting force were measured and it is useful for the design of manufacturing and storage equipment, as well as handling and development of process machineries, feed hoppers, storage structure, material handling equipments and packaging purpose.

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