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Determination of engineering properties of sweet orange (*Citrus sinensis* L.) fruits

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Abstract
Engineering properties of sweet oranges are very important to optimize the design parameters of processing equipment. The knowledge of engineering properties of sweet oranges is important for the design of grading, conveying, processing and packaging systems. Some engineering properties of grade I (>150 g), grade II (130-150 g), grade III (110-130 g) and IV (<110 g) sweet oranges were investigated. This study was undertaken to determine some important engineering properties such as axial dimensions, equivalent diameter, sphericity, surface area, individual fruit weight, volume, bulk density, true density, coefficient of friction and firmness of for the design of grading or sorting machine for sweet orange fruits. The shapes of the fruits were found to be round and the size of the fruits was characterized using length, width and thickness of fruits. The average volume of the fruits ranged from 177.86 to 100.76 cm^3; the individual fruit weight ranged from 175.52 g to 100.23 g and the average sphericity ranged from 0.976 to 0.970 whereas the range of fruit size was observed to be 67.64 to 54.56 mm from grade I to grade IV, respectively. The bulk density for the fruits varying from 564.47 kg/m^3 to 533.06 kg/m^3; and the true density varies from 967.70 kg/m^3 to 957.80 kg/m^3, respectively. The coefficient of friction of the sweet orange fruits on glass, GI (galvanized iron) sheet and plywood surfaces of four grades were ranges from 0.19 to 0.26. The force required to penetrate the fruits on stem, centre and tail ends of sweet orange fruits was found to 37.62, 26.29, 21.98 and 19.35 N, respectively. Maximum penetration force was found in grade I fruits at the tail end because of more compactness of the fruit and the minimum value was observed at centre portion of grade I fruits. Results shows that the four grades of sweet orange fruits were significantly different from each other regarding their engineering properties.

Keywords: sweet oranges, engineering properties, axial dimensions, coefficient of friction

Introduction
Sweet orange (*Citrus sinensis*) is the most common among citrus fruits grown in India and occupies nearly 30% of the total area under citrus cultivation. In India sweet orange has a production of 3266 million tons for the year 2017-2018 (Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare, 2018). Andhra Pradesh, Maharashtra and Telangana are the leading producers of sweet orange for the year 2017-2018. Sweet orange is commercially important for production of palatable juice and used in many applications because of its sweet flavor, sweet aroma and abundant source of Vitamin C, but, its main uses are for food and beverages and cosmetics.

The fruits are graded on the basis of size, shape, colour, weight and other quality aspects. The knowledge of engineering properties relevant to the fruits is important for the design and development of various graders, transportation and packaging systems of a high valued product such as sweet orange. Grading is one of the most important operations that affect its acceptance to the consumers in national and international market. which require the proper knowledge of engineering properties of the commodities.

Physical properties of fruits and vegetables are the subject of many researches because of its importance in determining the standards of design of grading, conveying, processing and packaging systems and fabrication of processing equipments (Soltani *et al*., 2011; Emadi *et al*., 2011) [3, 8]. Engineering properties like fruit dimensions, volume, mass, sphericity and coefficientoffrictionofdifferentgradesofsweetorangeswasdeterminedandreportedbyVeeravenkatesh and Vishnuvardhan, (2014) [10]. The major, intermediate and minor diameters of the grade two orange were determined by Sharifi *et al*. (2007) [7] are 84.1, 77.4 and 75.5 mm, respectively. Whereas the volume and mass of the grade two orange were found to be 217.8 68 cm^3 and 215.4 g, respectively. The static angle of friction of grade two orange on galvanized, glass and plywood surfaces were found to be 20.2, 23.4° and 23.5°, respectively.

Information about the engineering properties of sweet orange fruits are scanty, so there is a definite need to be investigate the properties which is relevant to the design and fabrication of various processing equipments. Hence this study was undertaken to determine some important engineering properties such as size, shape, sphericity, volume and density, surface area, coefficient of friction and firmness for different grades of sweet orange fruits. Measured attributes include axial dimensions, individual fruit mass, volume, coefficient of friction and firmness. The calculated attributes were geometric mean diameter, sphericity, surface area, bulk density and true density.

Materials and Methods

Material

Sweet orange fruits of *satugudi* variety, were purchased from the local market of Bapatla and were separated into four grades based on their weight as grade I (>150 g), grade II (130-150 g), grade III (110-130 g) and IV (<110 g). The good healthy, matured and uniform sized fruits from each grade were selected for the study. 15 samples of each grade were selected for determining the engineering properties.

Determination engineering properties of sweet oranges

The Fresh sweet orange fruit was randomly selected for determination of engineering properties. Statistical analysis was used to determine maximum, minimum, mean and standard deviation of the fruit dimensions. In order to determine size and shape of the fruits, 15 fruits of each variety randomly selected from the lot. The fruit mass was measured by using an electronic balance of 0.0001 g sensitivity. Bulk density and true density were calculated using bulk mass, bulk volume and toluene displacement method. Coefficient of friction and firmness of different grades of fruits were determined by inclined plate apparatus and a force gauge.

Axial dimensions

Three axial dimensions namely as length, width and thickness were determined using a digital vernier caliper (Aerospace Model, 0-300 mm) with a least count of 0.01 mm.

Dimension ‘a’ (length) is longest, ‘b’ (width) is the longest dimension perpendicular to ‘a’ and ‘c’ (thickness) is the longest dimension perpendicular to ‘a’ and ‘b’.

Equivalent diameter (De)

The equivalent diameter of orange fruits was calculated by the geometric mean of the three dimensions *viz*., length of major axis (a), length of intermediate axis (b) and length of minor axis (c). The equivalent diameter was calculated using the following expression.

$$De = (a \times b \times c)^{1/3} \quad (1)$$

Where,
De = Equivalent diameter, mm
a = Longest intercept, mm
b = Intermediate intercept normal to a, mm
c = Intercept normal to a and b, mm

Sphericity

The geometric foundation of the concept of sphericity rests upon the isoperimetric property of a sphere. Sphericity is defined as the ratio of diameter of a sphere having same volume as that of the object to the diameter of the smallest circumscribing circle (Mohsenin, 1970) [6]. It can also be defined as the ratio of geometric mean diameter to the major diameter of fruit. The sphericity of sweet oranges was determined by considering the geometric mean diameter or equivalent diameter of fruit as per following formula,

$$\text{Sphericity} = (\text{Equivalent diameter, De})/(\text{Longest intercept, mm}) \quad (2)$$

Where,
S = Sphericity,
De = Equivalent diameter, mm
a = Longest intercept, mm

Surface area

Surface area (S) was calculated using the equation (Topuz *et al*., 2005) [9] as given below.

$$S = \pi \times (GMD)^2 \quad (3)$$

Where,
S = Surface area, mm^2
GMD = Geometric mean diameter, mm

Individual fruit weight

For determination of individual fruit weight, 15 fruits were randomly selected from each grade and weighed using a sensitive digital balance (HTR-220E, Essae-Teraoka Pvt. Ltd., Bangalore) with an accuracy of 0.0001 g and their average weights were recorded as fruit weight. This parameter was used for setting up the limits in load cell.

Volume of fruit

Volume (V) of individual fruit was determined by toluene displacement method. The sweet orange fruits were dropped into a 1000 mL measuring cylinder, partially filled with toluene. The rise in toluene in the cylinder indicated the true volume of sweet orange.

Volume of sample, V (mL) = Final toluene level (mL) – Initial toluene level (mL)

Bulk density

Bulk density of sweet orange fruits was determined by using a cylindrical container. Fruits were filled in to the container above its top edge and mass of the fruits filled in thecontainer was measured using a weighing balance. The bulk density was calculated using following formula (Singh *et al*., 2004; Sharifi *et al*., 2007)[4, 7].

$$\text{Bulk density (kg/m}^3) = \frac{W}{V} \quad (5)$$

Where,
W = Weight of sample, kg
V = Volume of the cylindrical container, m^3

True density

True density is defined as the ratio of mass of sample to its true volume. True density was measured using toluene displacement method. Mass of the single sweet orange fruit was taken with electronic balance having a resolution of 0.0001 g and fruit was immersed carefully into a 1000 mL measuring cylinder partially filled with toluene (Singh *et al*., 2004)[4]. The volume of toluene displaced by the fruit was noted and the true density was calculated as,

$$\text{True density } (kg/cm^3) = \frac{M}{Vd} \quad (6)$$

Where,
M = Mass of sample (kg)
V_d = Volume of toluene displaced (m^3)

Coefficient of friction
The coefficient of friction is the ratio of force needed to start sliding the sample over a surface by the weight of the sample. It was determined on three different structural surfaces, namely galvanized iron, plywood and glass by using an inclined plate apparatus. Each fruit was placed on the surface and raised gradually by screw until the fruit began to slide. The angle that the inclined surface makes with the horizontal when sliding begins was measured (Dhineshkumar and Siddharth, 2015)[2]. The coefficient of friction (μ_s) was calculated using the following expression

$$\mu_s = \tan\theta = \frac{F}{N} \quad (7)$$

θ = Angle of inclination of material surface
F = Frictional force, N
N = Normal force, N

Firmness
A digital force gauge (FG-20KG) was used to determine the firmness of sweet orange. It was given as an indicator of the mechanical strength of the fruit to withstand mechanical harvesting and postharvest handling operations (Bahnasawy *et al*., 2004) [1]. Sweet orange was kept stationary over horizontal platform above the punch. A cylindrical probe of 8 mm diameter was forced into the sample. Direct readings of force for rupture were displayed in Newton (Mazidi *et al*., 2016) [5]. Sweet oranges were tested for firmness on apex, centre and stem ends and average values were taken. The available data were analyzed by using WINSTAT 2012.1 in micro soft excel (2010).

Results and Discussions
Fruit size and shape
The geometric mean diameter of the grade I, II, III and IV sweet orange fruits ranged from 67.64 to 54.56 mm. Among all the four grades of fruits, grade I has higher diameter (size) with standard deviation (2.403) followed by grade II (1.397), grade III (1.067) and grade IV (1.974). The deviation of size more in grade I fruits as compared to other three fruit grades. The shape of the fruit was assessed after calculation of axial dimensions and comparing the results with the standard chart reported by Mohsenin (1970)[6]. The shape was observed as round, since the sphericity of the grades more than 0.90. The sphericity of the grade I, grade II, grade III and grade IV fruits were found to be 0.976, 0.972, 0.974 and 0.970, respectively. Among all the grades, grade I was more spheroidal than other three grades of fruits (Table1). The sphericity of the sweet orange fruits was close to the values reported by Veeravenkatesh and Vishnuvardhan, (2014)[10] and Topuz *et al*. (2005)[9] for sweet orange and orange. Sphericity values for citrus have a practical application in the designing of handling, conveying and grading equipments.

Fruit mass and volume
The volume of sweet orange fruits were varied from 177.86 (Fruit mass: 175.52 g) to100.76 cm3 (fruit mass: 100.23 g). The average fruit volume for the grade I fruits was 177.86 cm3 and 100.76 for grade IV fruits, respectively. Veeravenkatesh and Vishnuvardhan, (2014)[10] reported the calculated volume of different grades of the sweet orange fruits were in the range of 285.55 to 88.73 cm^3. The average value of fruit mass was 175.52 g for grade I and 100.23g for grade II fruits, respectively (table 1). The relationship between individual fruit mass in g and the individual fruit volume in cm3 for sweet orange fruits were shown in the fig. 2 and it can be represented by the following regression equation,

Sweet orange: y = 1.023 x – 1.805 (R2 = 1) (8)

Regression analysis shows a good linear and positive correlation between the individual fruit mass and volume of different fruit grades, and it is valid within the experimental limits.

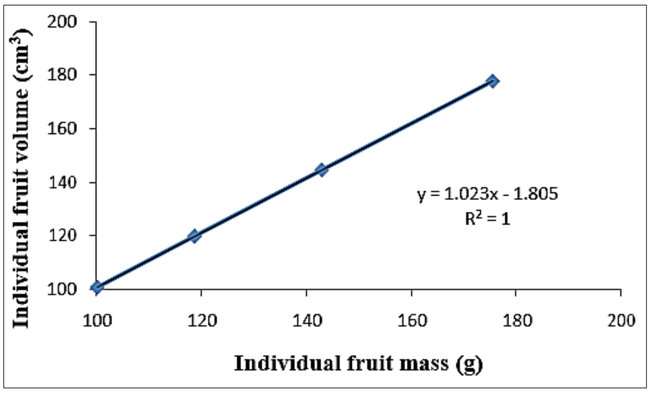

Fig 1: Relationship between individual fruit weight and volume of sweet oranges bulk density and true density

The bulk density of the grade I sweet orange fruit was found to be 564.47 kg/m3,whereas the grade IV fruit was 513.46 kg/m3. The observed values of densities have a very good agreement with that of reported data (Veeravenkatesh and Vishnuvardhan, 2014)[10]. The true density of sweet orange fruits for grade I and grade IV fruits was found to be 967.70 and 957.80 kg/m^3, respectively. Bulk density and true density shows a positive relation with weight of different grades of sweet orange fruits.

Coefficient of friction and firmness
A summary of coefficient of static friction and firmness data for different grades of sweet orange fruits were presented in table 1. Coefficient of friction of the sweet orange fruits of grade I and grade IV fruits varies from 0.24 to 0.19 (for GI sheet), 0.25 to 0.21 (for glass) and 0.26 to 0.20 (for plywood), respectively. In the case of the sweet orange fruits, the static coefficient of friction of galvanized iron was significantly higher than that of glass and plywood. It is observed that the coefficient of friction increased with weight of the sweet oranges on all the three surfaces.
The firmness or penetration force required to penetrate the fruits at the stem, centre and tail end of four grades of sweet orange was varied from 94.54 to 84.15 N (stem end), 155.68 to 125.29 N (tail end) and 72.22 to 65.44 N (centre), respectively (Fig. 2). Firmness of sweet oranges increased with increase in weight of the fruits. It was also observed that firmness values at the tail end were more compared to stem

end and centre of fruit. This is due to the presence of hard stalk of sweet orange at the tail end and hence, more penetration load was required to puncture the tail end compared to the stem end and centre portion of the fruits. Similar trend was observed in onion bulbs (Bahnasawy *et al.*, 2004)[1]. The four classes of sweet orange fruits were significantly different from each other regarding their engineering properties.

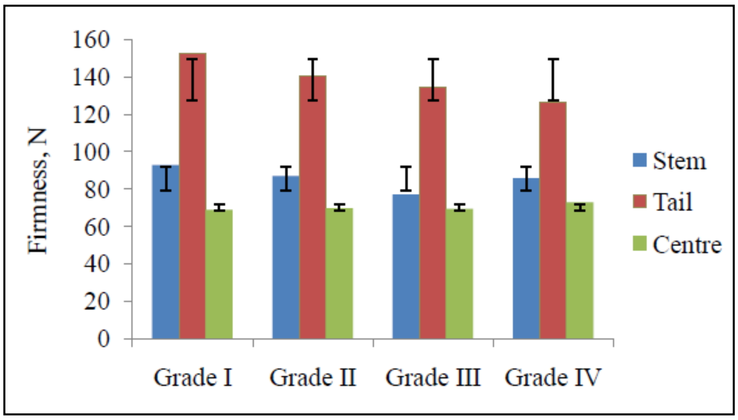

Fig 2: Relation between firmness and grade of sweet oranges

Table 1: Average engineering property of different grades of sweet orange fruits

Properties	No. Obs.	Grade I	Grade II	Grade III	Grade IV
Length, a(mm)	15	65.65	61.65	56.62	52.40
Width, b(mm)	15	69.33	65.63	60.17	56.26
Thickness, c(mm)	15	68.00	64.50	59.07	55.10
Equivalent diameter (mm)	15	67.64	63.79	58.60	54.56
Sphericity	15	0.976	0.972	0.974	0.970
Surface area, mm^2	15	14392.91	12790.02	10791.93	9364.05
Individual fruit mass, g	15	175.52	142.97	118.76	100.23
Individual fruit volume, cm3	15	177.86	144.63	119.83	100.76
Bulk density (kg/m3)	10	564.47	544.00	533.06	513.46
True density (kg/m3)	10	967.70	964.10	959.90	957.80
Coefficient of friction (Plywood)	10	0.24	0.21	0.20	0.19
Coefficient of friction (Glass)	10	0.26	0.24	0.22	0.21
Coefficient of friction (G.I)	10	0.25	0.23	0.21	0.20
Firmness, N (Stem)	12	94.54	87.24	78.24	84.15
Firmness, N (Centre)	12	72.22	69.61	67.49	65.44
Firmness, N (Tail)	12	155.68	139.78	134.97	125.29

Conclusion

Engineering properties of sweet orange fruits were studied. The physical properties of sweet orange fruits were used in the designing of equipment, transport, material handling and packaging etc. The engineering properties were determined for four different grades of fruits based on their weight. Average values of axial dimensions of four grades of sweet oranges were in the range of length 65.65 to 52.40 mm, width 69.33 mm to 56.26 mm and thickness68.00 mm to 55.101 mm for grade I to grade IV. It shows the linear dimensions of grade I fruits were more when compared to the grade IV fruits. Individual fruit mass and volume of four grades varies from 175.52 g to 100.23 g and 177.86 cm^3 to 100.76 cm^3. Bulk density and true density values of sweet orange fruits were ranged from 564.47 $kg/m^3$to 513.46 $kg/m^3$and 967.70 $kg/m^3$to 957.80 kg/m^3, respectively. The value of the coefficient of friction of sweet orange on glass, galvanized iron (GI) and plywood surfaces ranged from 0.19 to 0.26. There was an increasing trend in coefficient of friction with increase in fruit weight. The highest value of firmness at stem, centre and tail ends are 94.54, 72.22 and 155.68 N for grade I sweet oranges and lowest values for grade IV fruits. There is an increase in firmness of fruits with respect to the increase in weight of the fruits. The result shows a significant difference among the four grades of sweet orange fruits.

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