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Assessment of the physical properties of sweet orange (*Citrus sinensis*) for post-harvest handling and processing applications

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Abstract
Sweet orange (*Citrus sinensis* L.) is a major citrus fruit of the Rutaceae family that accounts for about 64% of total world citrus production with Brazil, China, India, and the USA as top producing players. In India, sweet orange is cultivated area of 5.8 lakh hectares, a production of 62 lakh metric tonnes annually, of which Maharashtra state is leading producer. The current study has evaluated certain crucial physical properties which included length (56.03 mm), width (54.10 mm), thickness (52.36 mm), geometric mean diameter (54.13 mm), sphericity (0.96), weight (82.5 g) and juice content (46.7%). The obtained results will be useful to design post-harvest and processing equipment which is optimum, effective, and minimizes waste during operations.

Keywords: Sweet orange, *Citrus sinensis*, Physical properties, Post-harvest handling

1. Introduction

Sweet orange (*Citrus sinensis* L. Osbeck) from Rutaceae family, Aurantoideae subfamily, and Citrus genus is one of the economically important citrus fruit worldwide. It is recognized for its contents of vitamin C, refreshing flavour, and use for fresh consumption and juice processing. Sweet oranges thrive best in medium black, deep loams, red soils and alluvial soils that have great drainage and a pH between 5.5 to 7.5. The crop is prone to waterlogging and prefers warm, drier microclimates at fruit ripening to maximize sweetness and juice quality. The growing area for sweet oranges is estimated to be over 64 percent of the total citrus output globally, with Brazil, China, India, and the United States as the main producers (FAO, 2022) [1]. In India, sweet orange cultivation spans an area of around 5.8 lakh hectares and yields nearly 62 lakh metric tonnes on a yearly basis (NHB, 2023) [4]. Maharashtra state has the highest area and production of sweet orange by accounted area of around 1.54 lakh hectares (19.93 lakh metric tonnes); Andhra Pradesh is second which, sweet orange is grown on 1.05 lakh hectares (16.58 lakh metric tonnes); while Madhya Pradesh is third with sweet orange cultivation in 0.73 lakh hectares (11.76 lakh metric tonnes). Next is Telangana with 0.45 lakh hectares (5.48 lakh metric tonnes) in sweet orange. Other states that contribute to the national output are Punjab, Rajasthan, Karnataka and Tamil Nadu with lesser outputs. The major sweet orange growing districts are located in the following: Jalna, Aurangabad, Parbhani, Nanded, and Nagpur in Maharashtra state which, are prominent for their agro-climatic conditions and established citrus orchards. Knowing the physical attributes, including the size of the fruit, mass, geometric mean diameter, sphericity and peel thickness is very important for developing post-harvest handling systems and processing machinery. In particular juice extracting machines must be calibrated using physical attributes to maximize juice extraction, avoid extracting bitter substances found in the rind and avoid damaging the fruit. Other attributes or characteristics such as specific gravity and the friction coefficient are also important for producing sorting lines, roller conveyors and washing units. Accurate knowledge of these engineering attributes enables people to utilize automation in processes, achieve better operational efficiency and decrease post-harvest and processing losses.

2. Materials and Methods
Sweet orange fruits were purchased from the local market of district Akola the good healthy and matured fruits were selected for the study. 30 samples were samples were taken for computing the physical properties.

2.1 Physical Properties of Sweet Orange
2.1.1 Size
The three principal dimensions length (L), width (W), and thickness (T) were measured using a digital vernier caliper (Mitutoyo 500-196-30, Japan) with a resolution of 0.01 mm. These dimensions are crucial for designing equipment for handling and sorting.

2.1.2 Sphericity (ϕ)
Sphericity is the ratio of the geometric mean diameter to the largest dimension (length): ϕ = Dg / L

2.1.3 Ellipsoid Ratio
The ellipsoid ratio is the ratio of the length of the major diameter (L) to the length of the minor diameter (T) (Rashidi and Arabsalmani, 2016) [5].it was measured using the following equation.

$$\text{Ellipsoid ratio} = \frac{L}{T}$$

2.1.4 Aspect Ratio
The aspect ratio is the ratio between the sizes in different directions i.e., Length to Width (Mohsenin, 1980) [3].

$$\text{Aspect ratio } (R_a) = \frac{L}{W}$$

2.1.5 Slenderness Ratio
Slenderness ratio is the ratio of effective length to the least radius of an object It is expressed as,

$$\text{Slenderness ratio} = \frac{2L}{T}$$

2.1.6 Equivalent Diameter (De)
Equivalent diameter (D_e) was calculated by taking the geometric mean of three dimensions; length of major axis, length of intermediate axis and length of minor axis. It is expressed as, (Selvan, *et al.*2021) [6].

$$D_e = (L \times W \times T)^{1/3}$$

2.1.7 Surface Area
Surface area was calculated by using the formula involving equivalent diameter of the fruit (Topuz, *et al.*2005) [7] and is given by,

$$\text{Surface area} = \pi (D_e)^2$$

2.1.8 Weight
The individual fruit weight was recorded using an electronic balance (Sansui SSP series) with a precision of 0.1 g.

2.1.9 Volume
Volume was determined using water displacement method:
Volume = Volume of displaced water (ml).

2.1.10 Specific Gravity
A sweet orange was submerged in a 500 ml water beaker and the weight of the water displaced was recorded and then the specific gravity was determined with the help of the following formula (Jaliliantabar *et al.*,2013) [2].

$$\text{Specific gravity}, S_g = \frac{\text{Weight in air} \times \text{Specific gravity of water (ml)}}{\text{Weight of displaced water (ml)}}$$

2.1.11 Bulk Density
Bulk density was calculated as:

$$\text{Bulk Density} = \frac{\text{Weight of fruit}}{\text{volume of container}}$$

2.1.12 Coefficient of Friction
Coefficient of friction was measured using an inclined plane:

$$\mu = \tan(\theta)$$

where θ is the angle at which the fruit starts to slide.

2.1.13 Color Measurement
Colour was evaluated using a chroma meter (Konica Minolta CR-400, Japan) using CIE Lab* scale (L*, a*, b*).

2.1.14 Juice Content
Juice was extracted, filtered, and measured:

$$\text{Juice Content (\%)} = \frac{\text{(weight of jiuce)}}{\text{weight of whole fruit}} \times 100$$

3. Results and Discussion
The physical properties of sweet orange fruits were measured and analysed to assess their suitability for post-harvest handling and food processing operations. The results are presented in Table 1, and the findings are discussed below in terms of their implications for processing and equipment design.

Table 1: Physical properties of sweet orange

Property	Min	Max	Avg	SD	CV (%)
Length (mm)	50	61	56.03	2.525	4.51
width(mm)	49	60	54.1	2.509	4.64
Thickness (mm)	47	59	52.36	2.442	4.66
Eq. Diameter (mm)	49.97	58.24	54.13	2.153	3.98
Sphericity	0.93	1.0	0.96	0.017	1.76
Ellipsoid Ratio	0.96	1.15	1.07	0.049	4.65
Aspect Ratio	1.0	1.08	1.03	0.019	1.9
Slenderness Ratio	1.92	2.3	2.14	0.099	4.65
Surface Area (mm²)	7841.62	10654	9215.1	726.98	7.89
Weight (g)	65	95	82.5	8.62	10.46
Volume (mm³)	80	105	94.86	7.25	7.65
Specific Gravity	0.86	0.97	0.92	0.034	3.78
Bulk Density (g/mm³)	0.194	0.423	0.294	0.046	0.209
Friction Coefficient	0.007	6.71	1.15	1.21	1.04
Juice Content (%)	38.5	55.3	46.7	5.86	0.23

Table 1 shows the measured physical properties of sweet orange fruits, which provide critical insights for the design and optimization of post-harvest handling and processing systems. The fruits demonstrated good dimensional uniformity, with mean lengths of 56.03 mm, width of 54.10 mm, and thickness of 52.36 mm. Collectively, with a geometric mean diameter of 54.13 mm, suggest the fruit samples could be considered nearly spherical in shape. This shape was also confirmed by an average sphericity of 0.96. The spherical shape in fruit is considered beneficial for mechanical grading and conveying because this shape offers less resistance and reduces bruising during movement. The surface area of 9215.1 mm² and mean volume of 94.86 mm³ will be useful for heat and mass transfer calculations when cooling, drying and wax coating. The mean weight of the fruit was 82.5 g which supports the fruit's commercial potential in the fresh market and also for processing markets. Specific gravity (0.92) and bulk density (0.294 g/mm³) indicate that the fruits are ideal for flotation-based washing systems and can be stacked well in packaging systems. The average coefficient of static friction, at 1.15 is useful for determining surface properties of contact materials used for hoppers, chutes and conveyor systems. The average juice content was an impressive 46.7% and indicates good potential for processing fruit for juice extraction. These physical and mechanical properties will help to guide the design of specialized equipment for customized juice extractors, sorters and graders, to assist with effective handling and reduce loss after harvest.

4. Conclusion

The present work has characterized the physical properties of sweet orange fruits to aid in the design of effective post-harvest and food processing equipment. The results showed that sweet orange had consistent dimensional characteristics with a near-spherical shape and little size variation, both positive traits to consider in mechanical methods of sorting, grading, and conveying. The average weight and juice content of the fruit confirmed the commercial usability of the variety in both the fresh fruit and juice processing industry. Other dimensions, like specific gravity, bulk density, and surface area will also contribute to the design of flotation-based washing systems, packaging systems, and thermal operations. Higher sphericity and uniform geometric characteristics limited risks of mechanical damage to fruit while moving. Frictional properties will assist with the management of surfaces in process lines. In general, these findings provide invaluable engineering information to help design equipment for the processing of sweet oranges, avert post-harvest losses, and allow processes that better sustain the demand for efficiency in citrus value chains.

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