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Studies on some physical properties of sweet orange relevant to bulk handling

M. VEERAVENKATESH AND S. VISHNUVARDHAN

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See end of the Paper for authors' affiliation

Correspondence to :

M. VEERAVENKATESH
Post Harvest Technology (ANGRAU), Bapatla, GUNTUR (A.P.) INDIA
Email : venki.mareedu868@gmail.com

ABSTRACT : Sizing and grading of orange is needed for the fruit to be presented to local markets and for proper handling, processing and storage. A study of sweet orange physical properties is therefore, indispensable. Some physical properties of grade I (large), grade II (medium) and grade III (small) oranges were investigated. These properties included: principal axial dimensions, mass, volume, sphericity, surface area, porosity, bulk volume, bulk density, co-efficient of packaging and co-efficient of static friction. The mean length, breadth and width of grade I (large) oranges were 75.97, 84.32 and 84.00 mm; grade II (medium) oranges were 61.08, 66.99 and 66.75 mm; grade III oranges were 53.71, 58.41 and 58.02 mm, respectively. Volume and mass of the grade I oranges were 285.55 c.c and 248.77 g; grade II oranges were 143.69 c.c and 152.62 g; grade III oranges were 88.73c.c and 96.80 g, respectively. The bulk density and fruit density for grade I oranges were 0.50 and 0.88 g cm^{-3}; grade II oranges were 0.58 and 1.06 g cm^{-3}; grade III oranges were 0.52 and 1.09 g cm^{-3}. Porosity of grade I, grade II and grade III oranges were 49.04, 51.04 and 49.00 per cent, with their sphericity being 1.01, 1.02 and 1.03, respectively. The co-efficient of static friction for grade I orange on mild steel, glass and plywood surfaces were 0.20, 0.22 and 0.23, respectively; for grade II orange on mild steel, glass and plywood surfaces were found to be 0.16, 0.21 and 0.18, respectively; for grade III orange on mild steel, glass and plywood surfaces were found to be 0.19, 0.22 and 0.21, respectively. The three classes of sweet oranges were significantly different from each other regarding their physical properties.

KEY WORDS : Physical properties, Sweet oranges, Co-efficient of static friction, Packaging co-efficient

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Citrus is of high importance in agriculture nowadays and a substantial source of income for the producing countries (Anonymous, 2011). Among citrus fruits, sweet orange is one of the important crops grown in the country with 12, 3, 186 MT of recent production (Kumar *et al*., 2012). It is consumed mostly either as a juice or whole fruit. Sweet oranges are the second largest citrus fruits cultivated in the country.

The chemical composition of sweet orange shows that it contains water (86-92%), sugar (5-8%), pectin (1-2%), glycosides (0.1-1.5%), pentosans (0.8-1.2%), citric acid (0.4 to 1.5%), fibre (0.6-0.9%), proteins (0.6-0.8%), fat (0.2-0.5%), minerals (0.5-0.9%) and essential oils (0.2-0.5%) (Siddiqi, 2005). Citrus fruit processing produces many byproduct with significant value. These by-products are considered to be rich source of edible and health promoting agents as polymethoxylated flavonoids, many of which are found exclusively in citrus peel Hatamipour *et al.* (2004). The sweet orange peel contain sugars, edible fibre and many other components that offer excellent opportunities as value-added products, particularly those components that have biological activities (antioxidant, anti-cancer, cardio-protective and food/drug-interactions) or other attributes that are useful in the development of high-value food products from citrus peel Widmer and Montanari (1994). The chemicals characteristics of sweet orange juice such as moisture content, protein, fat, carbohydrate, ash and fibre were determined as per standard procedure (AOAC, 2000).

Andhra Pradesh is the leading producer of citrus fruits (23.81%) with recent production of 18,86,890 MT and occupies first (46.78%) in overall production of sweet oranges produced from the country, with recent production of 5,76,340 MT (Kumar *et al*., 2012). The production catchments of sweet oranges is found in Nalgonda, Prakasam, Guntur, Ananthapur, Mahabubnagar, Rangareddy and Kurnool districts of Andhra Pradesh. Nalgonda and Prakasam are the major sweet orange producing districts of Andhra Pradesh.

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 (Soltani *et al.*, 2011). Designing of such equipments and machines without taking these into considerations may yield poor results. Principle axial dimensions are important in sorting and sizing of fruits and to determine how many fruits can be placed in shipping containers or plastic bags of a given size. Fruit weight can be used in order to determine the best time to harvest fruits. Quality differences in fruits, vegetables, grain and seeds can often be detected by differences in density. Porosity, which is the percentage of air space in particulate solids, affects the resistance to air flow through bulk solids. Volume and surface area of solids must be known for accurate modelling of heat and mass transfer during cooling and drying. Angle of repose and co-efficient of static friction were important in design of handling and conveying equipment of fruits.

The objective of this study was to investigate different physical properties of sweet orange fruits. Measured attributes include physical dimensions, mass, volume, angle of repose. The calculated attributes were geometric mean diameter, sphericity, true density, bulk density, porosity, co-efficient of packaging, and static co-efficient of friction were evaluated as a function of size of the fruit. This information about physical properties is valuable not only to engineers but also to food scientists and processors and plant breeders.

METHODOLOGY

Sample preparation :

Fruits were purchased from the local market of Bapatla and were separated into three lots based on their size into large, medium and small grades. The good healthy, matured and uniform sized fruits from each grade were selected for the study. Some physical properties of grade I (large), grade II (medium) and grade III (small) oranges were investigated. Sweet oranges in three size grades: I (large), II (medium) and III (small), 50 of each, were taken as study samples.

Determination of engineering properties :

Axial dimensions were measured using digital callipers; geometric mean diameter and sphericity were calculated from the measured dimensions. Mass of individual fruits and bulk mass of fruit carton was measured using a digital weighing balance (Precision: ±5g) Individual fruit volume and bulk volume was measured by using water displacement method. Density, porosity and co-efficient of packaging were calculated using bulk mass and bulk volume. Angle of repose for individual fruits was measured using an Inclinometer. Co-efficient of friction was calculated using the values of angle of repose.

Principle axial dimensions :

Dimensions of each orange were recorded using Vernier calipers. Dimension ‘a’ is the main (length) diameter, ‘*b*’ (breadth) is the longest dimension perpendicular to ‘a’ and ‘c’ (width) is the longest dimension perpendicular to ‘a’ and ‘b’ (Dash *et al.*, 2008).

Geometric mean diameter :

Mean geometrical diameter was determined from equation (Keyhani *et al.*, 2008).

$$GM = \sqrt[3]{abc} \qquad .....(1)$$

where, GM is geometric mean diameter, a is major axis, b is dimension perpendicular to ‘a’ and c is dimension perpendicular to both ‘a’ and ‘b’.

Sphericity :

Sphericity is the ratio of volume of solid to the volume of circumscribed sphere that has a diameter equal to the longest diameter of the solid so that it can circumscribe the solid sample (Mohsenin, 1986). Sphericity was obtained from equation (Rafiee *et al.*, 2007).

$$S_{ph} = GM/a \qquad .....(2)$$

where, S_{ph} is sphericity, GM is Geometric m ean diameter and ‘a’ is major axis.

Total surface area :

The total surface area (S_T) was calculated using the equation (Rafiee *et al.*, 2007).

$$S_T = \pi \times (GM)^2 \qquad .....(3)$$

where, S_T is total surface area and GM is mean geometric diameter.

Mass of fruit :

Fruit mass (M) was determined through a digitalized sensitive balance with accuracy of ±0.01 g.

Volume and fruit density of fruit :

Volume (V) and weight density (D) of individual fruit were determined by using water displacement method. The fruit was weighed on a digital balance of accuracy of ± 5g. The fruit was then forced into water in a beaker by means of a sinker rod to determine the volume. The displaced water was collected in a measuring cylinder and the volume was determined. The volume of fruit was equal to the displaced volume of water. The weight density (D) of fruit was then obtained by the ratio of weight to volume (Humeida and Hobani, 1993).

Weight density of fruit is given as the ratio of individual fruit mass to its volume.

$$D = M/V \qquad .....(4)$$

where, D is true density of fruit, M is mass of fruit and V is volume of individual fruit.

Bulk volume :

Bulk volume (V_o) is the volume of a material when packed or stacked in bulk. It includes all the pores enclosed within the material (internal pores) and also the void volume outside the boundary of individual particles when stacked in bulk (external pores) (Sahin and Sumnu, 2006).

A carton of known volume made of paper board was used to calculate bulk volume. The carton was filled with possible number of fruits avoiding overcrowding. The excess fruits were removed by sweeping the surface of the carton. Filled carton was weighed using a digital weighing balance. Bulk volume (V_o) of fruits was measured using water displacement method (Humeida and Hobani, 1993). 10 readings were taken using a sample size of 50 different fruits for each grade.

Bulk density :

Bulk density is the density of a material when packed or stacked in bulk (Sahin and Sumnu, 2006). Bulk density (BD) was obtained using equation (5) as the ratio of carton mass (M_C) to the carton volume (V_c) (Rafiee *et al.*, 2007).

$$BD = M_C / V_c \qquad .....(5)$$

where, BD is bulk density, M_C is mass of carton containing fruits and V_c is volume of carton.

Porosity :

Porosity (ε) is defined as the volume fraction of the air or the void fraction in the sample as expressed in equation (6) (Sahin and Sumnu, 2006).

Porosity (%) = Void volume/Total volume

It can be expressed as

$$\varepsilon = \frac{(V_C - V_O) \times 100}{V_C} \qquad .....(6)$$

where, ε is porosity, V_C is volume of carton and V_O is bulk volume of fruits in carton.

Co-efficient of packaging :

Packing co-efficient (λ) was obtained from the equation (7) (Tarighi *et al.*, 2010)

It is expressed as

$$\lambda = V_o/V_C \qquad ......(7)$$

where, λ is co-efficient of packaging, V_C is volume of carton and V_O is volume of fruits in carton.

Angle of repose and static co-efficient of friction :

The co-efficients of static friction were obtained with respect to three different surfaces, namely mild steel, plywood and glass surfaces, by using an inclined plane apparatus. The inclined plane was gently raised and the angle of inclination at which the sample started sliding was read off the protractor with sensitivity of one degree. The tangent of the angle (tan θ) was reported as the co-efficient of friction (Bousejin *et al.*, 2008).

RESULTS AND DISCUSSION

Determined physical features of three grades of sweet orange samples are presented in Table 1. The mean lengths of the grade I (large), II (medium) and III (small) sweet oranges were 75.97, 61.08 and 53.71 mm, for the mean width were 84.00, 66.75 and 58.02 mm, respectively, and for the mean thickness values of grade I, grade II and grade III sweet oranges were 84.32, 66.99 and 58.41 mm, respectively. Mean values for individual fruit mass of grade I, grade II and grade III sweet oranges were 248.77, 152.62 and 96.80. Fruit density of grade I, grade II and grade III sweet oranges was 0.88, 1.06 and 1.09. Also as seen in the same table, the mean volumes of grade I, grade II and grade III sweet oranges were 285.55, 143.69 and 88.73 c.c, respectively. Surface area of grade I, grade II and grade III sweet oranges was 19.1×10^3, 12.2×10^3 and $9.22 \times 10^3 mm^2$, respectively. Bulk density of grade I, grade II and grade III oranges were 0.50, 0.58, 0.52g cm^{-3}. Porosity of grade I, II and III oranges was 49.04, 51.04, and 49.00 per cent, respectively. Co-efficient of static friction for grade I, grade II and grade III sweet oranges on different surfaces was found to be as follows: Mild steel, 0.22, 0.16 and 0.19; glass surface, 0.23, 0.21 and 0.22; wooden surface 0.23, 0.18 and 0.21. Packing co-efficients, as indicated in Table 1 were 0.51, 0.49 and 0.51 for the three sizes of grade I, grade II and grade III oranges. Length, breadth and thickness values for grade I oranges were higher than those of the grade II as well as those of the grade III oranges, respectively. These figures are higher for the medium size oranges as compared with the small ones, similar trend have been followed for fruit mass and fruit volume, respectively. Fruit density was found higher for grade III fruits compared to other two grades indicating incomplete maturity of the fruits. Bulk volume and co-efficient of packaging was higher for grade III fruits in comparison to other two grades indicating that more number of small fruits can be placed in a container. Density of a pile of sweet oranges was significantly higher for grade II oranges in comparison with those of grade I and grade III fruits. Co-efficient of static friction on mild steel and wooden surface of grade I oranges was found to be higher than other two grades and it was higher for grade three fruits in comparison with grade II fruits. No difference was observed between grade I and three oranges as far as co-efficient of

Table 1 : Assessed mean physical characteristics of sweet oranges

Property	No. of observations	Grade I	Grade II	Grade III
a (mm)	50	75.97	61.08	53.71
b (mm)	50	84.32	66.99	58.41
c (mm)	50	84.00	66.75	58.02
Geometric mean diameter (mm)	50	77.79	62.19	54.07
Sphericity	50	0.92	0.93	0.93
Surface area(mm^2)	50	19.1×10^3	12.2×10^3	9.22×10^3
Weight (g)	50	248.77	152.62	96.80
Volume (cc)	50	285.55	143.69	88.73
Fruit density (g/cc)	50	0.88	1.06	1.09
Bulk weight (g)	10	1081.50	1255.50	1109.00
Bulk volume (cc)	10	1097.00	1054.00	1098.00
Bulk density (g/cc)	10	0.50	0.58	0.52
Porosity	10	49.04	51.04	49.00
Coe. of packing	10	0.51	0.49	0.51
Angle of repose (Mild steel)	25	12.50	8.91	10.66
Angle of repose (Glass)	25	12.73	11.73	12.66
Angle of repose (Plywood)	25	12.73	10.27	11.64
Coe. of static friction (Mild steel)	25	0.22	0.16	0.19
Coe. of static friction (Glass)	25	0.23	0.21	0.22
Coe. of static friction (Plywood)	25	0.23	0.18	0.21

static friction on glass surface is concerned, it was observed comparatively less in grade II oranges than other grades. The three classes of fruits were significantly different from each other regarding their physical properties.

Evaluation of regression models :

Fruit mass was taken as independent variable on the basis of which fruit volume was estimated.

An equation of the second degree was found to be more responsive to estimate the mass of orange based upon its volume. Equations (Eq. 8, 9 and 10) were developed relating mass and volume with co-efficients of determination 0.894, 0.893 and 0.932, respectively for grade 1, 2 and 3 fruits (Fig. 1, 2 and 3).

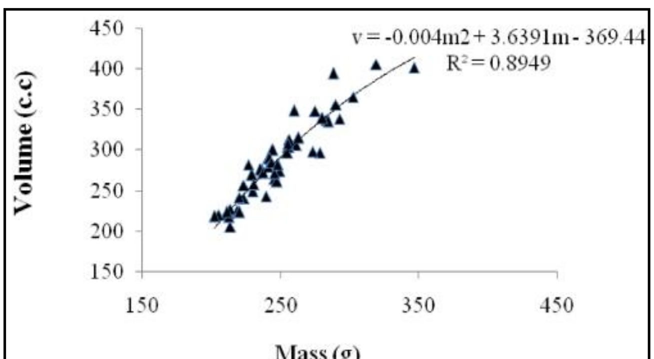

Fig. 1 : The relationship between volume and mass of sweet orange (grade I)

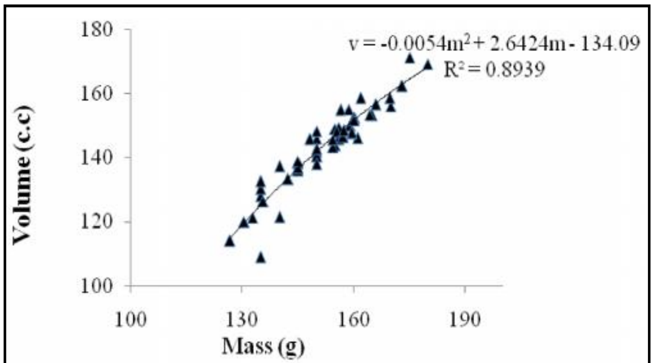

Fig. 2 : The relationship between volume and mass of sweet orange (grade II)

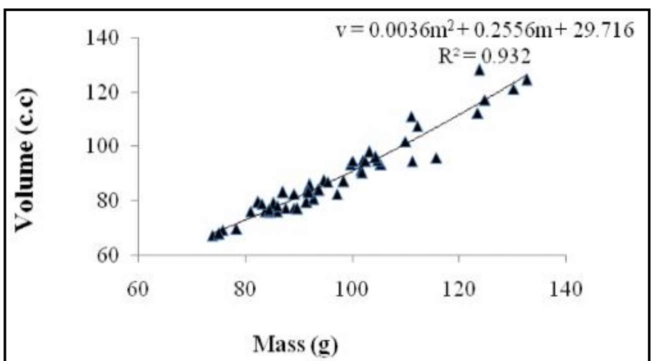

Fig. 3 : The relationship between volume and mass of sweet orange (grade III)

Since measurement of the fruit mass is the easiest, this parameter can be employed in an equation to predict the fruit volume as follows

Grade I: $v = -0.004m^2 + 3.6391m - 369.44$ (8)

Grade II: $v = -0.0054m^2 + 2.6424m - 134.09$ (9)

Grade III: $v = 0.0036m^2 + 0.2556m + 29.716$ (10).

Conclusion :

Some physical properties of sweet orange were studied. The studied physical properties of sweet orange measured will serve as a useful tool in bulk handling, process and equipment design and this will go in long way in assisting to improve the handling of fruits improving quality of sweet oranges. Regression equations were developed for three grades of sweet oranges which serve to predict volume of the fruit when mass is known. The following conclusions were drawn from this investigation.

Maximum, average and minimum length, width, thickness, volume and mass were determined for sweet oranges as follows :

Grade 1 :

Maximum: 89.99, 102.51 and 99.65mm, 406.36 (c.c), and 346.49 (g)

Average: 75.97, 84.32 and 84.00mm, 285.78 (c.c), and 248.84 (g)

Minimum: 62.62, 72.19 and 73.58 mm, 204.95 (c.c), and 200.00 (g).

Grade 2 :

Maximum: 68.10, 74.30 and 73.39mm, 171.28 (c.c), and 180.00 (g)

Average: 61.08, 66.99 and 66.75 mm, 143.70 (c.c), and 152.62 (g)

Minimum: 50.45, 54.97 and 55.17 mm, 108.95 (c.c), and 125.00 (g).

Grade 3 :

Maximum: 60.51, 64.12and 63.83mm, 115.00 (c.c), and 130.21 (g)

Average: 53.71, 58.41 and 58.02 mm, 89.83 (c.c), and 96.88 (g)

Minimum: 48.07, 52.24 and 53.20 mm, 66.00 (c.c), and 73.86 (g).

Authors' affiliations:

S. VISHNUVARDHAN, Post Harvest Technology, ANGRAU, Bapatla, GUNTUR (A.P.) INDIA
Email : vishnuvardhan@yahoo.com

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