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Cantaloupe Volume Determination Using Image Processing Method

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Abstract: Cantaloupe (*Cucumis melo*) volume was measured using water displacement and image processing methods. The volume determined from image processing method (IPM) was compared to the volume determined by the water displacement method (WDM) using the paired samples t-test and the Bland-Altman approach. The paired samples t-test results showed that the volume determined by image processing method was not significantly different from the volume measured by water displacement method (P = 0.207). The mean and standard deviation of the volume difference between two methods were -81.1 cm^3 and 237.4 cm^3, respectively (95% confidence interval: -212.5 and 50.4 cm^3). The average percentage difference between two methods was 7.60%. The Bland-Altman approach also indicated that for all sized cantaloupe, image processing method satisfactorily estimated cantaloupe volume. Accordingly, image processing provides an accurate, simple, rapid and non-invasive method to estimate fruit volume and can be easily implemented in monitoring fruit growth and sorting of fruits during postharvest processing.

Key words: Cantaloupe · Volume · Image processing · Fruit sorting

INTRODUCTION

Cantaloupe (*Cucumis melo*) is a subtropical fruit and belongs to the family Cucurbitaceae. Its spread from Italy to other parts of the world was rapid due to its ordinary climatic requirements. Cantaloupe is considered as one of the best fruits due to its high nutritive value. Besides a rich source of vitamin A and C, it contains a fair amount of nutrients (Calcium, Magnesium, Phosphorus, Potassium and Iron) and vitamins (B_1, B_3, B_5 and B_6). Cantaloupe contains 55-59% edible portion, 87-92% moisture, 0.1-0.2% oil, 0.60-1.0% protein and 6.3-10.3% total soluble solids [1]. Fruit size is one of the most important quality parameters for evaluation by consumer preference [2]. Consumers prefer fruits of equal weight and uniform shape [3]. The estimation of mean fruit size is important in meeting quality standards, increasing market value, monitoring fruit growth, predicting fruit yield and sorting of fruits [4]. Fruit size estimation is also helpful in planning packaging, transportation and marketing operations [5]. The size of an agricultural produce is frequently represented by its mass because it is relatively simple to measure. However, volume-based sorting may provide a more efficient method than mass sorting. In addition, the mass of agricultural produce can be estimated from volume if the density of the produce is known.

Two common methods of volume measurement include gas displacement and water displacement. Gas displacement method does not harm the fruit but it is time-consuming. While water displacement method takes less time, it may have harmful effects on the produce. Both methods are best performed indoors and may not be practical [6]. Another method to determine fruit volume is the use of outer dimensions [6, 7]. However, measuring dimensions using a caliper, subject to human error, may not be an efficient and practical approach to estimate volume, particularly in sorting large quantities of fruit in distribution terminals [2]. Nowadays, the use of image processing is gaining interest for the surface area and volume determination of fruit. Sabliov *et al.* (2002) used an image processing algorithm to determine the surface area and volume of axisymmetric agricultural products [8]. Wang and Nguang (2007) used the methodology developed by Sabliov *et al.* to measure the surface area and volume of agricultural products [9]. They created a

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representation of the produce with a set of elementary cylindrical objects and estimated the volume by summing the elementary volumes of individual cylinders. Both Sabliov *et al.* and Wang and Nguang reported that the method successfully estimated the surface area and volume of lemons, limes and peaches [8, 9]. Bailey *et al.* (2004) demonstrated an image processing approach which estimated the mass of agricultural products rapidly and accurately. They used two perpendicular views to estimate fruit volume and then used the volume information to calculate the mass through a closed-loop calibration [10].

The image processing estimation methods reported in the literature were successfully applied to agricultural produce such as limes, lemons and peaches. All of these products are relatively smaller and more regularly shaped than cantaloupe. The estimation of cantaloupe volume is important for size sorting and monitoring growth development under various management practices. Image processing can also provide an alternative method to estimate the volume of cantaloupe. The aim of this study was to estimate cantaloupe volume by image processing and utilizing of standard softwares for data handling and analysis.

MATERIALS AND METHODS

Plant Material: Fifteen randomly selected cantaloupes (*Cucumis melo cv.* Samsouri) of various sizes were picked up from their storage piles. Fruits were selected for freedom from defects by careful visual inspection, transferred to the laboratory and held at 5±1°C and 90±5% relative humidity until use.

Experimental Procedure: The dimensions (length, major diameter and minor diameter) were measured using a digital caliper. The mass of each cantaloupe was measured using a digital balance with ±5.0 g accuracy. The minimum and maximum cantaloupe mass was 1245 and 3380 g, respectively. The volume of each cantaloupe was measured using the water displacement method. Each cantaloupe was submerged in a container full of water and the volume of the displaced water was measured using a 250 cm^3 capacity graduated cylinder. Water temperature during measurements was kept at 25°C.

The image processing system consisted of a digital camera with USB connection, a fluorescent ring light source (40 W) and a personal computer (PC) equipped with ADOBE PHOTOSHOP 8.0 (Version 2003), COMPAQ VISUAL FORTRAN 6.5 (Version 2000) and MICROSOFT EXCEL (Version 2003) programs. A white cardboard was placed on a table to provide a white background. The digital camera was placed at the center of the fluorescent ring light source. The light source and camera mounted on an adjustable frame was attached to the measurement table. A schematic picture of the image acquisition system is presented in Fig. 1. The distance between the measurement table surface and the camera was set at 45 cm. Each cantaloupe was placed at the center of the camera's field of view and two RGB color images were captured before and after manually rotating the cantaloupe 90° around the lateral axis.

The original RGB color image of each cantaloupe was converted to a grayscale image. Grayscale intensity represents 256 different shades of gray from black (0) to white (255). Using the threshold technique, the selected region of interest on the grayscale image was then converted to a black-and-white image with pixel values of 0 or 255. From the grayscale image, pixel values less than 155 were converted to 0 (black) and pixel values higher than 155 were converted to 255 (white), producing a black-and-white image for each cantaloupe. The threshold level of 155 was determined experimentally. The edge detection technique was then used to identify the cantaloupe edge in each image. The pixels showing the cantaloupe outline had the value of 0 and the remainder of the pixels in the image had the value of 255. Examples of the original RGB color, grayscale, black-and-white and outline images of a cantaloupe are shown in Fig. 2. The original RGB color, grayscale and black-and-white images were recorded as a bitmap file while the cantaloupe outline image was recorded as a DAT file with a two-dimensional array. The purpose of processing and converting the original RGB color images to black-and-white and outline images was to reduce the file size and processing time during volume calculation using the computer software.

Dimensional Calibration: Each cantaloupe was placed at the center of the camera's field of view. Cantaloupe major and minor diameters were measured with a digital caliper. Without changing the position of the fruit, the first surface image was captured with the image acquisition system. The number of pixels representing the major and minor diameter of the cantaloupe was measured on the first captured image. Then, the cantaloupe was manually rotated 90° around the latitudinal axis and cantaloupe length was measured with a digital caliper. Again, without changing the position of the fruit, the second surface image was captured and the number of the pixels representing the length of the cantaloupe was measured.

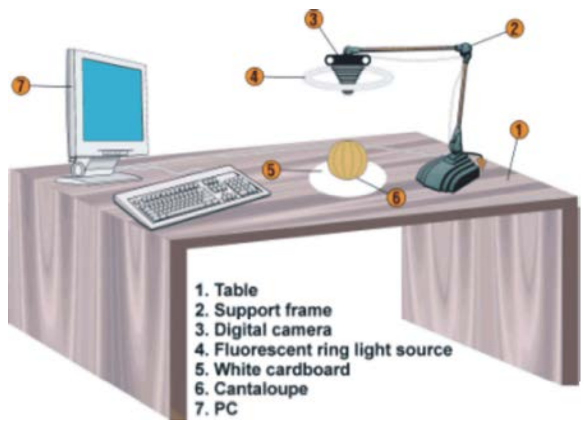

Fig. 1: Image acquisition system

(I) (II) (III) (IV)

Fig. 2: (I) Original RGB color, (II) grayscale, (III) black-and-white and (IV) outline images of a cantaloupe

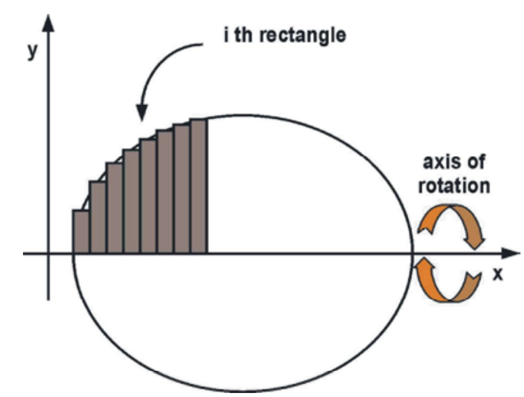

Fig. 3: The outline image of the cantaloupe was assumed to be composed of individual rectangular elements

The dimensions in millimeters were divided by the dimensions in pixels and a mean conversion factor was calculated for each cantaloupe. The mean conversion factor of 15 cantaloupes was averaged and a single conversion factor was determined. The same conversion factor was later used to estimate the volume of each cantaloupe.

Volume Evaluation from Surface Images: The outline images of each cantaloupe as shown in Fig. 2 (IV) were used to calculate volume using the disk technique [11].

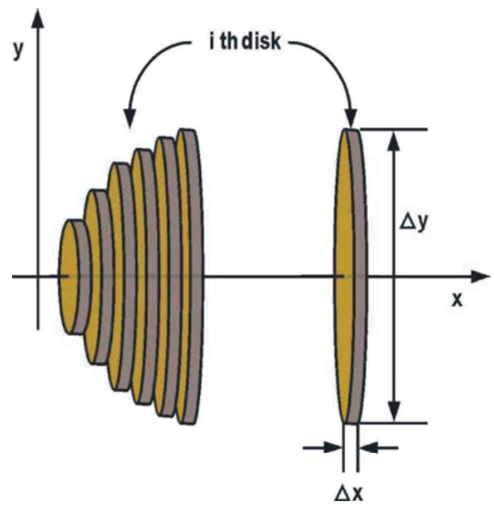

Fig. 4: Revolving each element around the x-axis generated cylindrical disks

Each two-dimensional outline image of cantaloupe was assumed to be composed of individual rectangular elements as shown in Fig. 3. Revolving the height of each rectangular element around the x-axis produces a cylindrical disk with a diameter of Δy as shown in Fig. 4. The volume of each cylindrical disk (V_i) shown in Fig. 4 is equal to the cross sectional area of the disk (A_i) times the thickness of the disk (Δx). Equation 1 shows the cross-sectional area of a cylindrical disk and equation 2 shows the volume of the same disk.

$$A_i = \pi(\frac{\Delta y}{2})^2 \quad (1)$$

$$V_i = A_i \Delta x \quad (2)$$

The program developed in COMPAQ VISUAL FORTRAN considered each disk as having a thickness of 1 pixel and used an algorithm to determine the major and minor diameters and calculate the mean diameter of each disk. Using the mean diameter, the volume of each disk was calculated. The volume of each disk was then summed to estimate the total volume as shown in equation 3. Finally, the same conversion factor was used to estimate the volume of each cantaloupe.

$$V = \sum_{i=1}^{n} V_i \quad (3)$$

Statistical Analysis: A paired samples t-test and the mean difference confidence interval approach were used to compare the volume determined from image processing method with the water displacement method. The Bland-Altman approach [12] was also used to plot the agreement between cantaloupe volumes determined by image processing method with the water displacement method. The statistical analyses were performed using MICROSOFT EXCEL.

RESULTS AND DISCUSSION

Dimensional Calibration Results: The dimensional calibration was determined by measuring cantaloupe length, major diameter and minor diameter in millimeters using a digital caliper and determining these parameters in pixels using image processing from the outline images. The dimensions measured with the digital caliper and with image processing are demonstrated in Table 1. From the digital caliper and image processing measurements, a conversion factor of 1 pixel to 1.62 mm was determined. This conversion factor was used to estimate the volume of each cantaloupe using image processing.

Comparison of Image Processing Method with Water Displacement Method: The paired samples t-test results (Table 2) showed that the volume determined with image processing was not significantly different from the volume measured with water displacement ($P = 0.207$). The mean volume difference between the two methods was -81.1 cm^3 (95% confidence interval: -212.5 and 50.4 cm^3). The standard deviation of the volume differences was 237.4 cm^3. A plot of the volumes determined by image processing method (IPM) and water displacement method (WDM) with the line of equality (1.0: 1.0) is shown in Fig. 5. As shown in Fig. 6, the volume differences between image processing and water displacement methods were normally distributed and the 95% limits of agreement in comparing these two methods were calculated to be -546.4 and 384.3 cm^3. Fig. 6 also shows that for small-sized cantaloupe, the volume estimated by image processing is less than the volume measured by water displacement (WDM-IPM > 0). As the size of cantaloupe increases, the image processing method overestimates the volume (WDM-IPM < 0). This is because of the change in distance between the digital camera and the cantaloupe surface. Although the distance between the digital camera and the measurement table is constant, the distance between cantaloupe and the digital camera reduces with increasing cantaloupe size.

The average percentage difference for volume estimation with image processing and water displacement was 7.60%. As in this study image processing method was based on the assumption that each cantaloupe was axisymmetric in shape, the accuracy of the determining volume depended on the uniformity of the fruit having the presumed shape. If we do not take into account misshapen cantaloupe, which are not axisymmetric in shape, image processing provides an accurate, simple,

Table 1: Mass, dimensions and volumes of cantaloupes used in this study

		Dimensions							
		With digital caliper (mm)			With image processing (pixel)			Volume (cm^3)	
Sample number	Mass (g)	Length	Major diameter	Minor diameter	Length	Major diameter	Minor diameter	Water displacement method	Image processing method
1	1245	123	139	136	78	81	80	1218	1010
2	1285	133	145	132	79	86	79	1333	1264
3	1340	127	151	144	78	89	87	1446	1400
4	1380	142	144	136	84	89	83	1456	1373
5	1390	145	155	123	87	93	75	1448	1287
6	1470	136	152	140	83	92	86	1516	1553
7	1540	140	152	150	87	92	91	1672	1605
8	1630	136	160	158	83	99	99	1800	1860
9	1695	144	160	152	91	99	93	1834	1784
10	1795	140	170	162	86	105	101	2019	2130
11	2035	155	182	162	97	112	101	2393	2492
12	2150	157	179	160	96	110	98	2355	2732
13	2300	161	181	171	101	115	111	2609	2719
14	2755	172	190	185	108	123	121	3166	3665
15	3380	183	205	186	117	134	124	3654	4260

Table 2: Paired sample t-test analyses on comparing volume measurement methods

Size	df	Average Difference (cm^3)	Standard deviation of difference (cm^3)	P value	95% confidence intervals for the difference in means (cm^3)
15	14	-81.1	237.4	0.207	-212.5, 50.4

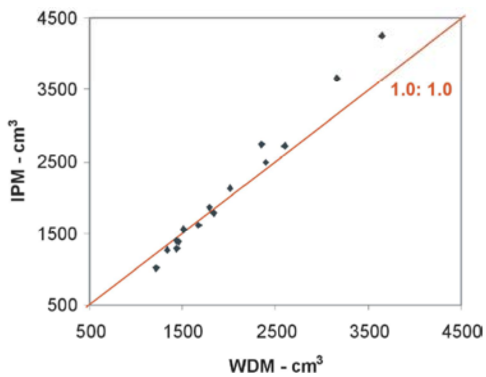

Fig. 5: Cantaloupe volume measured using water displacement method (WDM) and image processing method (IPM) with the line of equality (1.0: 1.0)

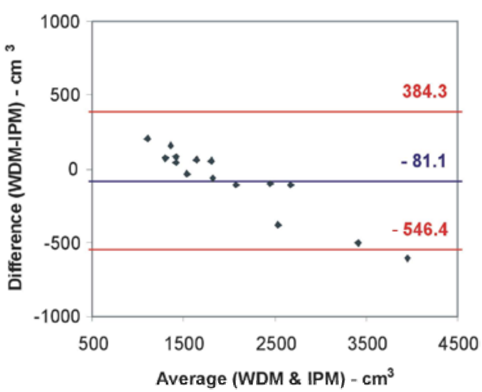

Fig. 6: Bland-Altman plot for the comparison of cantaloupe volumes measured with water displacement method (WDM) and image processing method (IPM); outer lines indicate the 95% limits of agreement (-546.4, 384.3) and center line shows the average difference (-81.1).

rapid and non-invasive method to estimate cantaloupe volume and can be easily implemented in monitoring growth development under various management practices, estimating the weight of individual cantaloupe and sorting of cantaloupe during postharvest processing.

CONCLUSIONS

Image processing method with the disk approximation technique was used to estimate the volume of cantaloupe of varying sizes from sets of two surface images captured with a digital camera. The volumes estimated using this method was statistically compared to the volumes measured with the water displacement method. The paired samples t-test results indicated that the difference between the volumes estimated by image processing and water displacement were not significant ($P > 0.05$). The Bland-Altman approach also showed that for all sized cantaloupe, image processing method satisfactorily estimated cantaloupe volume. Accordingly, image processing provides an accurate, simple, rapid and non-invasive method to estimate cantaloupe volume and can be easily implemented in monitoring growth development under various management practices and sorting of cantaloupe during postharvest processing.

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