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Determination of Kiwifruit Volume Using Image Processing

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Abstract: Kiwifruit (Actinidia deliciosa) volume was determined using water displacement and image processing methods. Surface images of each kiwifruit, captured with a digital camera, were utilized in the image processing method. 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 ($P>0.05$) different from the volume measured by water displacement method. The mean difference between water displacement and image processing methods was -2.23 cm^3 (95% confidence interval: -6.71 and 2.25 cm^3; $P = 0.304$). The standard deviation of the volume differences was 8.10 cm^3. The Bland-Altman approach also indicated that for all sized kiwifruits, image processing method satisfactorily estimated kiwifruit volume. Accordingly, image processing provides an accurate, simple, rapid and non-invasive method to estimate kiwifruit volume and can be easily implemented in monitoring growth development under various management practices and sorting of kiwifruits during postharvest processing.

Key words: Volume · kiwifruit · image processing · fruit sorting

INTRODUCTION

Kiwifruit is a subtropical fruit and belongs to the family Actinidiaceae. Its spread from China to other parts of the world was rapid due to its ordinary climatic requirements [1]. It is considered as one of the best fruits due to its high nutritive value. Besides a rich source of vitamin C, kiwifruit contains a fair amount of nutrients (Calcium, Magnesium, Nitrogen, Phosphorus, Potassium, Iron, Sodium, Manganese, Zinc and Copper) and vitamins (A, B_1, B_2, B_6 and E). Kiwifruit contains 90-95% edible portion, 80-88% moisture, 1.0-1.6% acid, 0.7-0.9% oil, 0.11-1.2% protein, 0.45-0.74% ash, 1.1-3.3% fiber, 17.5% carbohydrate and 12-18% total soluble solids [1, 2].

The main commercial producers are Italy, New Zealand, Chili, France, Japan, U.S.A., Iran, Greece, Spain and Portugal [1]. Iran produces 35,000 tons of kiwifruit and is ranked 7th in the world, but Iranian kiwifruit are not exported because of variability in size and shape and lack of proper packaging.

Fruit size is one of the most important quality parameters for evaluation by consumer preference [3]. Consumers prefer fruits of equal weight and uniform shape [4]. 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 [5]. Fruit size estimation is also helpful in planning packaging, transportation and marketing operations [6]. 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 [7].

Another method to determine fruit volume is the use of outer dimensions [7, 8]. 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 [3].

Nowadays, the use of image processing is gaining interest for the surface area and volume determination of

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fruit. Sabliov *et al.* [9] used an image processing algorithm to determine the surface area and volume of axisymmetric agricultural products [9]. Wang and Nguang [10] used the methodology developed by Sabliov *et al.* [9] to measure the surface area and volume of agricultural products [10]. They created a 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.* [9] and Wang and Nguang [10] reported that the method successfully estimated the surface area and volume of lemons, limes and peaches [9, 10]. Bailey *et al.* [11] demonstrated an image processing approach which estimated the mass of agricultural products rapidly and accurately [11]. They used two perpendicular views to estimate fruit volume and then used the volume information to calculate the mass through a closed-loop calibration.

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 greater and more regularly shaped than kiwifruits [12]. The estimation of kiwifruit 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 kiwifruit. The aim of this study was to estimate kiwifruit volume by image processing and utilizing of standard softwares for data handling and analysis.

MATERIALS AND METHODS

Plant material: The most common commercial variety of kiwifruit cv. Hayward was considered for this study and 15 randomly selected kiwifruits 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 kiwifruit was measured using a digital balance with ±0.1 g accuracy. The minimum and maximum kiwifruit mass was 55.3 and 112.3 g, respectively. The volume of each kiwifruit was measured using the water displacement method. Each kiwifruit was submerged in a 250 cm^3 graduated cylinder and the volume of water displaced was measured. 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 25 cm. Each kiwifruit 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 kiwifruit 90° around the longitudinal axis.

The original RGB color image of each kiwifruit 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 205 were converted to 0 (black) and pixel values higher than 205 were converted to 255 (white), producing a black-and-white image for each kiwifruit. The threshold level of 205 was determined experimentally. The edge detection technique was then used to identify the kiwifruit edge in each image. The pixels showing the kiwifruit 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 kiwifruit are shown in Fig. 2. The original RGB color, grayscale and black-and-white images were recorded as a bitmap file while the kiwifruit 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 kiwifruit was placed at the center of the camera's field of view. Kiwifruit length and major diameter 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 length and major diameter of the kiwifruit was measured on the first captured image. Then, the kiwifruit was manually rotated

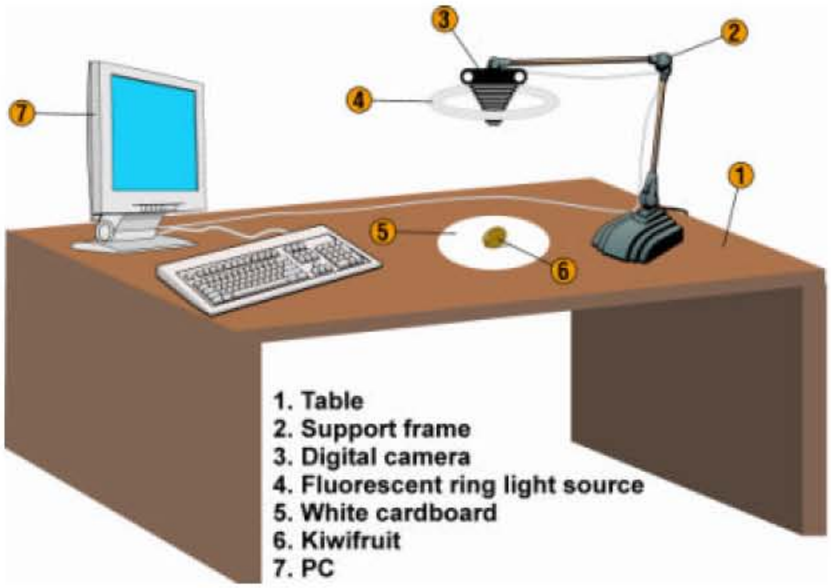

Fig. 1: Image acquisition system

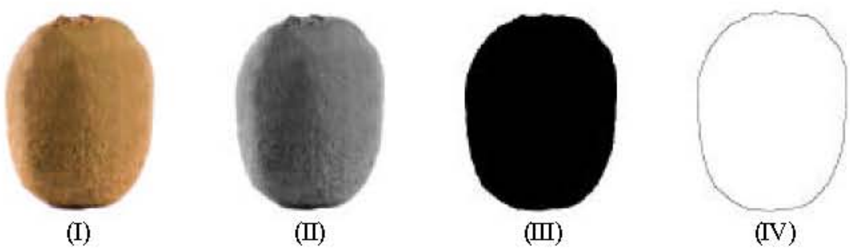

Fig. 2: (I) Original RGB color, (II) grayscale, (III) black-and-white and (IV) outline images of a kiwifruit

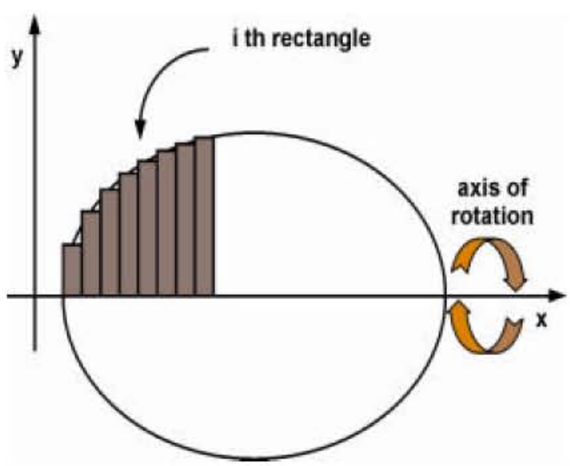

Fig. 3: The outline image of the kiwifruit was assumed to be composed of individual rectangular elements

90° around the longitudinal axis and kiwifruit minor diameter 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 minor diameter of the kiwifruit was measured. The dimensions in millimeters were divided by the dimensions in pixels and a mean conversion factor was calculated for each kiwifruit. The mean conversion factor of 15 kiwifruits was averaged and a single conversion factor was determined. The same conversion factor was later used to estimate the volume of each kiwifruit.

Volume evaluation from surface images: The outline images of each kiwifruit as shown in Fig. 2 (IV) were used to calculate volume using the disk technique [13]. Each two-dimensional outline image of kiwifruit 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). Eq. (1) shows the cross-sectional area of a cylindrical disk and Eq. (2) shows the volume of the same disk.

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

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

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 Eq. (3). Finally, the same conversion factor was used to estimate the volume of each kiwifruit.

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

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 [14] approach was also used to plot the agreement between kiwifruit 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 kiwifruit 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

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

		Dimensions							
		With digital caliper (mm)			With image processing (pixel)			Volumes (cm^3)	
Sample number	Mass (g)	Length	Major diameter	Minor diameter	Length	Major diameter	Minor diameter	Water displacement method	Image processing method
1	55.3	52	45	41	37	29	27	54.7	45.4
2	59.1	52	47	43	35	31	29	57.0	54.0
3	63.0	57	47	40	39	31	27	60.3	58.4
4	65.2	51	46	43	34	32	29	62.2	58.7
5	67.1	53	47	43	36	32	29	64.1	57.0
6	68.2	59	49	41	40	33	28	65.8	67.4
7	69.2	64	46	39	45	31	27	66.0	63.4
8	72.2	59	47	44	41	33	31	69.7	72.0
9	73.0	65	48	41	46	33	28	70.4	68.5
10	76.2	59	50	45	41	35	32	73.6	77.6
11	80.7	69	46	43	49	32	30	77.3	80.5
12	88.5	65	50	47	45	35	32	85.4	99.1
13	98.5	70	51	47	49	36	34	95.0	99.0
14	105.7	68	52	51	48	38	38	102.0	118.1
15	112.3	75	51	47	54	37	35	108.3	126.2

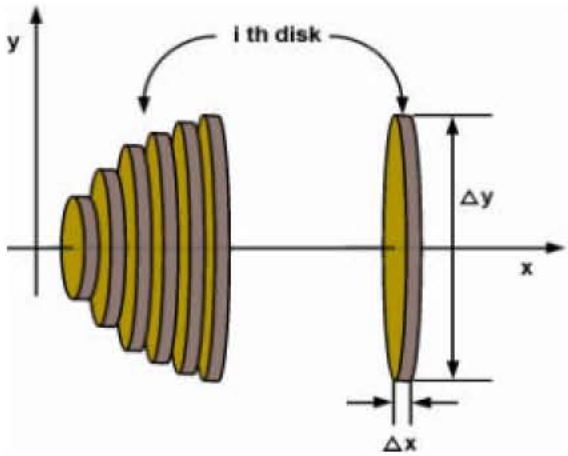

Fig. 4: Revolving each element around the x-axis generated cylindrical disks

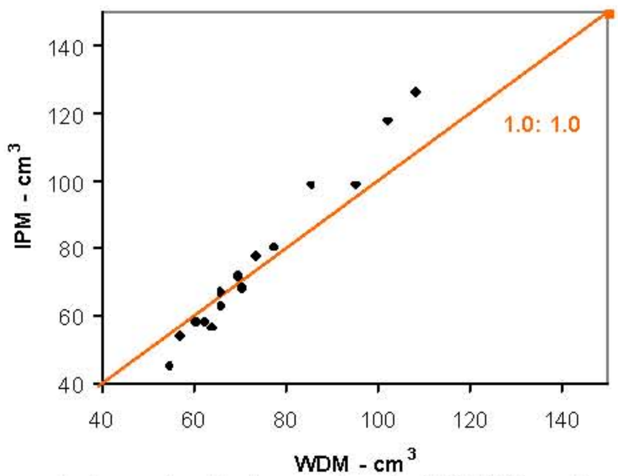

Fig. 5: Kiwifruit volume measured using water displacement method (WDM) and image processing method (IPM) with the line of equality (1.0: 1.0)

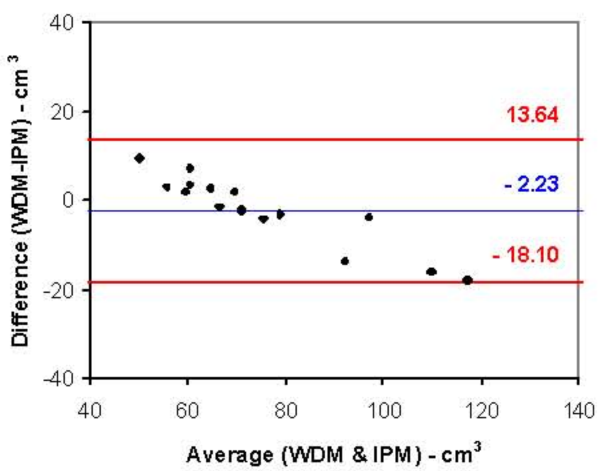

Fig. 6: Bland-Altman plot for the comparison of kiwifruit volumes measured with water displacement method (WDM) and image processing method (IPM); outer lines indicate the 95% limits of agreement (-18.10, 13.64) and center line shows the average difference (-2.23)

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	-2.23	8.10	0.304	-6.71, 2.25

image processing are demonstrated in Table 1. From the digital caliper and image processing measurements, a conversion factor of 1 pixel to 1.44 mm was determined. This conversion factor was used to estimate the volume of each kiwifruit 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 ($P>0.05$) different from the volume m easured with water displacement. The mean volume difference between the two methods was -2.23 cm^3 (95% confidence interval: -6.71 and 2.25 cm^3; P = 0.304). The standard deviation of the volume differences was 8.10 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 -18.10 and 13.64 cm^3. Figure 6 also shows that for small-sized kiwifruits, the volume estimated by image processing is less than the volume measured by water displacement (WDM-IPM>0). As the size of kiwifruit 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 kiwifruit surface. Although the distance between the digital camera and the measurement table is constant, the distance between kiwifruit and the digital camera reduces with increasing kiwifruit size.

The average percentage difference for volume estimation with image processing and water displacement was 7.80%. As in this study image processing method was based on the assumption that each kiwifruit 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 about 4.0% amount of flattened kind of misshapen kiwifruits [12], which are not axisymmetric in shape, image processing provides an accurate, simple, rapid and non-invasive method to estimate kiwifruit volume and can be easily implemented in monitoring growth development under various management practices, monitoring yield during mechanical harvesting, estimating the weight of individual kiwifruits and sorting of kiwifruits during postharvest processing.

CONCLUSSIONS

Image processing method with the disk approximation technique was used to estimate the volume of kiwifruits 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 kiwifruits, image processing method satisfactorily estimated kiwifruit volume. Accordingly, image processing provides an accurate, simple, rapid and non-invasive method to estimate kiwifruit volume and can be easily implemented in monitoring growth development under various management practices and sorting of kiwifruits during postharvest processing.

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