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Determination of Kiwifruit Volume Using Ellipsoid Approximation and Image-processing Methods

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ABSTRACT

Kiwifruit (*Actinidia deliciosa*) volume was determined using water displacement, ellipsoid approximation and image-processing methods. The length, major and minor diameters of each kiwifruit was used in the ellipsoid approximation method (EAM). Surface images of each kiwifruit, captured with a digital camera, were utilized in the image-processing method (IPM). The volumes determined from ellipsoid approximation and image-processing methods was compared to the volumes measured by water displacement method (WDM) using the paired samples t-test. The volumes determined by EAM were significantly ($P < 0.05$) different from the volumes measured by WDM, while the volumes determined by IPM were not significantly ($P > 0.05$) different from the volumes measured by WDM. There was a mean difference of 6.10 cm^3 (95% confidence interval: 4.46 and 7.74 cm^3; $P < 0.0001$) between EAM and WDM. The standard deviation of the volume differences between EAM and WDM was 2.97 cm^3. The mean difference between IPM and WDM was -2.23 cm^3 (95% confidence interval: -6.71 & 2.25 cm^3; $P = 0.304$). The standard deviation of the volume differences between IPM and WDM was 8.10 cm^3. For all sized kiwifruits, except flattened kind of misshapen kiwifruits, image-processing method satisfactorily determined kiwifruit volume. Therefore, image-processing method was found to be an accurate, simple, rapid and non-invasive to estimate kiwifruit volume and can easily be employed in monitoring growth development under various management practices and sorting of kiwifruits in postharvest processing.

Key Words: Volume; Ellipsoid approximation; Image-processing; Sorting; Kiwifruit

INTRODUCTION

Kiwifruit is a subtropical fruit that belongs to the family Actinidiaceae and it has spread from China to other parts of the world rapidly due to its adaptability of local climatic where grown (Abedini, 2004). It is considered as one of the best fruits due to its high nutritive value. Besides its high nutritive value, it is a rich source of vitamin C; and contains a fair amount of Calcium, Magnesium, Nitrogen, Phosphorus, Potassium, Iron, Sodium, Manganese, Zinc, Copper and vitamins A, B_1, B_2, B_6 and E. Moreover, it 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 (Mohammadian & Teimouri, 1999; Abedini, 2004).

Fruit size is one of the most important quality parameters for evaluation by consumer preference (Sadrnia *et al.*, 2007), because they prefer fruits of equal weight and uniform shape (Waseem *et al.*, 2002). From the commercial considerations, the estimation of mean fruit size is important to meet market quality standards. Moreover, fruit size estimation helps in monitoring fruit growth and predicting fruit yield (Wilhelm *et al.*, 2005). Fruit size estimation is also helpful in planning for packaging, transportation and marketing operations (Tabatabaeefar *et al.*, 2000). The size of an agricultural produce is directly related to its mass, however, volume-based sorting may provide a more efficient method than mass sorting. Moreover, the mass of agricultural produce can be estimated from its volume if the density of the produce is known.

Two common methods of volume measurement include gas displacement and water displacement methods. 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 (Ngouajio *et al.*, 2003). Another method is based on the measurement of fruit dimensions i.e., length, major diameter and minor diameter. In this method, the accuracy of determining volume depends on the uniformity of the fruit having the presumed shape (Hall *et al.*, 1996; Ngouajio *et al.*, 2003). However, using calipers may not be an efficient and practical approach to estimate volume, particularly in sorting large quantities of fruit in distribution terminals (Sadrnia *et al.*, 2007). Alternatively, the use of image-processing is reliable for the surface area and volume determination of fruit. Sabliov *et al.* (2002) used an image-processing algorithm to determine the surface area and

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volume of axisymmetric agricultural products. Wang and Nguang (2007) used the methodology developed by Sabliov *et al.* (2002) to measure the surface area and volume of agricultural products. 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.* (2002) and Wang and Nguang (2007) reported that the method successfully estimated the surface area and volume of lemons, limes and peaches. Bailey *et al.* (2004) demonstrated an image-processing approach, which gave rapid and quick estimate of mass of agricultural products. They used two perpendicular views to estimate fruit volume and then used the volume information to calculate the mass through a closed-loop calibration.

In this work, image-processing is employed to estimate the volume of kiwifruit by utilizing of standard softwares for data acquisition and analysis.

MATERIALS AND METHODS

Plant material. The most common commercial variety of kiwifruit (Hayward) was chosen for this study and 15 randomly selected kiwifruits of various sizes were picked up from their storage piles. The selected fruits were free from physical defects and this was done by careful visual inspection. These were then transferred to the laboratory and held at 5±1˚C and 90±5% relative humidity until use.

Experimental procedure. The dimensions (length, major diameter & 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 container full of water and the volume of displaced water was directly measured using a 125 cm^3 graduated cylinder. Water temperature during measurements was maintained 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 used to provide a white background needed in imaging process. The digital camera was placed at the center of the fluorescent ring shaped light source. The light source and camera were mounted on an adjustable frame which 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 field view of camera and two RGB color images were captured before and after manually rotating the kiwifruit by 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 tone 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

Fig. 1. Image acquisition system

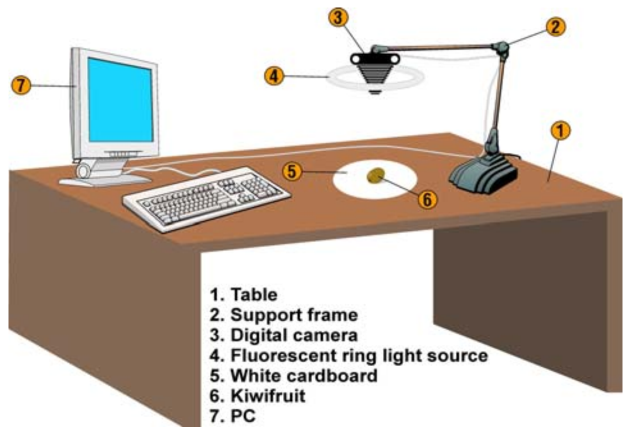


Fig. 2. (I) Original RGB color, (II) grayscale, (III) black-and-white and (IV) outline images of a kiwifruit

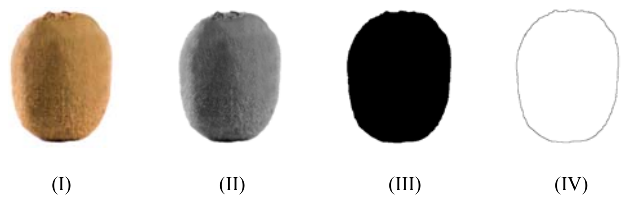
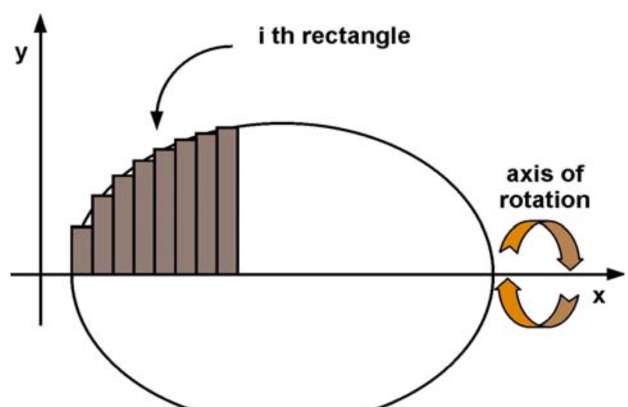


Fig. 3. The outline image of the kiwifruit was assumed to be composed of individual rectangular elements



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. 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 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 used to estimate the volume of each kiwifruit.

Volume evaluation using image-processing. The outline images of each kiwifruit as shown in Fig. 2 (IV) were used to calculate volume using the disk technique (Riddle, 1979). 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.

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

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

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

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

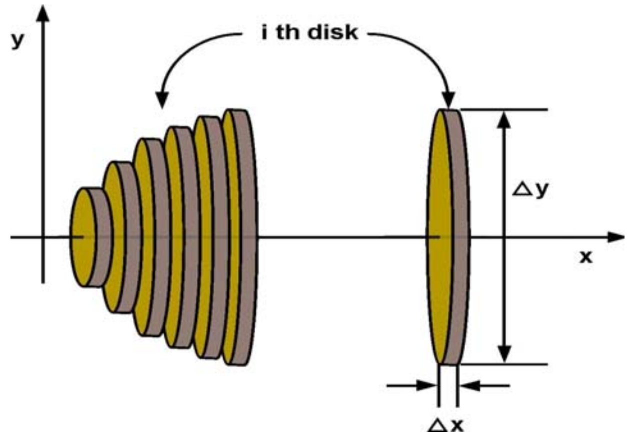


Fig. 5. The dimensions of a perfect ellipsoid

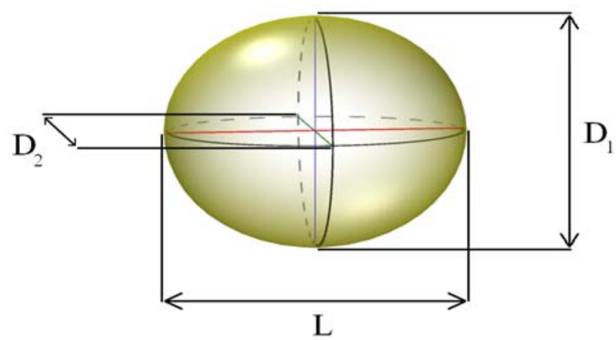
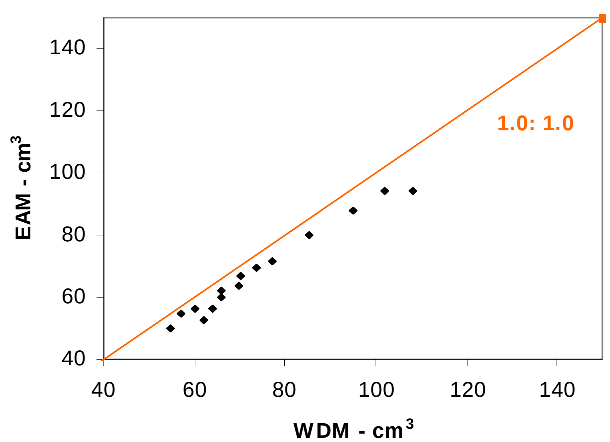


Fig. 6. Kiwifruit volume measured using water displacement method (WDM) and ellipsoid approximation method (EAM) with the line of equality (1.0: 1.0)



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

Volume evaluation using ellipsoid approximation. Each kiwifruit was considered as an ideal ellipsoid. The volume of an ideal ellipsoid can be calculated from length (L), major diameter (D_1) and minor diameter (D_2), which are shown in Fig. 5. Length and major diameter of each kiwifruit were measured before capturing the first image and the minor diameter was measured after rotating the fruit 90° around its longitudinal axis. The volume of kiwifruits was then calculated by using Eq. (4):

$$V_{ellipsoid} = \frac{4}{3}\pi \frac{L}{2}\frac{D_1}{2}\frac{D_2}{2} = \pi \frac{LD_1D_2}{6} \qquad (4)$$

Statistical analysis. A paired samples t-test and the mean difference confidence interval approach were used to compare the volume determined from ellipsoid approximation and image-processing methods with the volume measured by water displacement method. The Bland and Altman (1999) approach was also used to plot the agreement between the kiwifruit volume measured by water displacement method with the volume determined from ellipsoid approximation and image-processing methods. The statistical analyses were performed using Microsoft Excel.

RESULTS AND DISCUSSION

Dimensional calibration results. The dimensions measured with the digital caliper and with image-processing are demonstrated in Table I. 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 determine the volume of each kiwifruit using image-processing.

Comparison of ellipsoid approximation method with water displacement method. The volume determined by ellipsoid approximation was compared with the volume measured by water displacement using the paired samples t-test. The paired samples t-test results (Table II) showed that the volume determined with ellipsoid approximation was significantly ($P < 0.05$) different from the volume measured with water displacement. The mean volume difference between the two methods was 6.10 cm^3 (95% confidence interval: 4.46 & 7.74 cm^3; $P < 0.0001$). The standard deviation of the volume differences was 2.97 cm^3. A plot of the volumes determined by ellipsoid approximation method (EAM) and water displacement method (WDM) with the line of equality (1.0: 1.0) is shown in Fig. 6. Also, as shown in Fig. 7, the volume differences between ellipsoid approximation and water displacement methods were normally distributed and the 95% of the volume differences were expected to be between $\mu - 1.96\sigma$ and $\mu + 1.96\sigma$, known as 95% limits of agreement (Bland & Altman, 1999). The 95% limits of agreement by comparing these two methods were found to be 0.28 and 11.92 cm^3. Thus, volumes determined by ellipsoid approximation may be about 0.28 or 11.92 cm^3 lower than volumes measured with water displacement method.

As it is indicated in Table I, the volumes determined

Fig. 7. Bland-Altman plot for the comparison of kiwifruit volumes measured with water displacement method (WDM) and ellipsoid approximation method (EAM); outer lines indicate the 95% limits of agreement (0.28, 11.92) and center line shows the average difference (6.10)

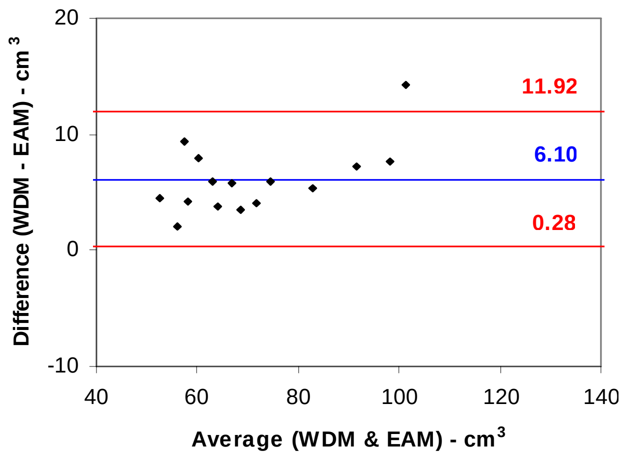
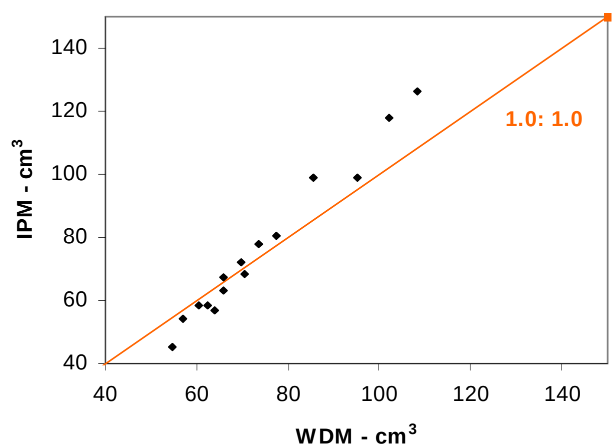


Fig. 8. Kiwifruit volume measured using water displacement method (WDM) and image-processing method (IPM) with the line of equality (1.0: 1.0)



using ellipsoid approximation is less than the volumes measured with water displacement. When ellipsoid approximation method was chosen for kiwifruit volume estimation, it was assumed that an ideal ellipsoid such as in Fig. 5 would be the standard shape to describe kiwifruits. However, in reality, because the kiwifruits were randomly selected from their storage piles (unsorted sources) their shapes were not perfect ellipsoids. In addition, the polar radii of kiwifruits were unequal and were greater than the polar radii of an ideal ellipsoid. Therefore, the volume determined by ellipsoid approximation was less than the volume measured with water displacement. The accuracy of the ellipsoid approximation method depends highly on the uniformity of the fruit having the presumed shape.

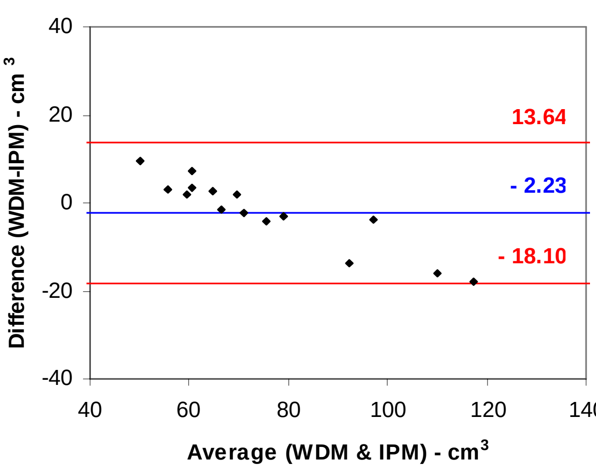
Table I. Mass, dimensions and volumes of kiwifruits used in this study

Sample number	Mass (g)	Dimensions						Volumes (cm^3)		
		With digital caliper (mm)			With image-processing (pixel)					
		Length	Major diameter	Minor diameter	Length	Major diameter	Minor diameter	WDM	EAM	IPM
1	55.3	52	45	41	37	29	27	54.7	50.2	45.4
2	59.1	52	47	43	35	31	29	57.0	55.0	54.0
3	63.0	57	47	40	39	31	27	60.3	56.1	58.4
4	65.2	51	46	43	34	32	29	62.2	52.8	58.7
5	67.1	53	47	43	36	32	29	64.1	56.1	57.0
6	68.2	59	49	41	40	33	28	65.8	62.0	67.4
7	69.2	64	46	39	45	31	27	66.0	60.1	63.4
8	72.2	59	47	44	41	33	31	69.7	63.9	72.0
9	73.0	65	48	41	46	33	28	70.4	66.9	68.5
10	76.2	59	50	45	41	35	32	73.6	69.5	77.6
11	80.7	69	46	43	49	32	30	77.3	71.4	80.5
12	88.5	65	50	47	45	35	32	85.4	80.0	99.1
13	98.5	70	51	47	49	36	34	95.0	87.8	99.0
14	105.7	68	52	51	48	38	38	102.0	94.4	118.1
15	112.3	75	51	47	54	37	35	108.3	94.1	126.2

Table II. Paired samples t-test analyses on comparing volume measurement methods

Measurement methods	Average Difference (cm^3)	Standard deviation of difference (cm^3)	P value	95% confidence intervals for the difference in means (cm^3)
EAM & WDM	6.10	2.97	< 0.0001	4.46, 7.74
IPM & WDM	-2.23	8.10	0.304	-6.71, 2.25

Fig. 9. 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)



Comparison of image-processing method with water displacement method. The volume determined by image-processing was also compared with the volume measured by water displacement using the paired samples t-test. The paired samples t-test results (Table II) showed that the volume determined with image-processing was not significantly ($P > 0.05$) different from the volume measured with water displacement. The mean volume difference between the two methods was -2.23 cm^3 (95% confidence interval: -6.71 & 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. 8. Moreover, as indicated in Fig. 9, 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. It is also obvious from Fig. 9 that for small-sized kiwifruits, the volume determined 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 (Rashidi & Seyfi, 2007), 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.

CONCLUSION

The volumes determined by using ellipsoid approximation and image-processing methods were statistically analyzed and compared to the volumes measured with the water displacement method. The results of paired samples t-test indicated that the difference between the volumes determined by ellipsoid approximation and water displacement was found to be statistically significant ($P < 0.05$), while the difference between the volumes determined by image-processing and water displacement was not statistically significant ($P > 0.05$). The Bland-Altman approach also revealed that for all sized kiwifruits, except flattened kind of misshapen kiwifruits, image-processing method satisfactorily determined kiwifruit volume. Therefore, image-processing method was found to be an accurate, simple, rapid and non-invasive to estimate kiwifruit volume and can easily be employed in monitoring growth development under various management practices and sorting of kiwifruits in postharvest processing.

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