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Estimation of Pomegranate Shape and Size by Machine Vision

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Abstract. A simplified machine vision system for estimating shape and size of pomegranates was developed. The system allows the estimation of volume, surface area, and weight of the fruit using prediction equations developed from the relationship between projected area and shape and size. This procedure resulted in excellent values of the coefficient of determination and can be used to estimate volume, surface area, and weight of Banati and Manfaluti pomegranates. The analysis of variance indicated that there was no significant difference in shape between Banati and Manfaluti cultivars at the 95% confidence level. A power law equation was obtained to describe the relationship between volume, surface area, and weight and the projected areas. The average measurement error of prediction was in the 1.5, 0.7 and 2.0% range for volume, surface area, and weight of Banati pomegranate, respectively. The Manfaluti pomegranate had average measurement errors in the range of 1.1, 1.4 and 3.2% for volume, surface area, and weight, respectively.

Introduction

Shape and size of pomegranate (*Punica granatum* L.) fruit are two physical properties needed for the designing, handling, and processing equipment. Furthermore, they are essential for many food engineering applications such as grading, sorting, and heat transfer in heating and cooling processes. A knowledge of these properties should be of great importance to engineers and food technologists involved with the design of machines or when studying handling and storage processes.

In the food industry, machine vision systems have been applied in order to overcome subjectivity, inconsistency, and labor intensity in manual operations. A simple machine vision system consists of a specialized computer connected to a video camera useful for the measurement of physical properties such as shape and size. This type of system provides a relatively rapid and effective means of gathering, storing, and using information [1]. It also permits rapid estimation of physical properties, including shape and size. Much of the recent work in machine vision was concerned specifically with inspection and grading of fruits and vegetables [2-6]. Machine vision was also used as a robotic sensor for locating citrus fruits [7].

The shape and size of pomegranate fruit are usually measured manually. Tediousness of the manual operation limits the number of samples that can be measured. Accuracy is difficult to maintain. No data are available in the published literature on shape and size of pomegranates. Therefore, it is desirable to develop a technique for estimating shape and size. The objective of this study was to develop an image processing technique for estimating shape and size of two pomegranate cultivars.

Materials and Methods

The Fruit

Pomegranates for the study were obtained from the King Saud University Dirab Research and Experimental Farm, and stored at 4°C for subsequent sample selection. Pomegranates were of the cultivars Banati and Manfaluti. A total of 100 fruits from each cultivar were selected at random. A group of 20 fruits were removed at a time from the cold store and kept for several hours in polyethylene bags at ambient temperature before measurement.

Apparatus

A schematic view of the apparatus used in these studies is shown in Fig. 1. It consisted of a camera, an image digitization board, and a microcomputer. A Sony* Model XC-711 color camera with a 25-mm (f/1.6) lens was used to acquire images. A back-lighting system is considered to be the most appropriate method for the measurement of dimensions [8,15-55]. Therefore, the fruits were imaged on a light table illuminated with fluorescent lamps. The camera was mounted above the fruit with a field of view (FOV) of about 150 cm^2. Image resolution was about 16 pixels/mm^2. A Data Translation Model DT2871 color frame grabber board was used with an Everex* 80486/33e micro-computer for image acquisition and processing. Images of the fruits were displayed on a Sony Model PVM 1342Q color monitor. Image acquisition was supported by Aurora [9], a software library package which provides a variety of image processing functions, as well as control of image digitization.

*Mention of firm names or trade products is solely for informational purposes and does not imply endorsement of these firms or products by the authors or King Saud University.

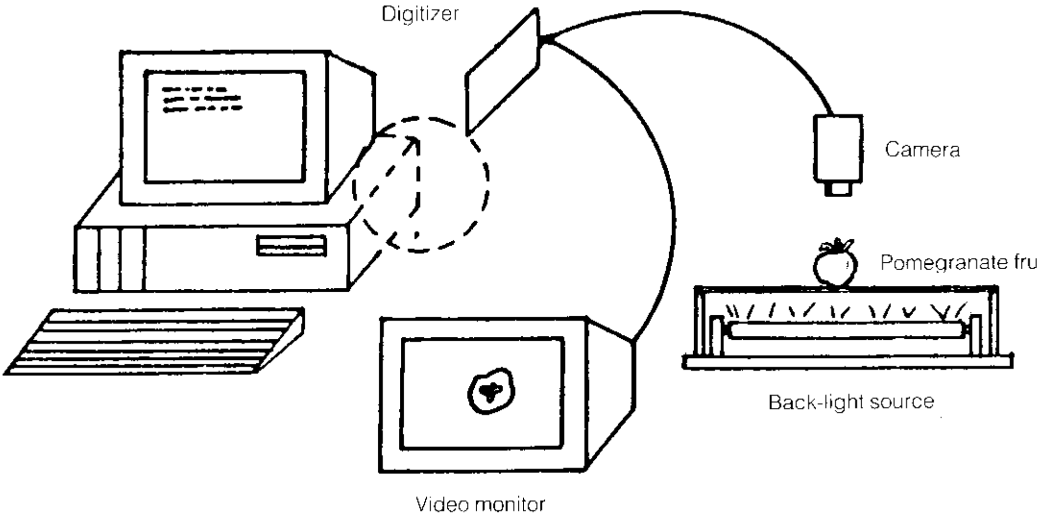

Fig. 1. Schematic diagram of the machine vision system.

Procedure

Each fruit in the group of 20 fruits was set on a holder over the illumination source. The object appeared as a black-on-white silhouette, enhancing the accuracy of area measurement.

Two images of each fruit were obtained. The first image was a top view of the fruit while the second one was a side view. Two projected areas, 'A_1' and 'A_2', were measured by counting the number of black pixels in the first and second images, respectively. The major axis, computed by determining the maximum number of black pixels in rows (y axes) from the first image, was considered as the ninth chord 'O' (Fig. 2). From the lower end of the ninth chord, sixteen chords were measured at steps of 10° from each other.

Each fruit was later weighed in free air on a digital balance and then submerged into water in a beaker. The volume of fruit was determined using the standard methods described by Mohsenin [10, 79-127]. Volumes were determined according to:

$$\text{Volume } (m^3) = \frac{\text{Weight of displaced water (kg)}}{\text{Weight density of water } (kg/m^3)}$$

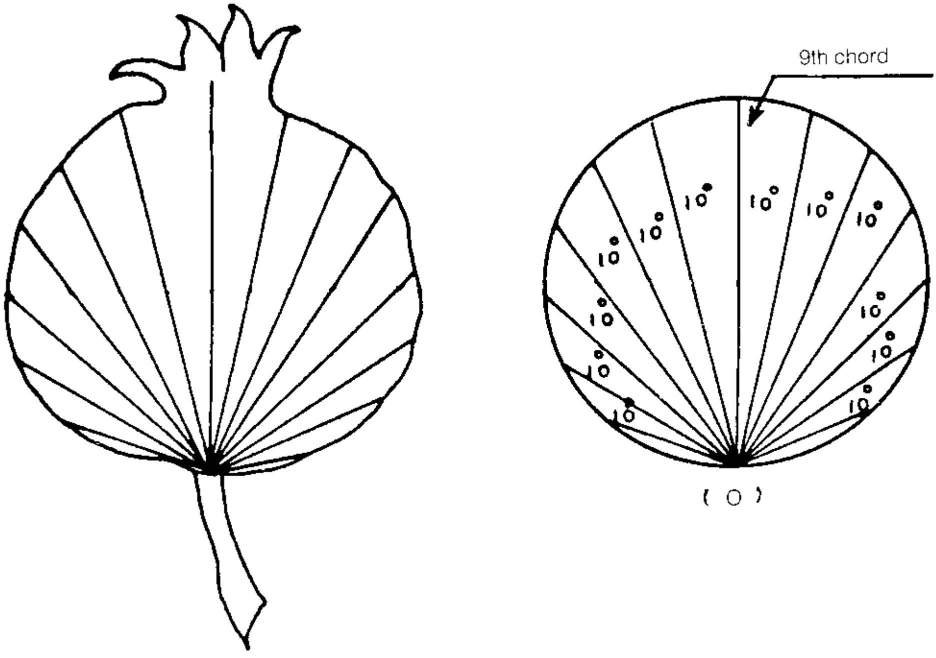

Fig. 2. Chords of pomegranate fruits.

Surface area of fruit was determined by means of carefully peeling the skin from the fruit and tracing with a planimeter. The sum of peeled strip areas was used as the surface area.

Machine vision algorithm

In the pomegranate vision system, the algorithm was composed of several basic tasks. These tasks were measurement of parameters of interest, shape analysis, and calibration.

I. Parameters

The parameters tested for usefulness in describing the physical properties of pomegranate fruit were the two projected areas and the seventeen chords. Regression equations predicting volume, surface area, and weight were determined for the two cultivars. Volume, surface area, and weight were predicted using the two projected areas ($A_1$and A_2) and the average of the two (A_3).

II. Shape analysis

Pomegranate fruit has a nearly spherical shape [11]. While the concept of shape is widely understood, it is difficult to define. Marshall [12] presented several shape analysis techniques. In general, the shape can be described as a function of position and direction of a single point on the curve with respect to another point. In this work, the shape of pomegranate fruit was compared with a circle. This comparison was based on the length of the seventeen chords. Nine features (F_1-F_9) were developed for analyzing the shape. The ratio of each chord length, C_j, to the diameter (ninth chord) was used to define the non-dimensional factor:

$$C_i = \frac{C_j}{C_9} \tag{2}$$

The first feature (F_1) is a comparison between right half and left half. This feature measures the symmetry of the fruit:

$$F_1 = \sum_{i=1}^{8} FC_i - \sum_{i=10}^{17} FC_i \tag{3}$$

The shape of a pomegranate fruit is approximately elliptical. Therefore, eight features, $F_2 - F_9$ were used to measure the smoothness of the end curves and the connection between the curves. These features can be used to represent the pomegranate graphically (3-D). The features $F_2 - F_5$, represented by equations 4-7, divided the shape of fruit into four curves. Length of chords to each curve was compared with the length of chords of a circle having the same curve. These features show the smoothness of the curves:

$$F_2 = \text{Abs}\left[\sum_{i=1}^{3} (FC_i - CC_i)\right] \tag{4}$$

$$F_3 = \text{Abs}\left[\sum_{i=6}^{8} (FC_i - CC_i)\right] \tag{5}$$

$$F_4 = \text{Abs}\left[\sum_{i=10}^{12} (FC_i - CC_i)\right] \tag{6}$$

$$F_5 = \text{Abs}\left[\sum_{i=15}^{17} (FC_i - CC_i)\right] \quad (7)$$

The features $F_6 - F_9$ represented by equations 8-11, measure the smoothness of the connection between the four curves:

$$F_6 = \text{Abs}\left[\sum_{i=3}^{6} (FC_i - CC_i)\right] \quad (8)$$

$$F_7 = \text{Abs}\left[\sum_{i=12}^{15} (FC_i - CC_i)\right] \quad (9)$$

$$F_8 = \text{Abs}\left[\sum_{i=7}^{11} (FC_i - CC_i)\right] \quad (10)$$

$$F_9 = \text{Abs}\,[FC_1 + FC_2 + FC_{16} + FC_{17}] - \text{Abs}\,[CC_1 + CC_2 + CC_{16} + CC_{17}] \quad (11)$$

The shape of pomegranate fruit can be estimated by processing the nine features. The first feature (F_1) measured the shape difference between right and left halves. The value of F_1 equals zero when the two halves are identical. The value increases as the regularity of shape changes. The shape of the pomegranate fruit is spherical when the values of all eight features are zero. A bulge in shape is indicated by an increase in the value of the feature specific to that part of the boundary.

III. Calibration

A square section of metal (1 cm^2) was used as a reference for calibrating the machine vision system. Prior to image acquisition, an image of the reference was acquired to measure the number of black pixels that represent the 1 cm^2. The camera position (FOV) was unchanged during the experiments to avoid variation in the number of pixels that represent the square centimeter.

Results and Discussion

The CORR procedure of the statistical program SAS [13] was used to test for correlation between volume (V), surface area (SA), and weight (W) and the two projected areas, A_1 and A_2, and their average, A_3. The relationship between the volume, surface area, and weight and the projected areas can be expressed by a power law relationship as follows:

$$Y = a X^b \tag{12}$$

where Y is the estimated volume, surface area, or weight, X is the projected area and a and b are constants, depending on the type of parameter and cultivar. Regression equations for volume ($V_1, \ldots V_3$), surface area ($SA_1, \ldots SA_3$), and weight ($W_1, \ldots W_3$) as a function of projected area were obtained. Results of the analysis for the Banati and Manfaluti pomegranates and the particular parameters are presented in Table 1.

Table 1. Prediction equations for estimating volume (V), surface area (SA), and weight (W) from projected areas of Banati and Manfaluti pomegranates

Cultivar	[a]Mean value	Regression equation	[b]SEE	R^2
Banati	314.51	$V_1 = 2.49\, A_1^{1.12}$	0.0193	0.96
	314.51	$V_2 = 6.95\, A_2^{0.90}$	0.0147	0.98
	314.51	$V_3 = 4.00\, A_3^{1.02}$	0.0119	0.98
	184.72	$SA_1 = 2.37\, A_1^{1.01}$	0.0240	0.92
	184.72	$SA_2 = 6.03\, A_2^{0.81}$	0.0222	0.93
	184.72	$SA_3 = 3.66\, A_3^{0.92}$	0.0204	0.94
	296.47	$W_1 = 2.65\, A_1^{1.10}$	0.0245	0.93
	296.47	$W_2 = 7.57\, A_2^{0.87}$	0.0258	0.92
	296.47	$W_3 = 4.34\, A_3^{0.99}$	0.0223	0.94
Manfaluti	288.35	$V_1 = 1.52\, A_1^{1.23}$	0.0213	0.95
	288.35	$V_2 = 1.41\, A_2^{1.27}$	0.0233	0.94
	288.35	$V_3 = 1.26\, A_3^{1.39}$	0.0157	0.97
	169.29	$SA_1 = 2.93\, A_1^{0.95}$	0.0243	0.90
	169.29	$SA_2 = 2.64\, A_2^{0.99}$	0.0232	0.91
	169.29	$SA_3 = 2.49\, A_3^{1.00}$	0.0204	0.93
	274.32	$W_1 = 1.05\, A_1^{1.31}$	0.0294	0.92
	274.32	$W_2 = 0.94\, A_2^{1.35}$	0.0296	0.92
	274.32	$W_3 = 0.85\, A_3^{1.37}$	0.0243	0.95

[a]mean of one hundred fruits.
[b]standard error of estimates.

Figures 3 and 4 show the relationships between the measured values of volume, surface area, and weight and projected areas for Banati and Manfaluti pomegra-

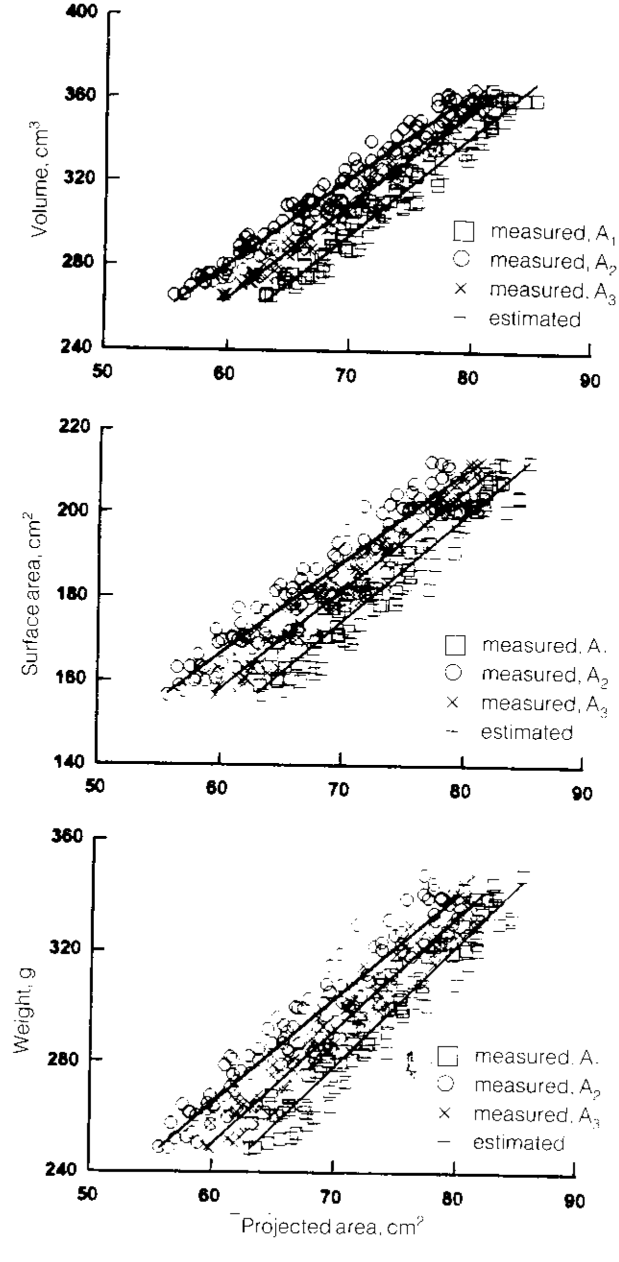

Fig. 3. Volume, surface area, and weight as a function of projected area; A_1 top view, A_2 side view, and A_3 average projected area for Banati pomegranate.

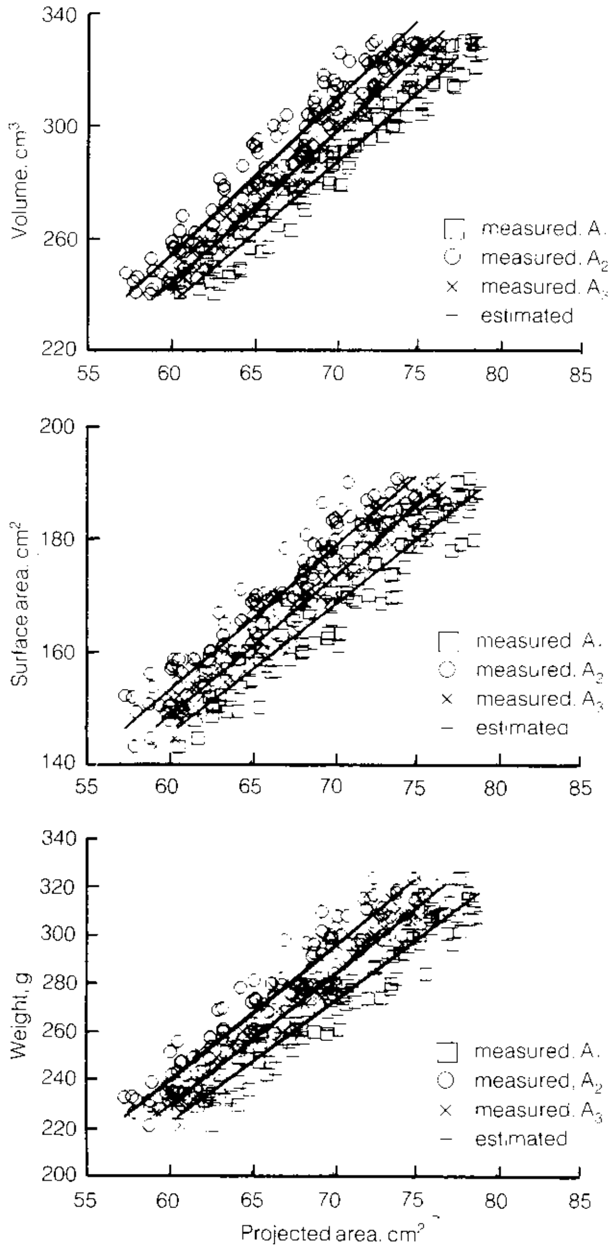

Fig. 4. Volume, surface area, and weight as a function of projected area; A_1 top view, A_2 side view, and A_3 average projected area for Manfaluti pomegranate.

nates, respectively. The solid lines represent the predicted values of the three parameters.

The best regression equations for volume, surface area, and weight as a function of the projected area (A_1) were used to estimate volume, surface area, and weight of the fruit. Selection of the equations was based on ease of measurement. The regression equations were:

$$V_B = 2.49\, A_1^{1.12} \qquad (R^2 = 0.96) \qquad (13)$$

$$SA_B = 2.37\, A_1^{1.01} \qquad (R^2 = 0.92) \qquad (14)$$

$$W_B = 2.65\, A_1^{1.10} \qquad (R^2 = 0.93) \qquad (15)$$

$$V_M = 1.52\, A_1^{1.23} \qquad (R^2 = 0.95) \qquad (16)$$

$$SA_M = 2.93\, A_1^{0.95} \qquad (R^2 = 0.90) \qquad (17)$$

$$W_M = 1.05\, A_1^{1.31} \qquad (R^2 = 0.92) \qquad (18)$$

where the subscripts B and M denote the cultivars Banati and Manfaluti pomegranates, respectively.

Equations 13 to 18 contain only one dependent parameter, (A_1). For the two cultivars, the parameter A_3 (average of the two projected areas, A_1 and A_2) improved the results slightly but doubled the processing time.

Measurement errors for equations 13 to 18 are presented in Table 2. These errors were generally small. The average errors were in the 1.5, 0.7 and 2.0% range for volume, surface area, and weight of Banati pomegranate, respectively. Manfaluti pomegranate on the other hand, had average errors in the range of 1.1, 1.4, and 3.2% for volume, surface area, and weight, respectively. A summary of the various error ranges for Banati and Manfaluti pomegranates is presented in Table 2. Error of measurement was calculated as:

$$\text{Error}\,(\%) = \frac{M_{me} - M_{es}}{M_{me}} \times 100 \qquad (19)$$

where M_{me} and M_{es} are the measured and estimated measurements, respectively.

Table 2. Measurement error for volume, surface area, and weight of Banati and Manfaluti pomegranates

Cultivar	Volume (cm^3)	Surface area (cm^2)	Weight (g)
Banati			
Measurement verage	314.51	184.72	296.47
Minimum error, %	-1.98	-4.80	-7.02
Maximum error, %	5.46	5.18	3.41
Average error, %	1.58	0.70	-1.95
Manfaluti			
Measurement average	288.35	169.29	274.32
Minimum error, %	-2.70	-3.79	-2.99
Maximum error, %	5.00	6.33	8.77
Average error, %	1.13	1.45	3.24

Average values and the standard deviation of shape features for top side views of the fruit are presented in Table 3. The average values of all features were greater than zero, indicating that the shape of pomegranate fruit expanded at both sides. Analysis of variance showed that there was no significant difference between top and side views for either Banati or Manfaluti cultivars (Table 4). The table also shows that there is no significant difference in shape analysis between Banati and Manfaluti cultivars at the 95% confidence level.

Conclusions

This work showed that the machine vision system developed for the measurement of pomegranate fruit shape and size has the potential to decrease the time required to estimate volume, surface area, and weight of pomegranate fruits. The vision system performed well for estimating the three parameters. Measurement average error for prediction equations was less than 2% for Banati and was less than 4% for Manfaluti pomegranate. Average values of pomegranate shape features for both cultivars were greater than zero, confirming the elliptical form.

Machine vision systems have been shown to be effective for grading and sorting many agricultural products. Consequently, the usefulness of the present machine vision system should be thoroughly explored in the food industry.

Table 3. Average and standard deviation of shape features

Shape features	Cultivar: Banati	Cultivar: Manfaluti
	Top view	
F_1	0.7943 (0.0123)	0.9975 (0.0082)
F_2	0.3207 (0.0033)	0.3482 (0.0011)
F_3	0.2046 (0.0019)	0.2103 (0.0024)
F_4	0.1928 (0.0025)	0.1991 (0.0002)
F_5	0.2669 (0.0009)	0.3302 (0.0015)
F_6	0.6208 (0.0084)	0.5723 (0.0040)
F_7	0.5975 (0.0070)	0.6248 (0.0037)
F_8	0.1767 (0.0003)	0.1761 (0.0005)
F_9	0.3114 (0.0039)	0.3876 (0.0057)
	Side view	
F_1	0.7482 (0.0030)	0.5997 (0.0041)
F_2	0.2954 (0.0001)	0.2982 (0.0027)
F_3	0.1335 (0.0004)	0.1578 (0.0017)
F_4	0.1068 (0.0007)	0.0922 (0.0008)
F_5	0.2777 (0.0003)	0.2426 (0.0014)
F_6	0.3997 (0.0062)	0.3872 (0.0044)
F_7	0.2474 (0.0018)	0.2353 (0.0021)
F_8	0.1389 (0.0010)	0.1356 (0.0010)
F_9	0.3647 (0.0026)	0.3373 (0.0001)

Note: values in parentheses are standard deviations.

Table 4. Analysis of variance

Source	DF	SS	MS	F-value	Pr > F
		Top and side views for Banati			
View	1	0.0332	0.0332	0.74	0.4009
Error	16	0.7139	0.0446		
Total	17	0.7471			
		Top and side views for Manfaluti			
View	1	0.1028	0.1028	2.17	0.1597
Error	16	0.7563	0.0473		
Total	17	0.8591			
		Banati and Manfaluti			
Cultivar	1	0.0005	0.0005	0.01	0.9188
Error	34	1.6062	0.0472		
Total	35	1.6067			

DF: degree of freedom, SS: sum of squares, MS: mean square

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تقدير الشكل والمقاس لثمار الرمان باستخدام الإبصار الآلي

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(قدم للنشر في ٢٣/١/١٤١٦هـ، وقبل للنشر في ١٣/١٠/١٤١٦هـ)

ملخص البحث. تم تطوير نظام إبصار آلي بسيط لتقدير الشكل والمقاس لصنفين من ثمار الرمان. ويسمح هذا النظام بتقدير الحجم والمساحة السطحية والوزن للثمار باستخدام معادلات التوقع المستنبطة التي تربط بين مساحة مسقطة واحدة لثمرة والمقاس. كما أنه تم الحصول على نتائج ممتازة للتوقع بالحجم والمساحة السطحية والوزن للرمان البناتي والمنفلوطي. وقد دل التحليل الإحصائي للنتائج أنه لا يوجد هناك أي فرق معنوي في الشكل بين ثمار الصنفين من الرمان.

ولقد تم استنباط معادلة أُسية تصف العلاقة بين الحجم والمساحة السطحية والوزن وبين المساحة المسقطة لثمرة الرمان. وكانت نسبة الخطأ في التوقع حوالي ١,٥ و٠,٧ و ٢,٠٪ لكل من الحجم والمساحة السطحية والوزن لصنف البناتي على التوالي. في حين بلغت هذه النسبة حوالي ١,١ و ١,٤ و ٣,٢٪ لكل من الحجم والمساحة السطحية والوزن لصنف المنفلوطي على الترتيب.