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Fruit Shape Classification in Kiwifruit Using the Analysis of Geometrical Attributes

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Abstract: Fruit shape is one of the most important quality parameters for evaluation by customer preference. Additionally, misshapen fruits are generally rejected according to sorting standards of fruit. This study was carried out to determine quantitative classification algorithm for fruit shape in kiwifruit. Geometrical attributes and some physical characteristics of kiwifruit such as length, major diameter, minor diameter, mass, volume and density were measured. To achieve objective and reproducible results, an assessment based on geometrical attributes analysis was proposed and significant differences in fruit shape parameters i.e. length to major diameter ratio (aspect ratio) and major diameter to minor diameter ratio (ellipsoid ratio) were detected between fruit shapes. Finally, the results of the study indicated that aspect ratio and ellipsoid ratio can be used effectively to determine normal and misshapen fruit.

Key words: Kiwifruit · Fruit shape · Classification · Geometrical attributes

INTRODUCTION

Kiwifruit (*Actinidia deliciosa*) 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 [1]. 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 [1, 2]. The main commercial producers are Italy, New Zealand, Chili, France, Japan, U.S.A. Iran, Greece, Spain and Portugal. Iran produces 35,000 tons of kiwifruit and is ranked 7th in the world, but Iranian kiwifruit are not exported extensively because of variability in size and shape and lack of proper packaging [1].

Fruit shape is one of the most important quality parameters for evaluation by consumer preference [3]. Consumers prefer fruits of equal weight and uniform shape [4]. Classification of fruit can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [5]. Fruit shape is affected by inheritance in addition to environmental growing conditions [3]. Description of fruit shape is often necessary in horticultural research for a range of different purposes such as cultivar descriptions in applications for plant variety rights or cultivar registers [6, 7, 8], evaluation of consumer preference [9], investigating heritability of fruit shape traits [10, 11], stress distribution analysis in the fruit skin [12] and determining misshapen fruit in a cultivar [3, 13].

On the other hand, the official quality definitions for fruit or vegetable are scarcely more than a measure on size and color. The USDA grade standard specifies shapes based on visual comparison of fruit shape relative to reference drawing. These drawing serve as a reference in classifying fruit shape. Ratings based on visual comparison don't require any equipment. However, the method is subjective and may depend on person who executes the rating. Moreover, rating scores may be biased by confusing variables such as fruit size or color. As a result, this process runs very slowly and seems not satisfactory for fruit classification in distribution terminals [3]. Substitute approaches describe fruit shape using

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indices calculated from geometrical attributes of fruit e.g. tomato [14], pear [11], watermelon [3] and cantaloupe [13]. Since such approaches are based on direct measurement, they are objective and reproducible. In addition, necessary measurements can be performed by a caliper and no complicated equipment is needed.

Therefore, the present study was designed to develop a rapid procedure that permits an un-biased and reproducible quantitative description of fruit shape in kiwifruit which is based on analysis of geometrical attributes of fruit.

MATERIALS AND METHODS

Plant Material: The most common commercial variety of kiwifruit (Hayward) was chosen for this study and about 100 randomly selected mature kiwifruits of various shapes and 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.

Primary investigation based on longitudinal and latitudinal cross section shapes indicated that six shapes were detectable and separable in samples. Fig. 1 shows six fruit shapes in kiwifruit such as: (I) short, (II) medium, (III) tall, (IV) round, (V) elliptical and (VI) flattened.

Experimental Procedure: In order to obtain required parameters for fruit shape detection algorithm, three mutually perpendicular axes, length (L; longest intercept), major diameter (D_1, longest intercept normal to L) and minor diameter (D_2; longest intercept normal to L and D_1) as shown in Fig. 2 were measured using a digital caliper with ±0.1 mm accuracy. The mass of each kiwifruit was measured using a digital precision scale with ±0.1 g accuracy. The volume of each kiwi fruit 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 density of each kiwifruit was then calculated from the mass divided by the measured volume. Table 1 shows geometrical attributes and some physical characteristics of kiwifruit in Hayward variety.

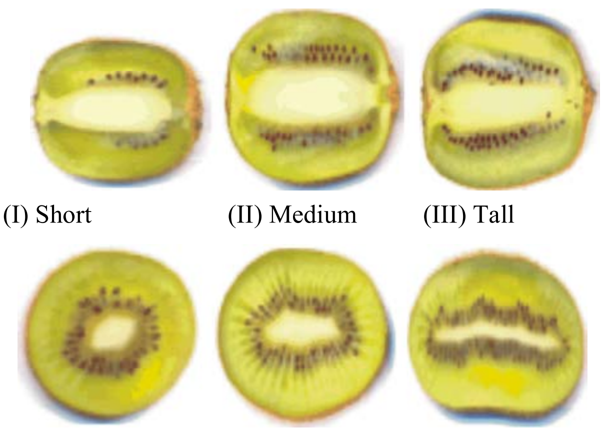

Fig. 1: Six fruit shapes in kiwifruit based on longitudinal and latitudinal cross section of fruits

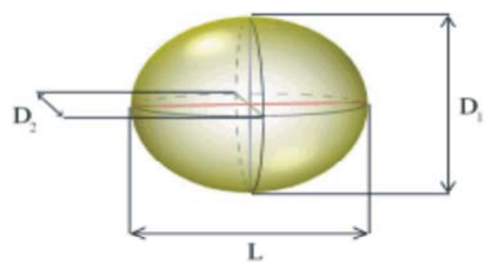

Fig. 2: Three mutually perpendicular axes, length (L), major diameter (D_1) and minor diameter (D_2) of kiwifruit

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of length, major diameter, minor diameter, mass, volume and density of kiwifruit in Hayward variety

Parameter	Mean	Minimum	Maximum	S.D.	C.V. (%)
Length (mm)	60.3	45	77	7.65	12.68
Major diameter (mm)	47.5	38	63	4.69	9.87
Minor diameter (mm)	42.6	33	53	3.35	7.87
Mass (g)	72.7	42.4	123.9	19.44	26.74
Volume (cm^3)	70.0	39.6	121.2	18.95	27.07
Density (g cm^{-3})	1.040	0.974	1.114	0.02	1.92

Fruit Shape Detection: An easy technique of judging based on analysis of geometrical attributes of kiwifruit was used for detecting shape of fruit. Aspect ratio (A.R.) was used to detect short, medium and tall fruits. Aspect ratio is defined by equation 1 [3, 15]:

$$A.R. = L / D_1 , (A.R. = 1.0) \quad (1)$$

Where:

A.R. = Aspect ratio, non-dimensional
L = Length, mm
D_1 = Major diameter, mm

Another parameter, ellipsoid ratio (E.R.), was used to detect round, elliptical and flattened fruits. Ellipsoid ratio is defined by Eq. (2) [13, 15]:

$$E.R. = D_1 / D_2 \text{ , } (E.R. = 1.0) \quad (2)$$

Where:

E.R. = Ellipsoid ratio, non-dimensional
D_1 = Major diameter, mm
D_2 = Minor diameter, mm

For mathematical describing of normal shape and misshapen kiwifruit, geometrical attributes of fruits, aspect ratio values and ellipsoid ratio values were subjected to statistical analysis using the Microsoft EXCEL program (Version 2003).

RESULTS

Short, Medium and Tall Fruit Shapes: Statistical results show that the mean aspect ratio value of medium fruits is 1.29, while the mean aspect ratio values of short and tall fruits are 1.13 and 1.48, respectively. Results also show that aspect ratio value for medium fruits ranged from 1.20 to 1.40, while aspect ratio value for short fruits ranged from 1.0 to 1.19 and for tall fruits from 1.41 to 1.63 (Table 2). Therefore, the aspect ratio lines 1: 1.19 and 1: 1.41 can be used as separating indicators. Fig. 3 demonstrates the aspect ratio lines 1: 1.19 and 1: 1.41 can separate medium fruits from short and tall fruits.

Round, Elliptical and Flattened Fruit Shapes: Statistical results of the study also indicate that the mean ellipsoid ratio value of round and elliptical fruits are 1.06 and 1.16, respectively, while the mean ellipsoid ratio value of flattened fruits is 1.35. Results also indicate that ellipsoid ratio value for round fruits ranged from 1.0 to 1.09 and for elliptical fruits from 1.10 to 1.23, while ellipsoid ratio value for flattened fruits ranged from 1.30 to 1.43 (Table 3). Therefore, the ellipsoid ratio lines 1: 1.09 and 1: 1.30 can be employed as separating indicators. Fig. 4 demonstrates the ellipsoid lines 1: 1.09 and 1: 1. 30 can separate elliptical fruits from round and flattened fruits.

Normal and Misshapen Fruit Shapes: Results of the study demonstrate that aspect ratio value for normal fruit shapes ranged from 1.20 to 1.40 and ellipsoid ratio value for them ranged from 1.0 to 1.23 (Table 4). Therefore, aspect ratio lines 1: 1.19 and 1: 1.41, together with the

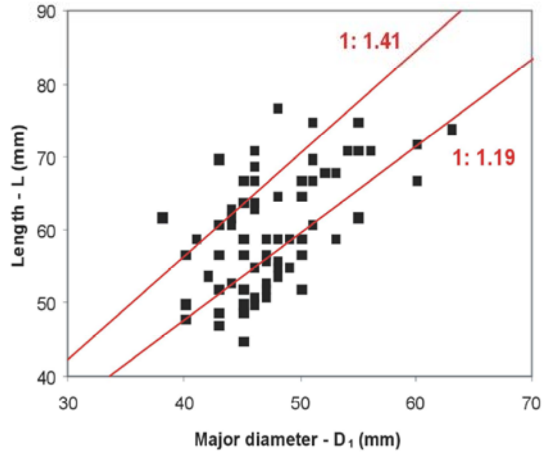

Fig. 3: Length versus major diameter and separator lines of medium fruits from short and tall fruits

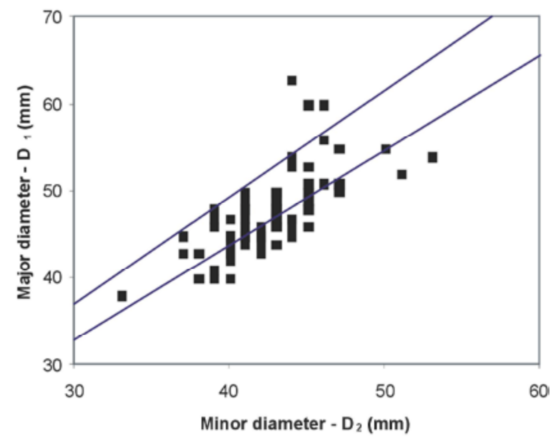

Fig. 4: Major diameter versus minor diameter and separator line of flattened fruits from round and elliptical fruits

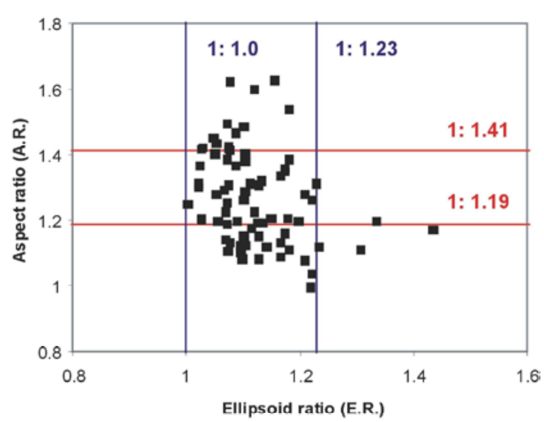

Fig. 5: Aspect ratio versus ellipsoid ratio and separator lines of normal fruits from misshapen fruits

Table 2: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of aspect ratio of short, medium and tall shapes of kiwifruit (shapes based on longitudinal cross section of fruits)

Shape	Mean	Minimum	Maximum	S.D.	C.V. (%)
Short	1.13	1.0	1.19	0.05	4.11
Medium	1.29	1.20	1.40	0.06	4.84
Tall	1.48	1.41	1.63	0.08	5.31

Table 3: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of ellipsoid ratio of round, elliptical and flattened shapes of kiwifruit (shapes based on latitudinal cross section of fruits)

Shape	Mean	Minimum	Maximum	S.D.	C.V. (%)
Round	1.06	1.0	1.09	0.03	2.48
Elliptical	1.16	1.10	1.23	0.04	3.53
Flattened	1.35	1.30	1.43	0.07	4.93

Table 4: Description, aspect ratio range and ellipsoid ratio range of normal and misshapen kiwifruit

Shape	Description	Aspect ratio range	Ellipsoid ratio range
Normal	Medium and not flattened	1.20 - 1.40	1.0 - 1.23
Misshapen	Short	= 1.19	-----
Misshapen	Tall	= 1.41	-----
Misshapen	Flattened	-----	= 1.30

ellipsoid ratio lines 1: 1.0 and 1: 1.23 can be used as separator of normal fruits from misshapen fruits. Fig. 5 shows the aspect ratio lines 1: 1.19 and 1: 1.41, in conjunction with the ellipsoid ratio lines 1: 1.0 and 1: 1.23 can separate normal fruits from misshapen fruits. Results of the study also indicated that aspect ratio value for small kind of misshapen fruits is less than or equal to 1.19 (A.R. $\leq$ 1.19) and for tall kind of misshapen fruits is more than or equal to 1.41 (A.R. $\geq$ 1.41). Moreover, ellipsoid ratio value for flattened kind of misshapen fruits is more than or equal to 1.30 (E.R. $\geq$ 1.30).

DISCUSSION

In this study, the geometrical attributes of kiwifruit, i.e. length, major diameter and minor diameters, were analyzed to classify fruit shape. The study indicated that six shapes, i.e. short (misshapen), medium (normal), tall (misshapen), round (normal), elliptical (normal) and flattened (misshapen), were detectable and separable in fruits. The results of the study also indicated that among all kinds of misshapen fruits, number of short kind followed by tall kind was the highest, while number of flattened kind was the lowest. In addition, amount of normal shape fruits and all kinds of misshapen fruits were in the order of normal (50.0%) > short (28.0%) > tall (18.0%) > flattened (4.0%).

These results are in line with those of Sadrnia *et al.* [3] and Rashidi and Seyfi [13] who reported that aspect ratio and ellipsoid ratio can be used effectively to determine normal and misshapen fruit and quite in agreement with those of Ku *et al.* [14] and White *et al.* [11] who concluded that classification of fruit shape using indices calculated from geometrical attributes of fruit, can increase uniformity in size and shape.

CONCLUSIONS

To achieve objective and reproducible results, an assessment based on geometrical attributes analysis was proposed and significant differences in fruit shape parameters i.e. aspect ratio and ellipsoid ratio were detected between normal and misshapen fruit shapes. Finally, aspect ratio and ellipsoid ratio were effectively used to determine normal and misshapen fruit. This method can also be adapted and applied to other products with the same physical features.

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