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ORIGINAL ARTICLE

Mass modeling of caper (*Capparis spinosa*) with some engineering properties

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Nomenclature
M = fruit mass, g; V = fruit Volume, cm^3; D_g = geometric mean diameter, mm; S = surface area, mm^2; L = length of fruits, mm; W = width of fruit, mm; T = thickness of fruit, mm; PA_1 = first projected area which perpendicular to L direction, mm^2; PA_2 = second projected area which perpendicular to W direction, mm^2; PA_3 = third projected area which perpendicular to T direction, mm^2; CPA = criteria projected area, mm^2; SD = standard deviation; b_0, b_1, b_2 = curve fitting parameters; X = independent parameter.

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Abstract

Introduction Horticultural crops used as food with a similar weight and uniform shape are in high demand in terms of marketing value. *Objectives* Therefore, an awareness of methods for grading fruits and vegetables based on weight is crucial. A part of this research was aimed at presenting some physical properties of caper. *Methods* In addition, in this study, the mass of caper was predicted using different physical characteristics in four models that include linear, quadratic, S-curve and power. *Results* According to the results, all properties considered in the current study were found to be statistically significant at the 1% probability level for the best and the worst models for prediction; the mass of caper was based on volume and second projected area of the caper with determination coefficients of 0.984 and 0.323, respectively. *Conclusion* Mass model based on first projected area from an economical standpoint is recommended.

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Introduction

Capparis spinosa, the caper bush, is a perennial winter-deciduous species that bears rounded fleshy leaves and large white to pinkish-white flowers. A caper is also the pickled bud of this plant. Caper bush is present in almost all the Mediterranean countries and is included in the floristic composition of most of them but whether it is indigenous to this region is uncertain. Movements in the earth's crust have pushed up a vast system of mountains, extending from the Pyrenees in Spain to the Zagros Mountains in Iran. Although the flora of the Mediterranean region has considerable endemism, the caper bush could have originated in the tropics, and later been naturalized to the Mediterranean basin. The plant is best known for the edible bud and fruit (caper berry), which are usually consumed pickled. Other species of

Capparis are also picked along with *C. spinosa* for their buds or fruits (available at http://en.wikipedia.org/wiki/Caper).

To design and optimize machines for handling, cleaning, conveying and storing fruits and seeds, the physical attributes and their relationships must be known. As an example, grading of fruits by their size can be replaced with grading by their weight because it may be more economical. Grading fruit based on weight is important in packing and handling. More recently, all cases of raw product grades are based on weight (O'Brian & Floyd, 1978). Size and shape determine how many fruit can be placed in a container of a given size. Volume and surface area could be beneficial in proper prediction of drying rates and hence drying time. On the other hand, volume and its relationship with packing coefficient are very important because having information about the packing coefficients of fruits could result in efficient control of fruit quality during storage. The physical characteristics of agricultural products are the most important parameters to determine the proper standards for design of grading, conveying, processing and packaging systems (Tabatabaeefar & Rajabipour, 2005).

Of these physical characteristics, mass, volume, projected area are the most important ones in determining sizing systems (Peleg & Ramraz, 1975; Khodabandehloo, 1999). Much research has been conducted to determine the physical properties of various types of agricultural products. Mass grading of fruit can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg, 1985). Determining relationships between mass and dimensions and projected areas are useful and have practical applications (Marvin *et al*., 1987; Stroshine, 1998). No detailed studies concerning the mass modeling of caper (*Capparis spinosa)* have yet been performed. The aims of this study were to determine the most suitable model for predicting caper mass by its physical attributes and to study some physical properties of Iranian caper to develop an important database for other investigators.

Materials and methods

The common caper was obtained from the Zagros Mountains in the west of Iran in June 2011. One hundred caper samples were collected from cultivation in Iran and measured in the biophysical laboratory and biological laboratory of Razi University of Kermanshah, Iran. Caper mass (M) was determined with an electronic balance with 0.01 g sensitivity. For determination of the moisture content of the samples, they were weighed and dried in an oven at 105 °C for 24 h (Suthar & Das, 1996) and then weight loss on drying to final content weight was recorded as moisture content (wet basis). The remaining material was kept in the desiccator until use. To determine the average size of the samples, three linear dimensions namely length, width and thickness were measured by using a digital calliper with 0.01 mm sensitivity. Volume (V) was determined by a water displacement method (Mohsenin, 1986). The geometric mean diameter (D_g) and surface areas (S) were determined using the following formulas (Mohsenin, 1986):

$$D_g = (LWT)^{1/3} \quad (1)$$

$$S = \pi (D_g)^2 \quad (2)$$

where L is length of caper (mm), W is the width of the caper (mm); T is its thickness (mm), S its surface area (mm^2) and D_g its geometric mean diameter (mm).

Then, projected areas (PA_1, PA_2 and PA_3) in three perpendicular directions were measured by a ΔT area meter, MK2 model device with 0.1 cm^2 accuracy (DELTA-T Devices Ltd., Cambridge, UK). Criteria projected area (CPA) is defined as follow (Mohsenin, 1986):

$$\text{CPA} = \frac{(PA_1 + PA_2 + PA_3)}{3} \quad (3)$$

where PA_1, PA_2 and PA_3 are the first, second and third projected areas (mm^2) that are perpendicular to L, W and T direction, respectively.

In order to estimate mass models of capers, the following models were considered:

(1) Single variable regression of caper mass based on caper dimensional characteristics: length (L), width (W), thickness (T) and geometric mean diameter (D_g).
(2) Single variable regressions of caper mass based on caper projected areas and criteria projected area.
(3) Single variable regression of caper mass based on measured volume.
(4) Single variable regression of caper mass based on surface area.

Lorestani *et al.* (2011) reported that linear regression models have higher R^2 than the other models and are economical models for application. Among the linear regression dimensions models, the model that is based on the smallest diameter (T), and among the linear projected area models, the model that is based on projected area normal to the smallest diameter (PA_3), and among the other linear regression models, the model that is based on measured volume (V), had higher R^2 and are recommended for the sizing of oak (Lorestani *et al.*, 2011).

Tabatabaeefar & Rajabipour (2005) predicted apple mass by models that were based upon apple physical properties. Al-Maiman & Ahmad (2002) studied the physical properties of pomegranate and found models for predicting fruit mass while employing dimensions, volume and surface areas. Keramat Jahromi *et al*. (2007) investigated some physical properties of date (cv. Lasht). They determined dimensions and projected areas using image processing technique. Lorestani & Tabatabaeefar (2006) concluded that the linear regression models of kiwi fruit have higher R^2 values than nonlinear models for them, and are economical models for application. Among the linear regression dimensions models, the model that is based on width and among the linear projected area models, the model that is based on third projected area, and among the other models, the model that is based on measured volume, had higher R^2 and are recommended for sizing of kiwi fruit. Also Tabatabaeefar & Rajabipour (2005) determined a total of 11 regression models in the three different categories for two different varieties of apple fruits. Lorestani & Ghari (2012) concluded that the best model for prediction the mass of fava bean among the dimensional models was linear, $M = -1.607 + 0.264W$; $R^2 = 0.733$, and the best model for prediction the mass of fava bean was based on the third projected area (perpendicular to L direction of the fava bean) and it was in a power law form as $M = 0.006\ PA_3^{1}.071, R^2 = 0.819$. The worst was based on the first projected area of fava bean and it was in a linear form as $M = 1.686 + 0.006PA_1$, $R^2 = 0.152$ (Lorestani & Ghari, 2012).

In all cases for capers, the results, which were obtained from experiments, were fitted to linear, quadratic, S-curve and power models, which are presented as following equations, respectively:

$$M = b_0 + b_1 X \quad (4)$$

$$M = b_0 + b_1 X + b_2 X^2 \quad (5)$$

$$\ln(M) = b_0 + \frac{b_1}{X} \quad (6)$$

$$M = b_0 X^{b_1} \quad (7)$$

Where M is the mass (g), X is the value of the independent parameter that we want to find its relationship with mass, and b_0, b_1 and b_2 are curve-fitting parameters, which are different in each equation.

One evaluation of the goodness of fit is the value of the coefficient of determination (R^2). SPSS 15 software (SPSS, Inc., Chicago, IL, USA) was used to analyze data and determine regression models among the physical attributes.

Results and discussion

A summary of the physical properties of caper is shown in Table 1. These properties were found at specific moisture contents about 82.23% wet basis. As can be seen in the results given in Table 1, all properties, which were considered in the current study, were found to be statistically significant at the 1% probability level. According to the results, the mean values of properties which were studied (length, width, thickness, geometric mean diameter, volume, surface area, mass and projected areas) are 31.16 mm, 20.44 mm, 20.19 mm, 23.17 mm, 6.82 cm^3, 1727.65 mm^2, 6.71 g, 354.69 mm^2, 560.61 mm^2 and 576.02 mm^2, respectively.

Mass models and coefficient of determination (R^2) that were obtained from the data are shown in Table 2. All of the models coefficients were analyzed with F- and t-tests in SPSS 15 Software where all of them were significant at $\alpha = 1\%$.

Nonlinear models were used only for comparison with linear regression models.

Table 1 Some physical properties of caper

	Caper				
Physical properties	Max	Min	Average	SD	Significant level
L (mm)	49.42	13.18	31.16	6.72	$P < 0.01$
W (mm)	41.63	13.47	20.44	5.16	$P < 0.01$
T (mm)	41.63	13.47	20.19	5.16	$P < 0.01$
M (g)	16.64	2.77	6.71	3.05	$P < 0.01$
V (mL)	18.86	2.71	6.82	3.43	$P < 0.01$
D_g (mm)	31.68	16.30	23.17	3.61	$P < 0.01$
S (mm^2)	3153.84	834.57	1727.65	540.89	$P < 0.01$
PA_1 (mm^2)	802.6	349.3	560.61	123.266	$P < 0.01$
PA_2 (mm^2)	502.6	232.3	354.69	89.748	$P < 0.01$
PA_3 (mm^2)	833.8	349.9	576.02	123.266	$P < 0.01$
CPA (mm^2)	704.8	312.4	497.105	109.58	$P < 0.01$

Table 2 The best models for prediction the mass of caper with some physical characteristics

Dependent parameter	Independent parameters	The best model	Constant values of models			R^2	*F*-value
			b_0	B_1	b_2		
M (g)	*L* (mm)	Quadratic	4.592	–0.176	0.007	0.473	30.303
M (g)	*W* (mm)	Quadratic	15.844	–2.290	0.090	0.477	45.201
M (g)	*T* (mm)	Quadratic	–19.652	2.075	–0.036	0.663	62.386
M (g)	*V* (ml)	Power	1.179	0.908	–	0.984	1391.139
M (g)	D_g (mm)	Quadratic	6.796	–0.749	0.031	0.805	187.965
M (g)	*S* (mm^2)	Quadratic	0.272	0.002	6.8×10^{-7}	0.802	187.656
M (g)	PA_1 (mm^2)	Linear	–4.348	0.040	–	0.840	76.449
M (g)	PA_2 (mm^2)	Quadratic	–15.285	0.091	-8×10^{-5}	0.323	1.197
M (g)	PA_3 (mm^2)	S-curve	3.780	–854.62	–	0.811	77.261
M (g)	CPA (mm^2)	Quadratic	4.211	–0.013	4.7×10^{-5}	0.911	87.140

For mass modeling based on dimensional characteristic including length, width and thickness, the best model was a quadratic form with $R^2 = 0.663$:

$$M = -19.652 + 2.075T - 0.036T^2 \quad R^2 = 0.663$$

This model can predict the relationships between the mass with length and width with R^2 of 0.473 and 0.477, respectively.

Tabatabaeefar *et al.* (2000) reported that among systems that sort oranges based on one dimension, the system that applies intermediate diameter is suited to a nonlinear relationship.

For prediction of the mass of caper based on volume, the best model was a power law form with $R^2 = 0.984$:

$$M = 1.179V^{0.908} \quad R^2 = 0.984$$

According to the results, for prediction of the mass of the caper based on geometric mean diameter, a quadratic form was the best model with $R^2 = 0.805$:

$$M = 6.796 - 0.749\, D_g + 0.031\, D_g^2 \quad R^2 = 0.805$$

This model is not economical because to calculate the geometric mean diameter (D_g), we must measure three dimensions of the capers and it is time-consuming and costly.

For the mass modeling of caper based on projected areas including PA_1, PA_2, PA_3 and CPA, the best model was a quadratic form with $R^2 = 0.911$:

$$M = 4.211 - 0.013\,\text{CPA} + 4.7 \times 10^{-5}\,\text{CPA}^2 \quad R^2 = 0.911$$

For prediction of the mass of the caper based on surface area, the best model was a quadratic form with $R^2 = 0.802$:

$$M = 0.272 + 0.002\,S + 6.8 \times 10^{-7}\,S^2 \quad R^2 = 0.802$$

According to the results, the quadratic model could predict the relationships between the mass and some physical properties of caper with good value for determination coefficients. So we suggest the quadratic model based on projected area for prediction the mass of caper because we need only one camera and it is an applicable and economical method.

Conclusions

Some physical properties and their relationships with caper mass are presented in this study. From this study, it can be concluded that

(1) All properties considered were found to be statistically significant at the 1% probability level.
(2) The best model for the prediction of the mass of caper among the dimensional models was quadratic, as $M = -19.652 + 2.075T - 0.036T^2 \quad R^2 = 0.663$.
(3) The best model for the prediction of the mass of caper was based on three projected areas and it was in a quadratic form, as $M = 4.211 - 0.013\ \text{CPA} + 4.7 \times 10^{-5}\ \text{CPA}^2 \quad R^2 = 0.911$.
(4) Finally, a mass model based on the first projected area from economical standpoint is recommended. It was of a linear form, as $M = -4.348 + 0.040\ PA_1 \quad R^2 = 0.84$.

This information can be used in the design and development of sizing mechanisms and other postharvest processing machines. In conclusion, it is recommended that other properties of caper such as thermal, mechanical and nutritional characteristics are to be studied and changes in these properties be examined as a function of moisture content and ripening phases.

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