Univerzitet u Beogradu
Poljoprivredni fakultet
Institut za poljoprivrednu tehniku
Naučni časopis
POLJOPRIVREDNA TEHNIKA
Godina XL
Broj 2, 2015.
Strane: 29 – 40

University of Belgrade
Faculty of Agriculture
Institute of Agricultural Engineering
Scientific Journal
AGRICULTURAL ENGINEERING
Year XL
No.2, 2015.
pp: 29 – 40

UDK: 621.397

Originalni naučni rad
Original scientific paper

MATHEMATICAL MODELING OF PHYSICAL PROPERTIES OF INDIAN MANGOES USING IMAGE PROCESSING METHOD FOR MACHINE VISION SYSTEMS

Eyarkai Nambi Vijayaram*, Thangavel Kulanthaisamy, Shahir Sulthan, Chandrasekar Veerapandian

Tamil Nadu Agricultural University,
Department of Food and Agricultural Process Engineering, Coimbatore, India

***Abstract*:** Mathematical modeling study was carried out with the measured physical properties of two varieties of Indian mangoes as a function of projected area (P_{ip}) calculated using image processing technique. Three models viz. linear, quadratic and cubic were explored. Quadratic model was found to be best suitable to predict weight, volume, surface area, geometric and arithmetic mean diameter with higher accuracy (R^2>0.95). At the same time length (L), width (W) and thickness (T) could not be predicted effectively (R^2<0.90) using projected area (P_{ip}) computed by image processing. These findings would be more useful in machine vision especially in grading and sorting of mango fruits using image processing techniques.

***Keywords*:** *mathematical modeling of mango, mathematical modeling for machine vision, physical properties of mango, image processing of Indian mangoes*

INTRODUCTION

In India, Mango (*Mangifera indica* L.) is called as king of fruit and it has great demand in world market due to its distinct taste, flavor and color. It is being consumed in fresh as well as processed form worldwide. India is one of the major mango producing country and exports fresh mangoes and processed products to more than 50 countries. Commercially mango fruits are being utilized for the production like pickles, chutney or

* Corresponding author. E-mail: eyarkainambi@gmail.com

mango sauce, *amchoor* (raw mango powder) and green mango beverage (*panna*), making pulp, juice, nectar, squash, mango leather, frozen and canned slices, jam, ready-to-serve beverages, mango puree, mango cereal flakes, mango powder, mango toffee and mango fruit bars

Though the mango processing on large scale is being carried out for past few decades, very few processes were automated like pulping, thermal processing and packing. The cleaning and grading of mangoes based on quality parameters are still carried out either semi automatically or manually. Since its heterogeneous nature, quality evaluation is very much labor intensive, tedious and it needs skilled & trained personnel. In spite of the many possibilities offered by new technologies to accurately measure the quality characteristics, human beings are more flexible and adaptable to evaluate the agricultural products than machines.

Automatic fruit sorting is an emerging area. Sorting of fruits based on color would be appropriate. Marković *et al*. [12] discussed new technologies in fruit color sorting. In designing of automatic machineries for handling, grading, and sorting *etc*. of agricultural produces, the knowledge of physical properties like weight, volume, surface area, bulk density, *etc*., are needed and hence investigating the relationship among them is very essential [8]. Quality prediction is made easy by determining correlation among these physical properties [5]. The prediction of any physical properties from other properties were reported by many researchers for many crops.

Previously mass of an orange was predicted from its projected area, mass grading is possible by knowing the relationship between weight and the diameter and also it is gaining importance and recommended for the irregular shaped products. Fruits with large length to diameter ratio were separated based on the sizing equation.

Projected and surface area are necessary to evaluate the heat transfer rate, respiration rate, water loss, gas permeability, quantity of pesticide applied and ripeness index [2,10,20,21]. Relationship between volume and surface area, mass, diameter and surface area [6,8,14] were studied and empirical equations were developed for different agricultural produces. Eleven models were recommended to predict mass of an apple based on geometrical attributes [18].

Models were developed for sizing of the different fruits based on the relationship between mass, volume, projected area and length. In case of correlation analysis, high correlations were obtained between mass and volume of Iranian grown potatoes and all varieties of kiwi fruit [11]. R. Ghabel *et al.* [3] described the relationship between weight and geometrical mean diameter. Surface area and volume modeling of different shaped fruits can be measured by estimating three mutually perpendicular axes [1].

Using these modeling studies, manual grading systems could be effectively replaced with the help of digital image processing and machine vision system. Digital image processing is one of the promising tools used for industrial automation to predict the external as well as internal quality parameters. Many researchers [16,17,19] reported that the image processing would be a rapid and non-destructive method and one of the best alternatives for grading of fruits and vegetables compared to the regular mechanical grading since they are highly heterogeneous in nature.

However, very limited studies were reported on predicting physical properties of fruits by image processing technique. Volume of the watermelon [9] cantaloupe [15] and orange [7] were estimated by the earlier researchers using image processing technique. Moreda *et al.* [13] reviewed about different electronic-based approaches used for horticultural produce size estimation with emphasis on the dimensional approaches. But the scientific reports about the prediction of many physical parameters using image processing is almost nil. Hence a study was conducted to develop models to predict physical properties like length, width, thickness, volume, surface area, weight, geometrical mean diameter *etc*., for Indian mangoes by image processing technique.

MATERIAL AND METHODS

Sample collection. Raw mangoes viz. Alphonso and Banganapalli were harvested at 100-105 *DFFB* (days from full bloom) from the University orchard and desapping were done in the field itself. Mangoes were arranged in single layer with proper cushioning in a plastic crates and transported to lab. Fully matured mangoes, free from bruises and debris were sorted manually. Thirty raw mangoes in each variety were selected randomly and their physical properties were evaluated at atmospheric temperature of 28 ± 2°C and R.H of 55%.

Physical properties measurement. Weight (*M*) of the mango was measured using an electronic balance (Ohaus corporation, pine brook, USA) with an accuracy of 0.01 g. Platform scale method was adopted for measuring true volume or actual volume (*V*). The length (*L*) width (*W*) and thickness (*T*) of the mango were measured using a digital vernier caliper (Mitutoyo digimatic caliper, Japan) with an accuracy of 0.01 mm. The width (*W*) and thickness (*T*) which are perpendicular to each other were measured at the middle portion of mango. Geometric mean diameter (D_g) and arithmetic mean diameter (D_a) was calculated using Eq. (1 and 2).

$$\mathrm{D_g} = \sqrt[3]{\mathrm{LWT}} \tag{1}$$

$$\mathrm{D_a} = \frac{LWT}{3} \tag{2}$$

Projected area (P_g) and surface area (S_g) were calculated using graphical method. Projected area was calculated by tracing the whole fruit at natural rest position in a graph paper and then the number of squares was counted. Similarly, the surface area (S_g) was calculated by placing its peel and tracing in the graph.

Imaging chamber. Shade free image capturing chamber was made with the dimension of 20”x20”x18” (Fig.1).

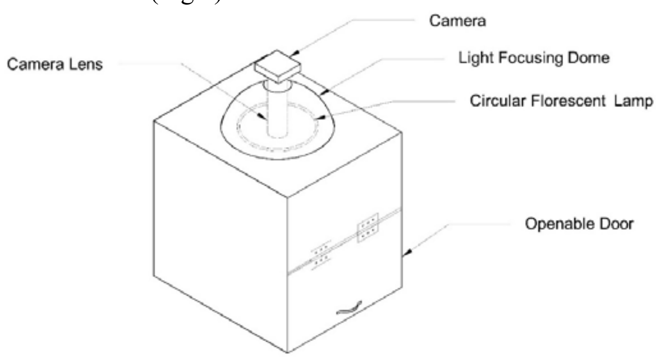

Figure 1. Schematic diagram of image capturing setup

The internal wall surface was made with light reflecting surface. *DSLR* camera (Nikon D60) equipped with *CMOS* sensor was fixed on the top center of the chamber. The circular florescent lamp was fixed concentrically with the camera lens along with the focusing arrangement in order to get proper lighting. Mango fruits were placed in its natural rest position on the flat platform with black background. All the images were taken at constant light intensity (820 lux), constant focal length and constant exposure value.

Image processing. The captured images were transferred to the computer and image processing was done using MATLAB (The Math Works, Inc., USA). The captured color images were converted into gray scale image. Threshold technique and morphological operations were done to separate the region of interest (*ROI*) from the background (Fig. 2) and to calculate the number of pixels inside the *ROI*, respectively. Object with known area was kept during image capturing as a reference in-order to convert the no. of pixel into area. The projected area (P_{ip}) was calculated by converting the number of pixels into real time value (area) using this reference.

Statistical analysis and mathematical modelling. Statistical analysis was done in Microsoft Excel and the mathematical modeling in MATLAB R2007a. Three models *viz.* linear, first order (quadratic) and second order (cubic) polynomials were used to develop a relation between projected area (P_{ip}) and other physical properties.

The mathematical modeling of physical properties were carried out with the following regression equations.

$$\text{Linear model: } f(x) = a*x + b \quad (3)$$

$$\text{Quadratic model: } (2^{nd} \text{ order}): f(x) = a*x^2 + b*x + c \quad (4)$$

$$\text{Cubic model } (3^{rd} \text{ order}): f(x) = a*x^3 + b*x^2 + c*x + d \quad (5)$$

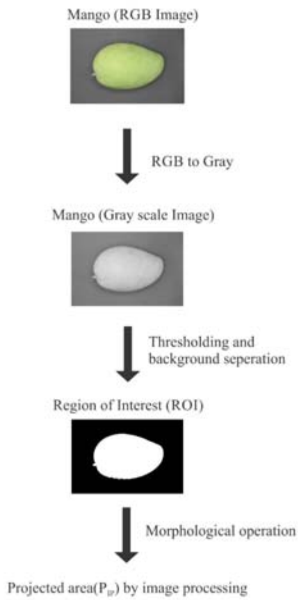

Figure 2. Process flow chart describing the image processing technique

In these models '*x*' denotes the project area by image processing (P_{ip}). The regression models were limited to third order polynomial in order to reduce the robustness and complexity in calculations and prediction. The prediction of projected area by graph (P_g) was done with the project area by image processing (P_{ip}) in order to validate the models and the whole methodology. Then other physical properties were modeled the P_{ip} was correlated with using image processing.

RESULTS AND DISCUSSION

The measured physical properties for two varieties of mangoes were statistically analyzed for its mean, standard deviation (*SD*) and coefficient of variance (*CV*) and given in Tab. 1.

Table 1. Physical properties of mangoes

Parameters	Alphonso				Bangapalli			
	Mean	SD	SE	CV	Mean	SD	SE	CV
PA [cm^2]	53.16	3.56	0.71	6.69	75.90	15.55	2.63	20.48
Weight [g]	256.20	28.22	5.64	11.01	353.49	78.71	13.30	22.27
Volume [cm^3]	256.33	32.15	6.43	12.54	351.74	81.89	13.84	23.28
L [cm]	9.38	0.35	0.07	3.77	11.63	1.33	0.22	11.42
W [cm]	7.18	0.20	0.04	2.79	8.23	0.74	0.12	8.96
T [cm]	6.77	0.34	0.07	5.00	6.82	0.31	0.05	4.48
Size (D_g) [cm]	7.70	0.31	0.06	3.98	8.67	0.68	0.11	7.81
D_a, [cm]	7.79	0.31	0.06	3.95	8.90	0.76	0.13	8.53
SA [cm^2]	192.65	13.93	2.79	7.23	185.93	57.17	9.66	30.75

In all physical properties, Banganapalli was found higher than Alphoso mangoes. The weight of the fruit was found to be 256.20±28.22 g and 353.49±78.71 g and the volume of the fruits was around 256.33±32.15 cm^3 and 351.74±81.89 cm^3 for Alphonso and Banganapalli respectively. The length (*L*), width (*W*) and thickness (*T*) were found to be 9.38±0.35 cm, 7.18±0.20 cm and 6.77±0.34 for Alphonso and 11.63±1.33 cm, 8.23±0.74 cm, 6.82±0.31 cm for Banganapalli respectively. The size of the fruits (geometrical mean diameter) were 7.70±0.31 and 8.67±0.68 for Alphonso and Banganapalli respectively. These dimensions are important in determining the aperture size of the sorting machines and also helpful in applying shear force during slicing and processing.

Table. 2. Regression models to predict the physical properties of Alphonso using image processing technique

	Regression coefficients				Goodness of fit			
	a	b	c	d	R^2	Adj. R^2	RMSE	χ^2
Projected area by graph (P_g)								
Cubic	139.86	-4.22	0.06	-0.0002	0.99	0.99	0.44	0.19
Quadratic	28.60	0.16	0.00		0.99	0.99	0.43	0.19
Linear	17.73	0.45			0.99	0.98	0.44	0.19
Surface area								
Cubic	-791.23	39.76	-0.56	0.00265	0.98	0.98	2.02	4.07

Quadratic	401.89	-7.28	0.06		0.98	0.98	2.10	4.42
Linear	59.14	1.69			0.91	0.91	4.21	17.74
Mass								
Cubic	-2088.85	89.64	-1.18	0.00536	0.97	0.97	5.08	25.82
Quadratic	326.17	-5.56	0.06		0.97	0.97	5.23	26.46
Linear	-20.04	3.50			0.95	0.95	6.37	37.62
Volume								
Cubic	-2572.10	106.45	-1.38	0.00615	0.98	0.98	4.85	23.49
Quadratic	199.37	-2.80	0.04		0.98	0.98	5.04	26.03
linear	-61.25	4.02			0.97	0.97	5.82	33.83
Length								
Cubic	30.22	-0.96	0.01	-0.0001	0.95	0.94	0.09	0.01
Quadratic	2.74	0.13	0.00		0.94	0.94	0.09	0.01
linear	5.95	0.04			0.93	0.93	0.09	0.01
Width								
Cubic	-36.04	1.70	-0.02	0.0001	0.87	0.86	0.08	0.01
Quadratic	8.55	-0.06	0.00		0.84	0.82	0.08	0.01
linear	5.37	0.02			0.81	0.80	0.09	0.01
Thickness								
Cubic	-18.44	0.94	-0.01	0.0001	0.87	0.85	0.13	0.02
Quadratic	6.09	-0.02	0.00		0.86	0.85	0.13	0.02
linear	3.62	0.04			0.86	0.85	0.13	0.02
D_a								
Cubic	-33.78	1.60	-0.02	0.0001	0.91	0.91	0.09	0.01
Quadratic	8.23	-0.05	0.00		0.91	0.90	0.10	0.01
linear	4.80	0.04			0.89	0.89	0.10	0.01
D_g								
Cubic	-29.63	1.44	-0.02	0.0001	0.91	0.91	0.09	0.01
Quadratic	8.22	-0.05	0.00		0.91	0.90	0.10	0.01
linear	4.86	0.04			0.90	0.89	0.10	0.01

Table. 3. Regression models to predict the physical properties of Banganapalli using image processing technique

	Regression coefficients				Goodness of fit			
	a	*b*	*c*	*d*	R^2	*Adj.* R^2	*RMSE*	χ^2
Projected area by gra. (P_g)								
Cubic	179.24	-4.95	0.06	-0.00018	0.99	0.99	1.61	2.61
Quadratic	-9.03	0.66	0.002		0.99	0.99	1.64	2.73
linear	-33.82	1.16			0.99	0.99	1.67	2.82
Surface Area								
Cubic	251.38	-6.41	0.07	-0.0001	0.99	0.99	5.29	27.99
Quadratic	117.30	-2.41	0.03		0.99	0.99	5.23	27.34
linear	-218.39	4.26			0.98	0.98	8.79	77.33
Mass								
Cubic	767.96	-20.36	0.23	-0.00065	0.98	0.98	10.71	114.73
Quadratic	69.91	0.44	0.03		0.98	0.98	10.80	116.04
linear	-202.23	5.86			0.98	0.98	12.16	147.77
Volume								
Cubic	-184.31	9.01	-0.07	0.00035	0.99	0.99	8.76	76.72

Quadratic	*192.42*	*-2.22*	*0.04*		*0.99*	*0.99*	*8.73*	*76.29*
linear	*-224.00*	*6.06*			*0.98*	*0.98*	*12.33*	*152.15*
Length								
Cubic	*36.06*	*-0.87*	*0.01*	*-0.00003*	*0.95*	*0.94*	*0.32*	*0.10*
Quadratic	*5.90*	*0.03*	*0.0003*		*0.94*	*0.94*	*0.34*	*0.11*
linear	*2.45*	*0.10*			*0.94*	*0.93*	*0.34*	*0.12*
Width								
Cubic	*-3.42*	*0.25*	*-0.002*	*0.00001*	*0.92*	*0.91*	*0.23*	*0.05*
Quadratic	*2.96*	*0.06*	*-0.00003*		*0.91*	*0.90*	*0.23*	*0.05*
linear	*3.28*	*0.05*			*0.91*	*0.91*	*0.22*	*0.05*
Thickness								
Cubic	*-10.72*	*0.50*	*-0.005*	*0.00002*	*0.82*	*0.81*	*0.14*	*0.02*
Quadratic	*6.73*	*-0.02*	*0.0002*		*0.78*	*0.77*	*0.15*	*0.02*
linear	*4.89*	*0.02*			*0.77*	*0.76*	*0.15*	*0.02*
Da								
Cubic	*2.78*	*0.10*	*-0.001*	*0.00003*	*0.99*	*0.99*	*0.07*	*0.01*
Quadratic	*5.63*	*0.02*	*0.0002*		*0.99*	*0.99*	*0.07*	*0.01*
linear	*3.88*	*0.05*			*0.99*	*0.99*	*0.08*	*0.01*
Dg								
Cubic	*8.79*	*-0.08*	*0.001*	*-0.00003*	*0.99*	*0.99*	*0.08*	*0.01*
Quadratic	*5.40*	*0.02*	*0.0002*		*0.99*	*0.99*	*0.08*	*0.01*
linear	*3.53*	*0.06*			*0.99*	*0.99*	*0.09*	*0.01*

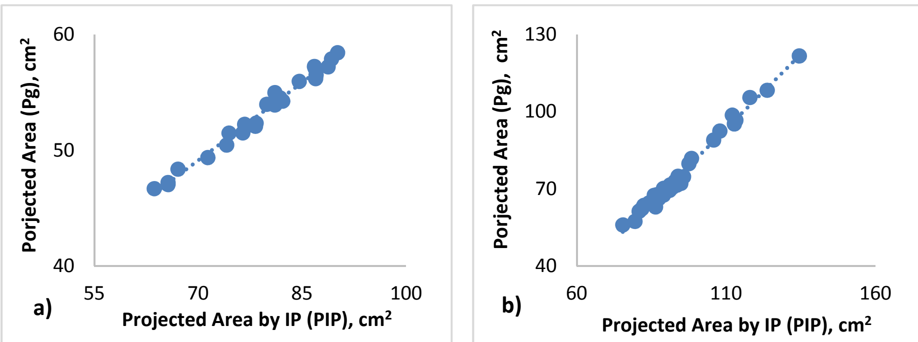

Figure 3. Linear relationship between projected area by graphical method and projected area by image processing method. (a) Alphonso mangoes (b) Banganapalli mangoes

Mathematical modeling. The results of the mathematical modeling viz. model coefficients, coefficient of determination, *RMSE* and chi-square values of physical properties were shown in the Tabs 2 and 3 for both the varieties. The predicted physical properties *viz*. length, width, thickness, weight, volume, surface area, geometrical mean diameter and arithmetical mean diameter were compared with the actual/observed values for computing Root Mean Square and chi-square (goodness of fit) value. Only better predicted models which has higher r^2 and adjusted r^2 values and lower *RMSE* and chi-square values were plotted and shown in Figs 3-7. For selection of better models, the higher weight was given to r^2 followed by *RMSE* then by χ^2 values.

Modelling of spatial parameters. The projected area (P_g) had shown linear relationship with P_{ip} with the R^2 value of 0.99 (Tabs 2, 3). This confirms that the image processing technique can be effectively used to predict the projected area (P_g) with lowest error for both varieties (Fig. 3). In case of *RMSE* and chi-square values, very negligible difference were observed between quadratic and cubic model for Alphonso. Quadratic model had shown higher r^2 value, lower *RMSE* and chi-square values for Banganapalli. So surface area can be better predicted using projected area (P_{ip}) with quadratic model for Alphonso and Banganapalli mangoes which has sown in Fig. 4.

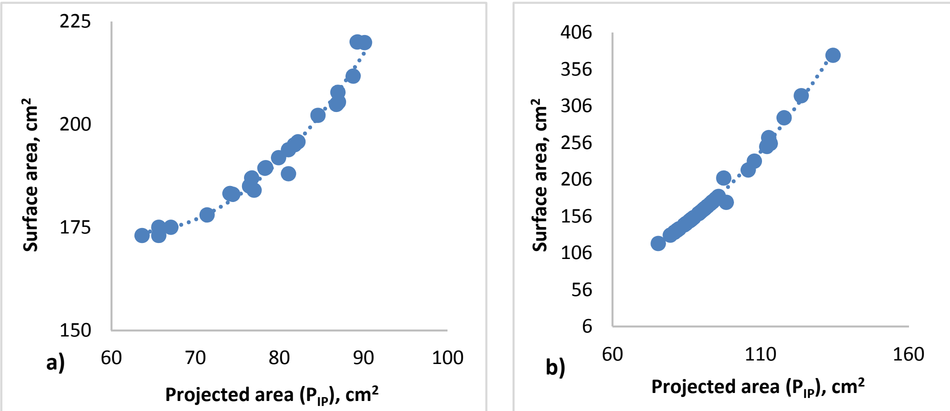

Figure 4. Quadratic relationship between surface area by graphical method and projected area by image processing method. (a) Alphonso mangoes (b) Banganapalli mangoes.

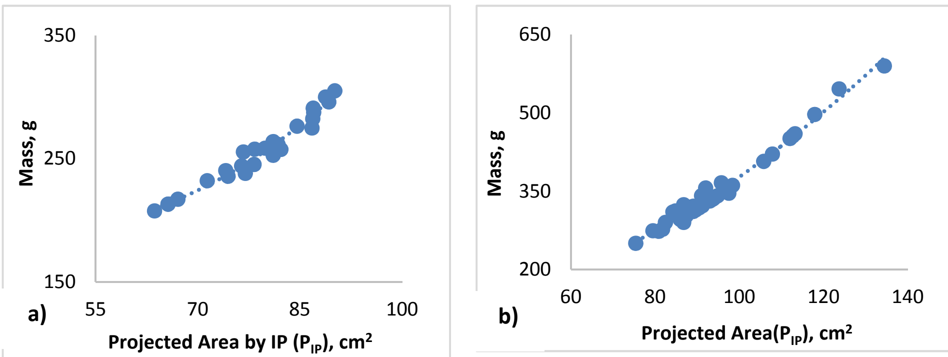

Figure 5. Quadratic relationship between mass of individual fruits and projected area by image processing method. (a) Alphonso mangoes (b) Banganapalli mangoes

Modelling of weight and volume. All the three models had shown good r^2 values (above 0.90) for both weight and volume. In mass modelling, the cubic and quadratic model had shown same r^2 values and cubic model had shown lower *RMSE* and chi-square value for both varieties.

Since the difference between the goodness of fit characteristics of quadratic and cubic model were negligible, moreover to avoid further complication in modelling, quadratic models could be chosen to predict weight of fruits using P_{ip}. Similarly, quadratic model would be more suitable to predict volume since it has lower *RMSE* and chi-square value for both varieties. Selected models were plotted and shown in Figs. 5,6.

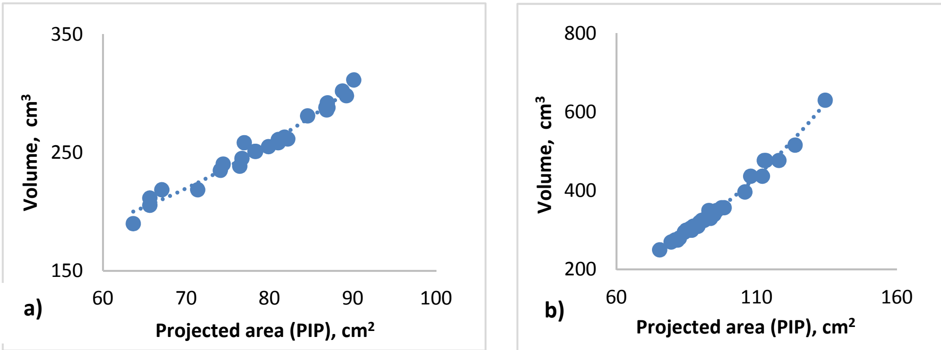

Figure 6. Quadratic relationship between volume of individual fruits and projected area by image processing method. (a) Alphonso mangoes (b) Banganapalli mangoes.

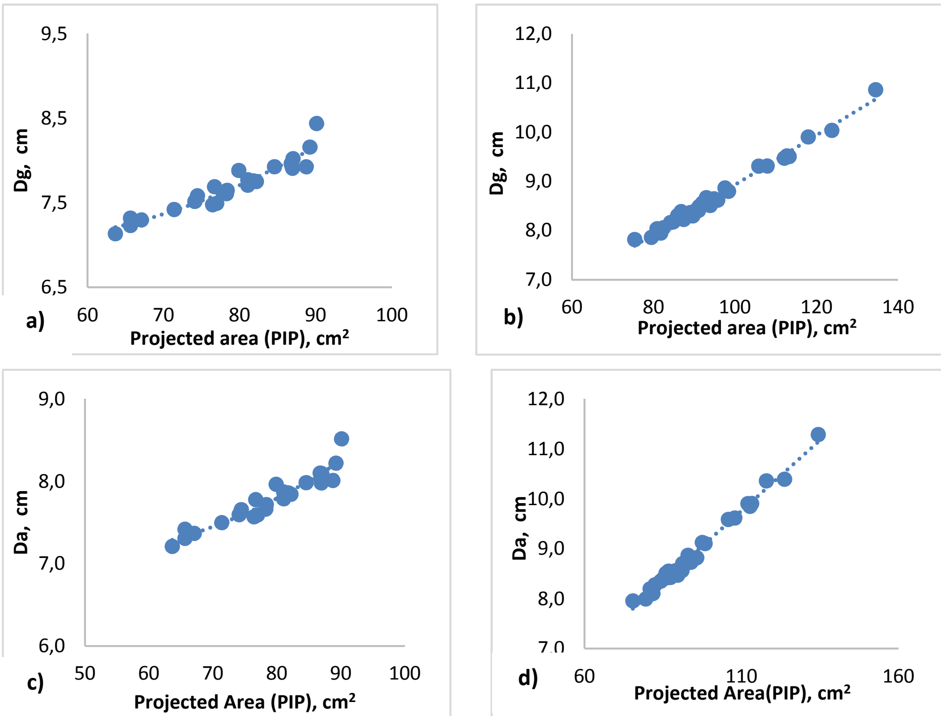

Figure 7. Quadratic relationship between geometrical parameters and projected area by image processing method. (a) and (c) Alphonso mangoes (b) and (d) Banganapalli mangoes

Modelling of geometrical parameters. Among the L, W and T, better prediction using P_{ip} was found in length of the fruit followed by width in both varieties. The thickness of Banganapalli fruits may not be predicted better using P_{ip} since it had shown lower r^2 values (< 0.8) than Alphonso fruits. Predicting the third dimension of mango from the two dimensional image may lead to poor prediction and this may be the reason for poor prediction of thickness of both fruit varieties. As reported by M. Hryniewicz and others

[4], this can be eliminated by passive 3-D machine vision technique using two camera with 90 degree view angle difference. Then both the images can be interpreted to find out the three geometrical parameters (*L, W, T*) effectively.

The second order polynomial (cubic) relations for length, width and thickness with P_{ip} can be used. To overcome this complication, prediction of size (D_g) or arithmetic mean diameters (D_a) of the fruit using P_{ip} would be more appropriate. From the results, higher r^2 values (>0.98) was observed for prediction of D_a and D_g in case of banganapalli mangoes using P_{ip}. At the same time, comparatively lower r^2 value (0.91) were observed for D_a and D_g for Alphonso mangoes. Among geometrical parameters, better prediction would be achieved for length followed by D_a and D_g for Alphonso mangoes. It may be due to sphericity of the mangoes (sphericity were found as 0.83 and 0.70 for Alphonso and banganapalli respectively). Thus, it can be concluded that more spherical shaped fruit leads to poor prediction of geometrical parameters using P_{ip}. In case of banganapalli, no much differences were observed between goodness of fit parameters among the three models (Tab. 3) while predicting the D_a and D_g. So simple linear model may be chosen to predict D_a and D_g which had higher r^2 value (0.99) and lower *RMSE* and chi-square values. The relationship between D_a and D_g to P_{ip} were plotted and given in Fig. 7.

CONCLUSIONS

The physical properties like spatial parameters, geometrical parameters, weight and volume were measured for two varieties of mango. Image processing technique was used to calculate projected area (P_{ip}) of whole fruit. Then the mathematical modeling of physical properties of Alphonso and banganapalli was performed as a function of projected area (P_{ip}). Three models were explored and the suitable model was selected based on coefficient of determination, root mean square error and chi square value. This study revealed that most of the commercially important properties like weight, surface area, geometric mean diameter and true volume were predicted with higher accuracy ($R^2>0.90$). At the same time length (*L*), width (*W*) and thickness (*T*) could not be predicted effectively ($R^2<0.90$) using projected area (P_{ip}) computed by image processing. These findings would be more useful and suitable for process automation especially in grading and sorting of mango fruits using machine vision and image processing techniques.

BIBLIOGRAPHY

[1] Babic, L., Matic-Kekic, S., Dedovic, N., Babic, M., Pavkov, I. 2012. Surface area and volume modeling of the Williams pear (*Pyrus communis*). *International Journal of Food Properties*, 15 (4),880-890.

[2] Eifert, J.D., Sanglay, G.C., Lee, D.J., Sumner, S.S., Pierson, M.D. 2006. Prediction of raw produce surface area from weight measurement. *Journal of food engineering*, 74 (4),552-556.

[3] Ghabel, R., Rajabipour, A., Ghasemi-Varnamkhasti, M., Oveisi, M. 2010. Modeling the mass of Iranian export onion (*Allium cepa L.*) varieties using some physical characteristics. *Research in Agricultural Engineering*, 56 (21),33-40.

[4] Hryniewicz, M., Sotome, I., Anthonis, J., Ramon, H., De Baerdemaeker, J. 3D surface modeling with stereovision; 2005. p 561-565.

[5] Jannatizadeh, A., Naderi Boldaji, M., Fatahi, R., Ghasemi Varnamkhasti, M., Tabatabaeefar, A. 2008. Some postharvest physical properties of Iranian apricot (*Prunus armeniaca L.*) fruit. *International Agrophysics*, 22 (2),125.

[6] Khanali, M., Ghasemi Varnamkhasti, M., Tabatabaeefar, A., Mobli, H. 2007. Mass and volume modelling of tangerine (*Citrus reticulate*) fruit with some physical attributes. *International Agrophysics*, 21 (4),329.

[7] Khojastehnazhand, M., Omid, M., Tabatabaeefar, A. 2009. Determination of orange volume and surface area using image processing technique. *International Agrophysics*, 23 (3),237-242.

[8] Khoshnam, F., Tabatabaeefar, A., Varnamkhasti, M. G., Borghei, A. 2007. Mass modeling of pomegranate (*Punica granatum L.*) fruit with some physical characteristics. *Scientia Horticulturae*, 114 (1),21-26.

[9] Koc, A.B. 2007. Determination of watermelon volume using ellipsoid approximation and image processing. *Postharvest Biology and Technology*, 45 (3),366-371.

[10] Lee, D.J., Eifert, J., Zhan, P., Xu, X. 2006. Area and volume measurements of objects with irregular shapes using multiple silhouettes. *Optical Engineering*, 45 (2), 202-211.

[11] Lorestani, A.N., Tabatabaeefar, A. 2006. Modelling the mass of kiwi fruit by geometrical attributes. *International Agrophysics*, 20 (2),135.

[12] Marković, D., Veljić, M., Čebela, Ž. 2009. New technologies in fruit color sorting. *Agricultural Engineering (Serbia)*, 2009 (3),113-118.

[13] Moreda, G., Ortiz-Cañavate, J., García-Ramos, F.J., Ruiz-Altisent, M. 2009. Non-destructive technologies for fruit and vegetable size determination–a review. *Journal of Food Engineering*, 92 (2),119-136.

[14] Naderi-Boldaji, M., Fattahi, R., Ghasemi-Varnamkhasti, M., Tabatabaeefar, A., Jannatizadeh, A. 2008. Models for predicting the mass of apricot fruits by geometrical attributes (cv. Shams, Nakhjavan, and Jahangiri). *Scientia Horticulturae*, 118 (4),293-298.

[15] Rashidi, M., Gholami, M., Abbassi, S. 2010. Cantaloupe volume determination through image processing. *Journal of Agricultural Science and Technology*, 11,623-631.

[16] Sadrnia, H., Rajabipour, A., Jafary, A., Javadi, A., Mostofi, Y. 2007. Classification and analysis of fruit shapes in long type watermelon using image processing. *International Journal of Agriculture and Biology*, 1,68-70.

[17] Soltani, M., Alimardani, R., Omid, M. 2010. A new mathematical modeling of banana fruit and comparison with actual values of dimensional properties. *Modern Applied Science*, 4 (8),P104.

[18] Tabatabaeefar, A., Rajabipour, A. 2005. Modeling the mass of apples by geometrical attributes. *Scientia Horticulturae*, 105 (3),373-382.

[19] Tarrío, P., Bernardos, A., Casar, J., Portillo, J. 2006. A Vision System to Efficiently Harvest Fruits Which Grow in Clusters. *Agricultural Engineering (Serbia)*, 2006 (3),43-48.

[20] Topuz, A., Topakci, M., Canakci, M., Akinci, I., Ozdemir, F. 2005. Physical and nutritional properties of four orange varieties. *Journal of Food Engineering*, 66 (4),519-523.

[21] Wilhelm, L., Suter, D., Brusewitz, G. 2005. Physical properties of food materials. *Food and Process Engineering Technology ASAE, St Joseph, Michigan, USA*, 22.

MATEMATIČKO MODELIRANJE FIZIČKIH OSOBINA INDIJSKOG MANGA KORIŠĆENJEM METODA OBRADE SLIKE ZA MAŠINSKU VIZUELIZACIJU

Eyarkai Nambi Vijayaram, Thangavel Kulanthai, Shahir Sulthan, Chandrasekar Veerapandian

Poljoprivredni univerzitet Tamil Nadu,
Institut za inženjering prehrambenih i poljoprivrednih procesa, Coimbatore, India

***Sažetak*:** Istraživanje matematičkog modeliranja je izvedeno sa izmerenim fizičkim osobinama dva varijeteta indijskog manga, kao funkcija projektovane površine (P_{ip}) izračunate tehnikom obrade slike. Istraživana su tri modela: linearni, kvadratni i kubni. Kvadratni model je bio najbolje prilagođen za predviđanje mase, zapremine, površine, geometrijskog i aritmetičkog srednjeg prečnika, sa najvišom tačnošću (R^2>0.95). Istovremeno, dužina (L), širina (W) i debljina (T) se ne mogu efikasno predvideti (R^2<0.90) upotrebom projektovane površine (P_{ip}) izračunate obradom slike. Ovi zaključci bi bili korisniji za mašinsku vizuelizaciju, posebno pri gradiranju i sortiranju plodova manga upotrebom tehnika obrade slike.

***Ključne reči*:** *matematičko modeliranje manga, matematičko modeliranje za mašinsku vizuelizaciju, fizičke osobine manga, obrada slike indijskog manga*

Prijavljen: *Submitted*: 22.12.2014.
Ispravljen: *Revised*: 17.06.2015.
Prihvaćen: *Accepted*: 17.06.2015.