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MODELING THE MASS OF BANANA FRUIT BY GEOMETRICAL ATTRIBUTES

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Abstract: Mathematical modeling was done to predict mass of the banana fruit *var. Grand Nain* from the physical characteristics like length, width, thickness, volume, geometrical mean diameter, etc. Some physical properties of banana were statistically analyzed and their mean, standard deviation, error and coefficient of variance were presented. Models were divided into three classifications. Among the first classification model, empirical equation describing the length and width (model No. 4) predicts the mass with highest R^2 value. In the second classification, mass models of surface area (model No. 8) had a linear relationship with R^2 = 0.91. Highest R^2 value of 0.85 and 0.83 were found for mass models with true and ellipsoidal volume (models No. 9 and 10) respectively in the third classification.

Key words: *banana fruit, mass models, physical properties, dimensions, geometrical attributes*

INTRODUCTION

Physical properties of agricultural products play an important role in determining standards for designing grading, processing, conveying and packaging systems. The major physical properties of banana fruit are mass, volume, size, density, porosity, surface area etc. Of these properties like mass, projected area, volume, etc are the most important in designing grading system [22]. Surface area is important in indicating heat

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transfer rate, respiration rate, water loss, gas permeability per unit surface area, quantity of pesticide applied and ripeness index [4,10,22,23].

Mass grading of fruit becomes more essential and it is used to attain uniform weight, optimum packaging configurations, reduces packaging and transportation costs [16]. Fruits are often graded by size and it would be more economical and ease when it is graded by weight. Also the mass grading is recommended for the irregular shaped products. This makes the relationship between weight and the diameter more crucial.

In weight sorter, constant density fruits can be sorted based on their volume. Models suitable for sizing of the kiwi fruit were determined between mass, volume, projected area and length. Volume can be used to monitor yield during harvesting and to predict harvest time [6]. Measuring dimensions by a digital caliper causes human error and is not an efficient method to estimate volume. Mathematical models involving geometric mean diameter and some common methods like water and gas displacement method are used to determine volume of different fruits [14].

Many researchers formulated empirical equations and studied relationship between volume and surface area [3], mass, diameter and surface area [8,9,13] for different agricultural produces. Based on geometrical attributes, eleven models were recommended to predict mass of an apple [20]. Mass of an orange was predicted from its projected area and dimensions [21]. High correlations were obtained between mass and volume of Iranian grown potatoes [19] and all varieties of kiwi fruit [11]. Quality inspection such as citrus granulation test can be conducted based on density difference [14]. The objective of this study was to establish the models based on physical characteristics to predict mass of the banana fruit.

MATERIAL AND METHODS

Thirty matured bananas (*var.* Grand Nain) were manually harvested and conducted various experiments to determine physical characteristics. Electronic balance with an accuracy of 0.01 g was used to measure weight (*M*) of the banana. True volume (*V*) was measured by Platform scale method [5,12] and by assuming the banana fruit as ellipsoid, its ellipsoidal volume (V_{ell}) [17] and ellipsoidal ratio [23] was calculated using the Eq. (1) and (2).

$$V_{ell} = \frac{\pi}{6} * LWT \tag{1}$$

$$Ellipsoidal\ Ratio = \frac{W}{T} \tag{2}$$

Bulk density (*BD*) was determined by filling banana up to the neck of an empty plastic crate of known volume and then the mass of the banana contained was weighed. The mean length (*L*) was measured using a flexible ruler from outer (L_o) and inner length (L_i) of the banana fruit. The width (*W*) and thickness (*T*) were measured using a digital vernier caliper. Diameter at three ends (Stem, middle and apex) were measured by a digital vernier caliper with an accuracy of 0.01 mm and its mean diameter (*D*) was calculated. Geometric mean diameter (D_g) and arithmetic mean diameter (D_a) was calculated using Eq. (3) and (4) respectively [2,12].

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

$$D_a = \frac{(LWT)}{3} \tag{4}$$

Surface area (S_g, cm^2) was calculated by graphical method [12]. Estimated or apparent surface area was calculated from the Eq.(5) and (6) given by [7,15].

$$S = \frac{\pi B L^2}{2L - B};\ B = (WT)^{0.5} \tag{5}$$

$$S = \pi D_g^2 \tag{6}$$

All experiments were analyzed for mean, standard deviation (*SD*), standard error (*SE*) and coefficient of variance (*CV*) in Spreadsheet software, Microsoft EXCEL 2007. To predict mass of the banana from dimensional properties and volume, three categories of models were considered as shown below:

1. Single or multiple regressions of mass (*M*) with dimensional properties like length (*L*), width (*W*), thickness (*T*) and geometrical mean diameter (D_g).
2. Single regression of mass (*M*) of banana fruit based on surface area (S_g).
3. Single regression models to predict mass of banana fruit from true volume (*V*) and ellipsoidal volume (V_{ell}).

In the first category model, mass was predicted by the independent variables: length, width, thickness and geometrical mean diameter.

$$M = K_1L + K_2 W + K_3T + K \tag{7}$$

$$M = K_1D_g + K \tag{8}$$

In the second category model, mass (*M*) was estimated as a function of surface area (S_g).

$$M = K_1S_g + K \tag{9}$$

In the third classification, mass (*M*) of the banana fruit was modelled with actual (*V*) and ellipsoidal volume (V_{ell}).

$$M = K_1V + K \tag{10}$$

$$M = K_1V_{ell} + K \tag{11}$$

In all the five equations, K_1, K_2 and K_3 indicates coefficient of independent variable and K is the constant. Modeling was done using SPSS 12 and the suitability of the model was selected based on the highest R^2 (coefficient of determination) and lowest *RMSE* (Root Mean Square Error) value.

RESULTS AND DISCUSSION

Some selected physical characteristics of the banana such as mass, true volume, bulk density, true density, geometric mean diameter, surface area etc. were presented in Tab. 1. Ten regression models classified into three categories were presented in Tab. 2.

Table 1. Physical properties of banana var. Grand Nain

S.No	Physical properties	Mean	SD	Min	Max	SE
1	Mass (M), g	139.65	7.66	126	154.29	1.47
2	True volume (V), cm^3	136.33	9.86	118	157.00	1.90
3	Ellipsoidal volume (V_{ell}), cm^3	117.92	9.09	98.15	131.33	1.75
4	Ellipsoidal ratio	1.08	0.02	1.05	1.12	0.00
5	Fruit density (TD), $g \cdot cm^{-3}$	1.03	0.03	0.98	1.11	0.01
6	Bulk density (BD), $g \cdot cm^{-3}$	0.41	0.03	0.35	0.46	0.01
7	Length (L), cm	16.99	0.71	15.45	18.20	0.14
8	Width (W), cm	3.78	0.08	3.61	3.91	0.02
9	Thickness (T), cm	3.50	0.10	3.31	3.68	0.02
10	Mean diameter, cm	3.56	0.18	3.25	4.04	0.03
11	Geometrical mean diameter (D_g),cm	6.08	0.16	5.72	6.31	0.03
12	Arithmetic mean diameter (D_a), cm	8.09	0.28	7.48	8.54	0.05
13	Surface area by graph (S_g) , cm^2	115.84	9.31	99.17	133.28	1.79
14	Surface area by Jean & Ball, cm^2	108.77	6.06	95.25	118.16	1.17
15	Surface area by McCabe, cm^2	116.20	6.04	102.9	124.93	1.16

Table 2. Mass models of banana var. Grand Nain

S.No	Models	K_1	K_2	K_3	k	R^2	RMSE
1	$M=K_1L+C$	8.79	-	-	-9.77	0.67	4.48
2	$M=K_1W+C$	66.59	-	-	-111.95	0.53	5.35
3	$M=K_1T+C$	57.44	-	-	-61.63	0.55	5.21
4	$M=K_1L+ K_2 W +C$	6.55	40.00	-	-122.88	0.82	3.39
5	$M=K_1L+ K_2 T+C$	6.22	29.44	-	-69.27	0.76	3.90
6	$M=K_1W+ K_2 T+C$	38.29	36.07		-131.42	0.65	4.69
7	$M=K_1L+ K_2 W +K_3T+C$	5.83	32.83	12.88	-128.62	0.83	3.34
8	$M=K_1D_g +C$	43.24	-	-	-123.29	0.82	3.33
9	$M=K_1D_a +C$	24.37	-	-	-57.57	0.76	3.81
10	$M=K_1S_g +C$	0.78	-	-	48.92	0.91	2.39
11	$M=K_1V+C$	0.72	-	-	42.09	0.85	3.03
12	$M=K_1V_{ell}+C$	0.77	-	-	49.37	0.83	3.27

Among the first category model (No. 1, 2, 3, 4, 5 and 6); model number 6 had the highest R^2 value as shown in Tab. 1. In order to predict the mass of the banana fruit using this equation, it is necessary to measure all the three variables like length, width and thickness. Measuring all the three parameters makes the system more tedious [1]. Hence the model No. 4 (Eq. 12) with the R^2 value of 0.82 can be used to predict mass of the banana fruit based on two (length and width) dimensional characteristics.

$$M = K_1L + K_2W + K;\ (R^2=0.82) \tag{12}$$

Mass can also be predicted (Eq. 13) well from geometrical mean diameter using the model number 7 as shown in Table 1. Relationship between geometric and arithmetic mean diameter of banana is shown in Fig. 1. From the Eq. 14, it is clear that the relationship between the two diameters fetches the coefficient of determination 0.90 and hence either the arithmetic mean or the geometric mean method can be used to calculate the equivalent diameter of banana.

$$M = K_1D_g + K;\ (R^2=0.82) \tag{13}$$

$$D_a = 1.632 * D_g - 1.836;\ (R^2=0.90) \tag{14}$$

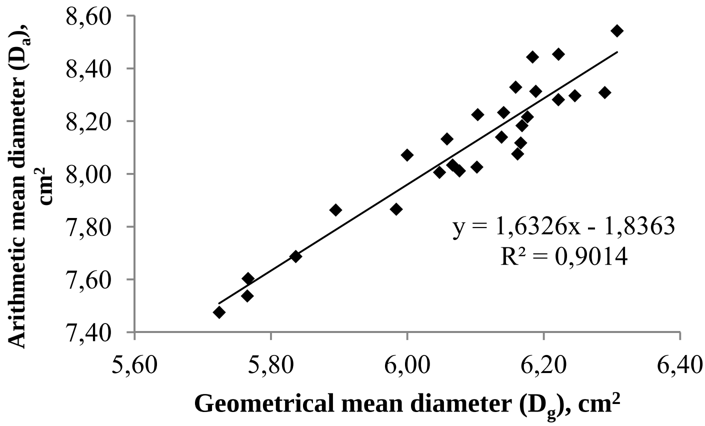


Figure 1. Relationship between geometric and arithmetic mean diameter

Model No. 8 of the second category model (Tab. 2) having the R^2 value of 0.91 shows the relationship between mass of the banana fruit and its surface area. The relationship between apparent and graphical surface area is illustrated in Fig. 2. The correlation between apparent and graphical surface area as demonstrated in Eq. 15 and 16 had the R^2 value of 0.88. This implies that there is a strong relationship between apparent and graphical surface area for the banana fruit (*var. Grand Nain*).

$$\text{McCabe method: } y = 0.598x + 46.22;\ (R^2 = 0.88) \tag{15}$$

$$\text{Jean and ball method: } y = 0.6x + 38.59;\ (R^2 = 0.88) \tag{16}$$

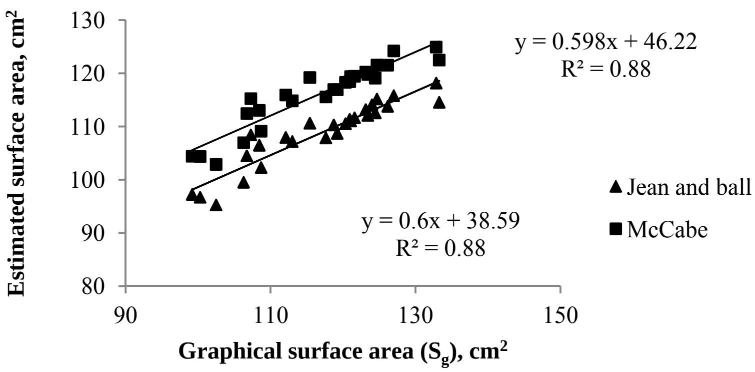
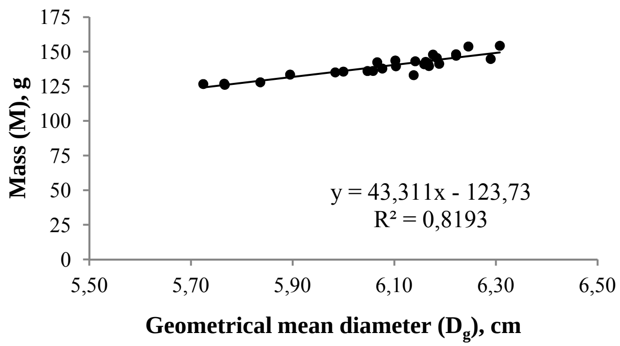
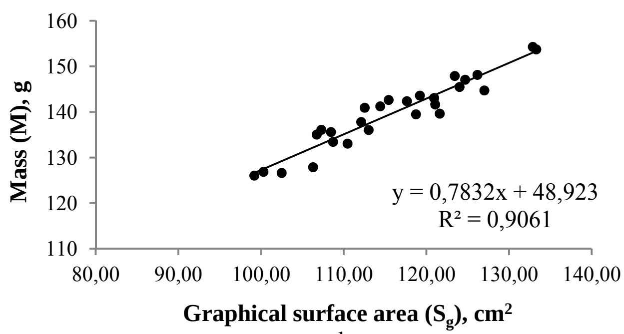


Figure 2. Relationship between graphical and estimated surface area

In the third model classification, model number 9 and 10 (Tab. 2) can be used to predict the mass of the banana fruit. This was clearly evident from the highest R^2 value of 0.85 and 0.83 for true and ellipsoidal volume of the banana fruit respectively. Fig. 3 depicts the relationship between mass, geometrical mean diameter, surface area by graph and true volume of the banana fruit.



a.



b.

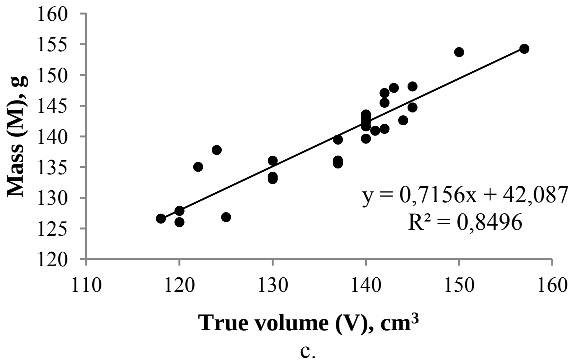


Figure 3. Relationship between mass, geometrical mean diameter (a), surface area (b) and true volume (c)

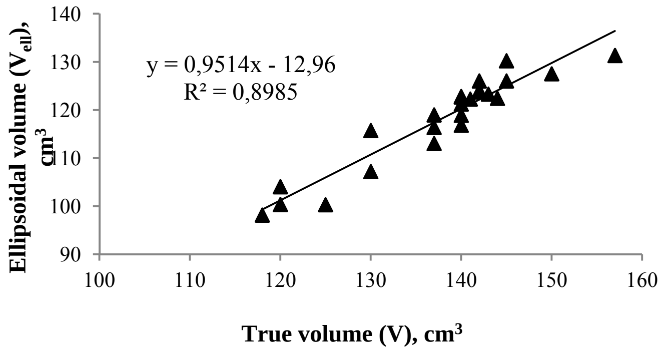


Figure 4. Relationship between true volume and ellipsoidal volume

$$V_{ell} = 0.951 \cdot V - 12.96; \; (R^2=0.898) \quad (17)$$

By assuming the volume of banana fruit as ellipsoid a linear relationship has been drawn as shown in Fig. 4. The high correlation coefficient (0.898) from the Eq. 17 confirms the shape of banana fruit as ellipsoid [18].

CONCLUSIONS

1. Some physical properties of banana fruit *var. Grand Nain* were presented.
2. All the three category models are in linear form.
3. The recommended equation (model No. 4) to estimate mass based on geometrical attributes (length and width) was found to be: $M = 6.55 \cdot L + 40 \cdot W - 122.88$; $R^2 = 0.82$.
4. The relationship (model No. 8) between mass and surface area was given by: $M = 0.78 \cdot S_g + 48.92$; $R^2 = 0.91$.

5. Good relationship was found between mass and measured volume of banana fruit with R^2 value of 0.85. The shape of the banana considered as ellipsoid was the most appropriate (model No. 10), since both the R^2 value of true and ellipsoidal was found to be approximately equal.

BIBLIOGRAPHY

[1] Chakespari, A.G., Rajabipour, A., Mobli, H. 2010. Mass modeling of two apple varieties by geometrical attributes. *PAT*, 100 (100),3975.

[2] Chandrasekar, V., Kailappan, R., Kasthuri, R., Rajamani, K. 2013. Moisture Dependent Physical and Thermal Properties of Coleus Tuber. *Journal of Agricultural Engineering*, 50 (1),19-26.

[3] Ravi, P., Venkatachalam, T. 2014. Important engineering properties of paddy. *Agricultural engineering*, 39 (4),73-83.

[4] 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.

[5] Shahir, S., Visvanathan, R. 2014. Maturity Measurement of Mango and Banana as Related to Ripening. *Trends in Biosciences*, 7 (9),741-744.

[6] Hahn, F., Sanchez, S. 2000. Carrot volume evaluation using imaging algorithms. *Journal of agricultural engineering research*, 75 (3),243-249.

[7] Kabas, O., Ozmerzi, A., Akinci, I. 2006. Physical properties of cactus pear (*Opuntia ficus india L.*) grown wild in Turkey. *Journal of Food Engineering*, 73 (2),198-202.

[8] 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.

[9] 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.

[10] Lee, D.J., Xu, X., Eifert, J., Zhan, P. 2006. Area and volume measurements of objects with irregular shapes using multiple silhouettes. *Optical Engineering*, 45 (2),027202-027202-027211.

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

[12] Mohsenin, N.N. 1986. *Physical properties of plant and animal materials*. New york: Gordon and Breach Science Publishers.

[13] 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.

[14] Omid, M., Khojastehnazhand, M., Tabatabaeefar, A. 2010. Estimating volume and mass of citrus fruits by image processing technique. *Journal of Food Engineering*, 100 (2),315-321.

[15] Razavi, S.M.A., BahramParvar, M. 2007. Some physical and mechanical properties of kiwifruit. *International Journal of Food Engineering*, 3 (6).

[16] Shahir, S., Thirupathi, V. 2009. Performance Evaluation of a Divergent Roller Grader for Selected Vegetables. *Ama, Agricultural Mechanization in Asia, Africa & Latin America*, 40 (4),60.

[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] Soltani, M., Alimardani, R., Omid, M. 2011. Modeling the main physical properties of banana fruit based on geometrical attributes. *Int J Multidiscip Sci Eng*, 2 (2),1-6.

[19] Tabatabaeefar, A. 2002. Size and shape of potato tubers. *International agrophysics*, 16 (4),301-306.

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

[21] Tabatabaeefar, A., Vefagh-Nematolahee, A., Rajabipour, A. 2000. Modeling of orange mass based on dimensions. *Journal of Agricultural Science and Technology*, 2 (4),299-305.

[22] 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.

[23] Wilhelm, L., Suter, D., Brusewitz, G. 2005. Physical properties of food materials. *Food and Process Engineering Technology ASAE, St Joseph, Michigan, USA*,23-52.

MODELIRANJE MASE BANANA GEOMETRIJSKIM ATRIBUTIMA

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Sažetak: Matematičko modeliranje je izvedeno da bi se predvidela masa banana *var. Grand Nain* iz fizičkih karakteristika kao što su dužina, širina, debljina, zapremina, srednji geometrijski prečnik, itd. Neke fizičke osobine banana su statistički analizirane i predstavljene su njihove srednje vrednosti, standardne devijacije, greške i koeficijenti varijanse. Modeli su podeljeni u tri klase. U prvom klasifikacionom modelu empirijska jednačina opisuje dužinu i širinu (model br. 4) i predviđa masu sa najvišom R^2 vrednošću. U drugoj klasifikaciji, maseni modeli površine (model br. 8) imali su linearni odnos sa R^2 = 0.91. Najviša vrednost R^2 od 0.85 i 0.83 dobijene su u trećoj klasifikaciji za masene modele sa pravilnom i elipsoidnom zapreminom (modeli br. 9 i 10), redom.

Ključne reči*: banane, maseni modeli, fizičke osobine, dimenzije, geometrijski atributi*

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