Adeleke University Journal of Engineering and Technology

[AUJET] Vol. 1, No 1, 123-130 (2018)

aujet.adelekeuniversity.edu.ng

Estimating Mass and Volume of Nigerian Grown Sweet and Irish Potato Tubers using their Geometrical Attributes

Oyefeso B. O., Raji A. O.

Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Nigeria.

Corresponding Author: *oyefesobabatunde@gmail.com*

ARTICLE INFO

Received: June/ 2018

Revised: July/ 2018

Accepted: August / 2018

Published: August / 2018

Keywords: *Sweet potato, Irish potato, Physical properties, Geometrical attributes, Mass/volume modelling.*

ABSTRACT

Sweet and Irish potato are tuber crops which have been domesticated and cultivated in different parts of the world including Nigeria. They are often prepared in various ways for food. A good knowledge of the physical properties of these tuber crops will enhance proper design of post-harvest processing machines and handling equipment with high level of performance. Also, functional relationships established between the various physical properties of these crops could assist in ensuring proper handling and more efficient and economical processing. This study was therefore, aimed at developing mathematical models for predicting the mass and volume of sweet and Irish potato tubers using some of their geometrical attributes. The research was conducted on fresh sweet and Irish potato tubers which were sorted into four fractions based on their individual mass. The physical characteristics measured include the mass, volume, linear dimensions (length, width and thickness) and the projected areas taken along the three mutually-perpendicular axes. The models were divided into three classifications namely: single and multiple variable regression models based on linear dimensions; single and multiple variable regression models based on the projected areas; single variable regression models based on mass or volume. Mass and volume models based on the projected areas and the volume were the best models for both crops. The highest coefficient of determination (R^2) for sweet potato was obtained for mass model based on the projected area along the longitudinal plane (R^2 = 0.981) while mass model expressed on the basis of the multiple regression of the three linear dimensions performed best (R^2 = 0.968) for Irish potato. This study provided useful information that can help in the design of systems for handling and processing of sweet and Irish potato tubers.

Adeleke University Journal of Engineering and Technology

[AUJET] Vol. 1, No 1, 123-130 (2018)

aujet.adelekeuniversity.edu.ng

INTRODUCTION

Root and tuber crops are staple foods in many parts of the tropics including Nigeria, being the source of most of the daily carbohydrate intake for large populations. These carbohydrates are mostly starches found in storage organs, which may be enlarged roots, corms, rhizomes, or tubers. Several of these crops have been termed under-exploited and deserving of considerably more research input. In fact, these crops remained neglected in terms of scientific input until the establishment of the International Center for Tropical Agriculture (CIAT) in Colombia (1967), the International Institute for Tropical Agriculture (IITA) in Nigeria (1968), and the International Potato Center (CIP) in Peru (1971) (O'Hair, 1990).Yam, cassava, tacca, edible aroids (e.g. cocoyam, taro), Irish potatoes and sweet potatoes are all examples of tuber and root crops. This study focused on Irish potato and sweet potato amongst all the root and tuber crops which are commonly cultivated in Nigeria.

The design of post-harvest handling equipment for sweet and Irish potato tubers depends on the knowledge of the physical properties of the tubers and the development of models that could predict these properties easily and quickly is therefore, important. This necessitates the development of models that could establish relationships between some of these physical attributes and help in predicting one or more of the attributes based on some others.

Among physical characteristics, linear dimensions, mass, volume and projected areas are important parameters in sizing and grading machines (Naderiboldaji *et al*., 2009). Crops are often graded on the basis of size and projected area, but it may be more economical to develop a machine which would grade by mass or volume. This therefore, necessitates establishing relationships between mass or volume and other physical attributes of crops (Khanali *et al*., 2007; Keramat-Jahromi *et al*., 2007a). Several researches have been carried out to predict one or more physical properties of crops using models developed based on the relationships established between these physical properties and the geometrical attributes of the crops. Some of these crops include Iranian grown potato (Tabatabaeefar, 2002), kiwi fruits (Lorestan and Tabatabaeefar, 2006), pomegranate fruit (Khoshnam *et al.*, 2007), tangerine fruit (Khanali *et al.*, 2007), bergamot fruits (Keramat-Jahromi *et al.*, 2007a), date fruits (Keramat-Jahromi *et al.*, 2007b), apricot fruit (Naderiboldaji *et al.*, 2009), walnut varieties (Ebrahimi *et al.*, 2009), apples (Meisami-asl *et al.*, 2009), citrus fruits (Omid *et al*., 2010), fava beans (Lorestani and Ghari, 2012), sweet cherry (Khadivi-Khub and Naderiboldaji, 2013), potato varieties (Berberoglu *et al*., 2014), persimmon fruits (Subbarao and Vivek, 2017) and almond nuts (Gürbüz *et al*., 2018). However, this study focused on the development of mathematical models that can be used for predicting the mass and volume of sweet and Irish potato tubers which were cultivated in Nigeria.

1. METHODOLOGY

Fresh wholesome tubers of sweet and Irish potato were purchased from Bodija market in Ibadan, Oyo State, Nigeria. The market is widely known for the bulk of freshly harvested produce which are brought to the market from the neighbouring farms. The study was conducted on 85 tubers of Irish potato and 85 tubers of sweet potato which were sorted into four fractions based on their mass and then labelled to enable proper identification and documentation of the results. Some wholesome sweet and Irish potato tubers are shown in Plates 1 and 2, respectively.

Plate 1: Sweet potato

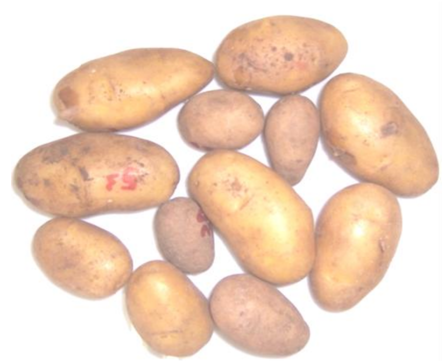


Plate 2: Irish potato

Adeleke University Journal of Engineering and Technology

[AUJET] Vol. 1, No 1, 123-130 (2018)

aujet.adelekeuniversity.edu.ng

The physical characteristics measured include the Mass (M), Volume (V), linear dimensions- Length (L), Width (W) and Thickness (T) and the Projected Areas (PA_L, PA_W and PA_T) along the three mutually perpendicular axes. The individual mass of each of the sweet and Irish potato tubers were measured using an electronic weighing balance (A&D Co. LTD, AND EK-6100i model, Japan) with an accuracy of 0.1g. The linear dimensions along the three mutually perpendicular axes were measured with the aid of a digital calliper (Carrera Precision model CP5912-T 12-Inch Titanium Digital LCD Calliper Micrometer, China, $\pm$0.01mm). The three mutually perpendicular axes were determined by allowing each tuber crop to drop freely under gravity and then rest on its natural axis. At this natural resting position, the linear dimensions along the three mutually perpendicular axes were easily obtained as length (the longest dimension), width (the linear dimension perpendicular to the length) and thickness (the linear dimension which is perpendicular to both length and width).

The projected areas along the three mutually perpendicular axes, PA_L (along the longitudinal plane), PA_C (along the cross-sectional plane) and PA_T (along the transverse plane), were obtained by digital image processing (Khanali *et al*, 2007; Keramat-Jahromi, 2007b; Omid *et al*., 2010; Ziaratbana *et al*., 2017). This involved the acquisition of the images of the Irish and sweet potato tubers using a digital camera (Kodak EasyShare Zoom Digital Camera, Z730 model, United States) with a resolution of 5 Megapixels.

An image acquisition lighting box was constructed and the tubers were placed on the base of the box for proper capturing of the images. The lighting box (Plate 3) helped to flood the samples with light to avoid casting of shadows which may introduce noise into the actual image and subsequently, give misleading results.

Since most agricultural products are irregular in shape and tubers do not readily absorb water within a short period, the volume of each of the sweet and Irish potato tubers were obtained using the water displacement method (Mohsenin, 1986; Khanali *et al*, 2007; Keramat-Jahromi, 2007a). This involved submerging each of the tuber crops into a known volume of water and the volume of water displaced was measured and recorded as the volume of the immersed sample.

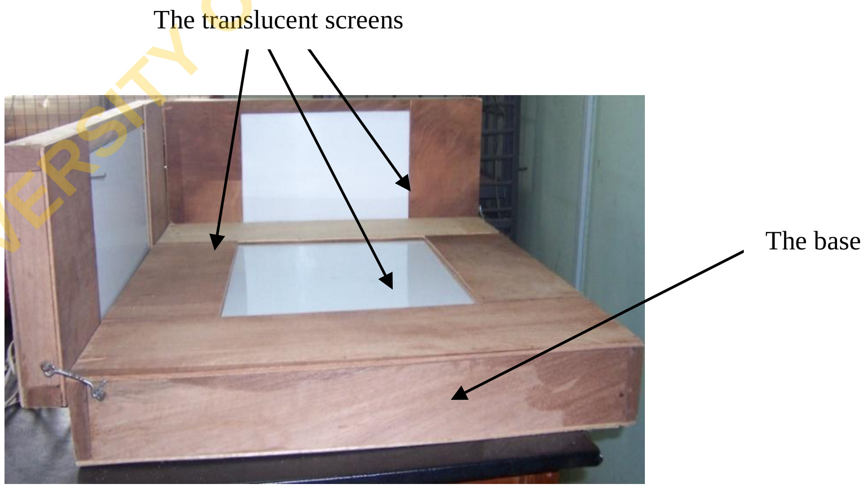


Plate 3: Image Acquisition Lighting Box.

The images acquired were cropped within rectangles touching all the four points along the edges of the images being cropped. The dimensions of the enclosing rectangles are equivalent to the actual dimensions measured for that object. Paintshop Pro, a graphic application, was then used to save the cropped images in portable pixel map (.ppm) format. This saved the images as digital graphics which can be opened as text files using Notepad or WordPad or other ASCII applications with digits indicating the RGB (red, green and blue) pixel values. These pixel values were then sequentially read as inputs into an algorithm developed in FORmular TRANslation (Fortran) 95 programming language. Since large data values were being processed, Fortran 95 online graphics was employed. This helped to plot the coordinates of the image projections as they resulted from the program being executed and therefore, reduced the memory space that would have been required if the results were saved in an external file and later plotted. The ratio of the pixels of the projected images to the total pixels of the images were then recorded when the plotted image projections compared well with the actual image. The actual projected area of each of the images was obtained from the product of the known rectangular area enclosing the cropped image and the recorded ratios corresponding to the particular image.

Regression analysis was carried out and this involved the prediction of the value of an unknown variable based on the past observations or experimental results of that variable and others. An estimating equation or a mathematical model or formula that relates the known variables to the unknown variable is developed in regression analysis. This involved plotting the scatter diagrams showing each pair of known data plotted as a single point and then determining the type of relationship that existed between the variables. The values of the unknown variables were then estimated or predicted by using the equation for the line of fit predicting the relationship (Richard, 1978).

E-regress (Essential Regression, 1997), an add-in to Microsoft Excel, was used to analyze the data and to determine the regression models between the variables of concern. There are different types of regression models that could represent the relationships that exist between a dependent variable and one or more independent variables. Some of these models include linear, exponential, logarithmic, polynomial of orders between 1 and 6 and power regression trends (Microsoft Excel, 2009). A typical linear multiple regression model is given as $Z = \mathrm{k} + a_1Y_1 + a_2Y_2 + \cdots + a_nY_n$, while exponential, logarithmic, polynomial of order 2 and power regression models are given as $Z = ae^{bY}, Z = a\ln Y + b, Z = aY^2 + bY + kandZ = aY^k$, respectively, where Z is the dependent variable e.g. the mass or volume of the crops being modelled; $Y_1, Y_2, \dots, Y_n$ are the independent variables such as the linear dimensions and the projected areas being used to model the mass and volume of the crops; $a_1, a_2, \dots, a_n, a\ and\ b$ are the coefficients of regression and k is the regression constant.

Correlation analysis was used along with regression to describe the degree of association between the variables and to measure how well the regression models explained the variation of the dependent variable since the estimating equations are not perfect predictors. The coefficient of determination (R^2) is the square of the correlation coefficient (R) and it helped to indicate the percentage of the variation in the dependent variable that could be explained by the variation in the independent variable. The following classifications were used in order to predict the mass or volume of the crops using their geometrical attributes, that is, the linear dimensions- length (L), thickness (T) and width (W), the projected areas along the three mutually perpendicular axes ($\mathrm{PA_L}, \mathrm{PA_C}$ and $\mathrm{PA_T}$) and the volume or mass:

i. Single or multiple variable regressions of the tubers' linear dimensions;
ii. Single or multiple variable regressions of the tubers' projected areas;
iii. Single variable regression of the tubers' volume.

RESULTS AND DISCUSSION

Summary of the measured physical properties of the sweet and Irish potato tubers is presented in Table 1. These physical properties include the linear dimensions (length, thickness and width), projected areas, mass and volume. Mass and volume models established for sweet potato tubers are shown in Tables 2 and 3, respectively while those for Irish potato tubers are as presented in Tables 4 and 5, respectively. Mass models developed based on volume of sweet and Irish potato are presented in Figures 1 and 2, respectively.

Table 1: Some physical properties of the sweet and Irish potato tubers

Characteristics	Sweet potato	Irish potato
Length (mm)	44.66 - 163.79	35.53 - 100.77
Thickness (mm)	25.35 - 79.18	21.33 - 39.48
Width (mm)	26.25 - 81.62	25.17 - 48.07
Longitudinal projected area, PA_L (cm^2)	11.61 – 60.21	5.87 – 26.13
Cross-sectional projected area, PA_c (cm^2)	5.99 – 50.18	4.56 – 13.95
Transversal projected area, PA_T (cm^2)	12.36 – 66.76	7.38 – 37.19
Mass (g)	27.60 – 334.20	12.40 – 99.50
Volume (cm^3)	25.00 – 290.00	10.00 – 80.00

Table 2: Mass models for sweet potato tubers

No.	Model Equation	R^2
1	$M = 27.884e^{0.008L}$	0.185
2	$M = 0.099T^{1.773}$	0.615
3	$M = 12.29e^{0.039W}$	0.594
4	$M = -129.10 + 0.688L + 2.906T + 0.599W$	0.652
5	$\mathrm{M} = 0.084(\mathrm{PA_L})^2 - 0.033(\mathrm{PA_L}) + 18.95$	0.981
6	$\mathrm{M} = 0.043(\mathrm{PA_C})^2 + 4.355(\mathrm{PA_C}) + 0.322$	0.888
7	$\mathrm{M} = 0.069(\mathrm{PA_T})^2 - 0.060(\mathrm{PA_T}) + 22.80$	0.975
8	$\mathrm{M} = -45.21 + 1.703(\mathrm{PA_L}) + 2.870(\mathrm{PA_C}) + 1.516\mathrm{PA_T})$	0.972
9	$\mathrm{M} = 1.158\mathrm{V} + 2.880$	0.974

Table 3: Volume models for sweet potato tubers

No.	Model Equation	R^2
1	$V = 23.84e^{0.008L}$	0.164
2	$V = 0.069T^{1.818}$	0.630
3	$V = 9.661e^{0.041W}$	0.613
4	$V = -109.44 + 0.559L + 2.492T + 0.504W$	0.642
5	$\mathrm{V} = 0.075(\mathrm{PA_L})^2 - 0.165(\mathrm{PA_L}) + 17.55$	0.978
6	$\mathrm{V} = 0.041(\mathrm{PA_C})^2 + 3.643(\mathrm{PA_C}) + 0.347$	0.901
7	$\mathrm{V} = 0.059(\mathrm{PA_T})^2 + 0.031(\mathrm{PA_T}) + 17.77$	0.971
8	$\mathrm{V} = -38.67 + 0.920(\mathrm{PA_L}) + 2.697(\mathrm{PA_C}) + 1.661(\mathrm{PA_T})$	0.975

Table 4: Mass models for Irish potato tubers

No.	Model Equation	R^2
1	$\mathrm{M} = 1.184\mathrm{L} - 29.11$	0.841
2	$\mathrm{M} = 0.002T^{2.825}$	0.781
3	$\mathrm{M} = 0.001W^{2.837}$	0.835
4	$\mathrm{M} = -63.66 + 0.736\mathrm{L} + 0.987\mathrm{T} + 0.811\mathrm{W}$	0.968
5	$\mathrm{M} = 1.207(\mathrm{PA_L})^{1.306}$	0.941

Adeleke University Journal of Engineering and Technology

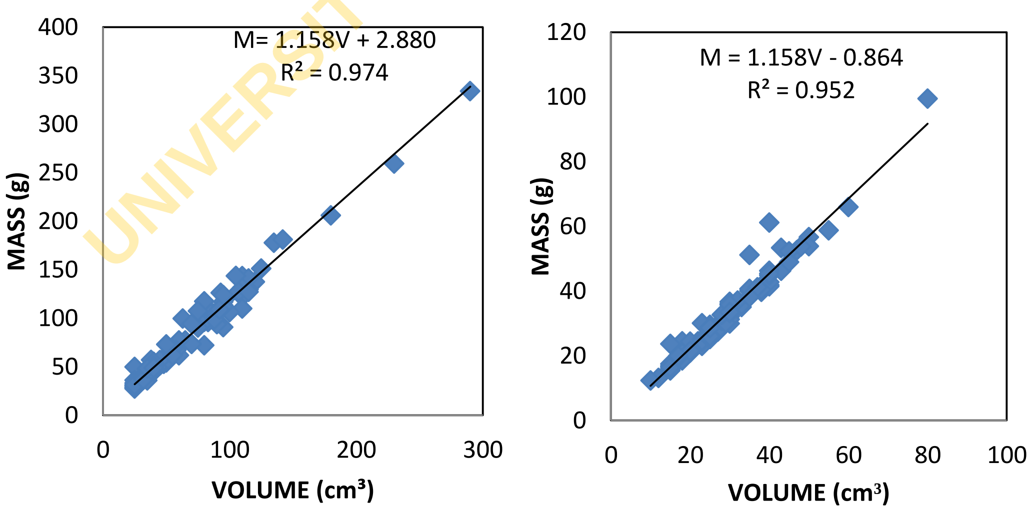
[AUJET] Vol. 1, No 1, 123-130 (2018)

aujet.adelekeuniversity.edu.ng

6	$M = 1.335(PA_C)^{1.534}$	0.871
7	$M = 1.030(PA_T)^{1.294}$	0.933
8	$M = -12.71 + 1.546(PA_L) + 0.304(PA_C) + 1.682(PA_T)$	0.931
9	$M = 1.158V - 0.864$	0.951

Table 5: Volume models for Irish potato tubers

No.	Model Equation	R^2
1	$V = 0.971L - 21.61$	0.796
2	$V = 0.002T^{2.797}$	0.789
3	$V = 0.001W^{2.761}$	0.815
4	$V = -53.43 + 0.566L + 1.058T + 0.504W$	0.947
5	$V = 1.132(PA_L)^{1.286}$	0.932
6	$V = 1.239(PA_C)^{1.514}$	0.868
7	$V = 0.992(PA_T)^{1.265}$	0.912
8	$V = -11.27 + 1.889(PA_L) + 0.665(PA_C) + 0.835(PA_T)$	0.918



(a) (b)

Figure 1: Mass model of: (a) -sweet potato on volume, (b) Irish potato on volume

The regression equations that best describe the relationships that exist between the independent and dependent variables (i.e., the models with the highest coefficients of determination, R^2) are the only ones presented in the tables. Models with R^2 that were in excess of 0.90 were considered as being highly acceptable or satisfactory.

Among the first classification models, the models which involved the consideration of all the three mutually perpendicular linear dimensions (L, T and W), as presented in Tables 2 to 5 for both sweet and Irish potato had the highest R^2 values. Of all the models on the basis of multiple variable regressions of the linear dimensions, those for Irish potato tubers were the most acceptable ($R^2 \geq 0.920$). It should however, be noted that all the three linear dimensions are needed to develop these models resulting in a more complex, cumbersome and costly sizing mechanism. Of all the one dimensional or single independent variable models, the ones based on the thickness (T) had the highest R^2 values for sweet potato while for Irish potato, the models based on width (W) are the best models for mass and volume predictions. Inconsistency of the models that were based on the linear dimensions was made obvious by extremely low coefficients of determination (of 0.185 for the best mass model and 0.164 for the volume model) for sweet potato tubers. This showed a very low correlation between the length and the mass or volume of sweet potato tubers being modelled and it clearly indicated that the length of a sweet potato tuber cannot be used to predict its mass or volume since there was little or no significant relationship between them.

For the second classification, the mass and volume models for sweet potato that were satisfactory include those single variable regressions based on the projected area along the longitudinal plane (PA_L) and that along the transverse plane (PA_T) as well as the multiple variable regressions based on all the three projected areas. The models which are based on the projected areas along the longitudinal and transverse planes (PA_L and PA_T) showed highest R^2 values for both sweet and Irish potato tubers. The models that were based on the projected areas gave consistently high R^2 values for all the classifications of the mass and volume models and this could therefore, be recommended as the best models to be adopted for the prediction of the mass and volume of these crops. The models based on the projected areas had higher R^2 in most of the cases. Subbarao and Vivek (2017) also reported that estimation of the mass of persimmon fruit based on projected area along the longitudinal orientation gave the best performance in terms of highest R^2.

The third classification was considered only for predicting the mass of the tuber crops on the basis of the volume because the results were the same for the prediction of volume based on mass. The mass models based on the volume are the most consistent for all the tuber crops. The results showed that the mass of each of the tubers is directly proportional to the respective volume. The mass models on the basis of volume and that of volume models on the basis of mass are the most acceptable in all cases since their R^2 values were in excess of 0.951 for both sweet and Irish potatoes. Therefore, the mass/volume of the tuber crops can be used to predict accurately its volume/mass. Similar results have been reported for kiwi fruits (Lorestan and Tabatabaeefar, 2006), bergamot fruits (Keramat-Jahromi *et al.*, 2007a) and date fruits (Keramat-Jahromi *et al.*, 2007b).

Information provided in this study will serve as a guide in ensuring accurate sorting and packaging of the crops based on the mass or volume as well as proper design of handling and processing machines for the tuber crops.

CONCLUSION

The following conclusions were drawn from the study:

- The data generated on the physical properties of these tuber crops are of great significance in ensuring accurate packaging of the crops based on the mass or volume, in the design of sorting equipment as well as in the design of processing machines and material handling equipment.
- There existed poor relationships between the individual linear dimensions and mass/volume of all the tuber crops since the coefficients of determination of their regression models were very low.
- The models recommended for predicting the mass and volume of sweet potato tubers based on the projected areas are those on the basis of the projected area along the longitudinal plane (PA_L) and these were of the non-linear form (polynomial of order 2).
- The models recommended for predicting the mass and volume of Irish potato tubers based on the projected areas are those on the basis of the projected area along the longitudinal plane (PA_L) and these were of the power form.
- There were very good and consistent relationships between mass and volume of all the tuber crops with their coefficients of determination, R^2, in excess of 0.951.

From the economical point of view, mass or volume modelling based on a single variable of any of the projected areas was the most convenient modelling for both sweet and Irish potato tubers since it involved the use of a single image capturing device and the whole measurement could be automated.

References

Berberoglu, E., Altuntas, E. and Dulger, E. (2014). Development of Adequate Mathematical Models to Predict the Mass of Potato Varieties From Their Some Physical Attributes. Journal of Agricultural Faculty of Gaziosmanpasa University, 31(3): 1-9.

Ebrahimi, A., Zarei, A., Fatahi, R. and Varnamkhasti, M. G. (2009). Study on Some Morphological and Physical Attributes of Walnut Used in Mass Models. Scientia Horticulturae, 121(4): 490-494.

Essential Regression (1997). Essential Regression and Experimental Design- A Free Statistical Software for Microsoft Excel 97/2000/2002/2003 Add-in.

Gürbüz, F., Demir, B., Eski, I., Kuş, Z. A., Yilmaz, K. U., İlikçioğlu, E. and Ercişli, S. (2018). Estimation of the Weights of Almond Nuts Based on Physical Properties through Data Mining. Notulae Botanicae Horti Agrobotanici, 46(2): 579-584.

Keramat-Jahromi, M., Rafiee, S., Mirasheh, R., Jafari, A., Mohtasebi, S. S. and Varnamkhasti, M. G. (2007). Mass and Surface Area Modelling of Bergamot (*Citrus medica*) Fruit with Some Physical Attributes. Agricultural Engineering International: the CIGR E-journal, Manuscript FP 07 029, Volume IX.

Keramat-Jahromi, M., Jafari, A., Rafiee, S., Keyhani, A. R., Mirasheh, R. and Mohtasebi, S.S. (2007). Some Physical properties of Date Fruit (cv. Lasht). Agricultural Engineering International: the CIGR Ejournal, Manuscript FP 07 019, Vol. IX.

Khadivi-Khub, A. and Naderiboldaji, M. (2013). Predicting Models for Mass and Volume of the Sweet Cherry (*Prunus avium* L.) Fruits Based on Some Physical Traits. Canadian Journal of Plant Science, 93: 831-838.

Khanali, M., Varnamkhasti, M. G., Tabatabaeefar, A. and Mobli, H. (2007). Mass and Volume Modelling of Tangerine (*Citrus reticulate*) Fruit with Some Physical Attributes. International Agrophysics, 21: 329-334.

Khoshnam, F., Tabatabaeefar, A., Varnamkhasti, M. G. and Borghei, A. (2007). Mass Modelling of Pomegranate (*Punica granatum* L.) Fruit with Some Physical Characteristics. Scientia Horticulturae, 114(1): 21-26.

Lorestani, A. N. and Ghari, M. (2012). Mass Modelling of Fava Beans (*Vicia faba* L.) with Some Physical Characteristics. Scientia Horticulturae 133(1): 6-9.

Lorestani, A. N. and Tabatabaeefar, A. (2006). Modelling the Mass of Kiwi Fruit by Geometrical Attributes. International Agrophysics, 20: 135-139.

Meisami-asl, E., Rafiee, S., Keyhani, A. and Tabatabaeefar, A. (2009). Some Physical Properties of Apple cv. 'Golab'. Agricultural Engineering International: the CIGR E-journal, Manuscript 1124, Vol. XI.

Microsoft Excel (2007). Microsoft Office Software Package, Microsoft Inc., Washington, USA. https://products.office.microsoft.com/en-us/excel

Mohsenin, N. N. (1986). Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publishers, New York. Pp 20–89.

Naderiboldaji, M., Jannatizadeh, A., Tabatabaeefar, A. and Fatahi, R. (2009). Development of 11 Mass Models for Iranian Apricot Fruits Based on Some Physical Attributes (cv. Shahroud-8 and Gheysi-2). Journal of Agricultural Technology, 4(1): 65-76.

O'Hair, S. K. (1990). Tropical Root and Tuber Crops. Timber Press, Portland. Pp 424-428.

Omid, M., Khojastehnazhand, M. and Tabatabaeefar, A. (2010). Estimating Volume and Mass of Citrus Fruits by Image Processing. Journal of Food Engineering, 100(2): 315-321.

Richard, I. L. (1978). Statistics for Management. Prentice-Hall Inc., Englewoods Cliffs, N. J., USA.

Subbarao, K.V. and Vivek, K. (2017). Models for Predicting the Mass of Persimmon (*Diospyros kaki*) Fruits by Some Physical Properties. International Food Research Journal 24(6): 2353-2359.

Tabatabaeefar, A. (2002). Size and Shape of Potato Tubers. International Agrophysics, 16: 301–305.