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ESTIMATION OF AN APRICOT (P*runus armeniaca*) HALVES SURFACE AREA

IZRAČUNAVANJE POVRŠINE POLUTKI KAJSIJE (*Prunus armeniaca*)

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SUMMARY

The surface area of any biomaterials is necessary data when heat and mass transfer are figure out. Two mathematical models for apricot halves surface area predicting are presented in the paper, based upon fruit dimensions estimation. The length, height and width of 30 apricots and stones samples have been measured. Additionally, the real surface area of 5 control fruit halves and stones were appraisaled too, by the help of narrow adhesive tapes. The first mathematical calculus is done according to assumption that apricot fruit shape is similar to ellipsoid. Therefore, this model has been used for counting an apricot halves surface area. The difference of surface area between predicting ellipsoid model results and real measured surface area values is 2%. When correlation matrix for apricot three dimensions applies, the confirmation of dependency between commodity heights with other two fruit dimensions is reached. That statement has been used for another mathematical model for apricot surface area creation. The advantage of second reorganized ellipsoid model is in simplicity, only one apricot dimension, height is necessary to be measured. An error which occurs when comparing second model results and measured surface area of apricot halves is 4.8%. It has been emphasized that second model is more practical useful, regardless of a larger results dispersion, therefore suitable for further usage.

Key words*: surface area, apricot.*

REZIME

Poznavanje površine biomaterijala je neophodno u svim slučajevima kada se analiziraju transporti toplote i materije između njih i radnog fluida. U radu su prezentovana dva matematička modela za izračunavanje površine polutki kajsije, koji su rađeni na osnovu merenja sve tri dimenzije plodova. Dužina, visina u širina celog ploda i koštice su mereni na 30 uzoraka. Pored toga, uzorak od pet celih kajsija je poslužio za merenje stvarne površine plodova metodom nalepljivanja uzanih papirnih traka. Prvi matematički model je urađen tako što se pošlo od predpostavke da je oblik ploda kajsije ličan elipsoidu. Zbog toga je elipsoidni model prezentovan na definisanje površine polutki kajsije. Razlika u površini polutki kajsija dobijena na osnovu rezultata elipsoidnog modela i stvarno izmerene površine iznosi 2%. Primenjena koleraciona matrica za dimenzije kajsije potvrdila je da postoji zavisnost visine ploda od ostalih dveju veličina dimenzije. Ovo saznanje je iskorišćeno za kreiranje drugog matematičkog modela. Prednost drugog modela je u njegovoj jednostavnosti, samo jedna dimenzija ploda kasije, visina je potrebna da se meri. Greška koja se javlja pri poređenju rezultata računanja drugog modela i stvarno izmerenih vrednosti površina polutki kajsija je u ovom slučaju 4.8%. Zbog toga se zaključuje da je drugi model pogodniji za praktičnu primenu, bez obzira na veće rasipanje poređenih rezultata, te je pogodniji za dalju upotrebu.

Ključne reči*: površina, kajsija.*

INTRODUCTION

The shape is physical property of body, but also an engineering parameter. For instance, in the food and processing industry heat energy is widely used, for cooling, heating or drying. Some quantity of heat energy transports during these processes from medium to objects by convection, conduction, radiation or by their combination (Luther et al. 2004). When analyzing quantity of heat energy which transfers to bio materials during convective drying, the starting point is Newton equation (Bošnjaković, 1976)

$$Q = \alpha A(t - t_n)$$

where: Q – heat transfer (W), A – surface area (m^2), α – heat transfer coefficient (W/m^2K), t- fluid temperature far away from bound surface (^oC), t_n – object surface temperature (^oC).

The calculation of the heat transfer coefficient can be done only for regular geometric body, like flat plate, cylinder and sphere. In every other cases of irregularity, correct evaluation of coefficient α is impossible.

The solution is found in replacing irregular body shape with some regular, like cube, cylinder, sphere, ellipsoid or parallelepiped. On the other hand bio materials usually have shapes which can be described as: oblate, conic, ovate, obovate, truncate and so on (Mohsenin, 1980). Many methods have been employed to estimate the confidence of remodeling irregular body shape into regular. But even in the case of regular shape, coefficient α can be only calculates according to mutual single arrangement and total body surface area. Those two parameters define the temperature and velocity of flowing fluid fields. It can be stated out that the heat transfer coefficient is evaluated when the shape and the surface area of the body are well known or mathematically described.

The similar analyze is in the case of mass transfer from boundary surface (Babic, 2000, Babić et al. 2004, Babić et al. 2002, Babić et al. 2003) during convective drying, starting upon Dalton model. The shape and the surface area are again dominant parameters on quantity of moisture drops out from bio materials.

The estimation of the fruit surface area can be done by the help of several methods (Mohsenin, 1980). It was found that the weight of apples, plums and pears is good indicator of the surface area. Linear, non-linear regression and second degree polynomial are employed for data evaluation and linear regression, gives best prediction equation for apple surface area judgment.

Actually, the first attempts for correct prediction the fruit surface area is covering each commodity, including areas around steam and calyx, by narrow adhesive tape with millimeter square printing network. Later, the tapes were removed from the fruit and the surface was determined by counting. According to literature, the correlation between the surface area and some other physical properties of fruits such as mass, volume or dimensional measure have formed the basic for many prediction models.

Clayton, M. at all (1995) used several methods for apple surface area predictions. The spherical model of commodity, ellipsoid model and Finite Element Method - dimensional model for volume calculation are employed. The inputs are mean transverse and longitudinal diameters of apples and fruit mass measurement. These four methods are in correlation. The real surface area of four apple varieties is measured by sticky tapes. Non-linear and linear regressions are generated for data analyzing. Authors conclude that calculated surface area is more strongly related to commodity mass and volume than to dimensional measures. Non-linear model of equation is more appropriate than linear function for mass and volume. And also, no variety difference according to linear regression model when correlation between surface area and fruit mass is found. Finite Element Model (FEM) is introducing as statistical method. Across the whole fruit size range FEM predicted the surface area of “Red Delicious” (overestimating was 3×10^{-4} m^2), “Granny Smith” (consistently overestimated by 8×10^{-4} m^2), “Royal Gala” and “Braeburn” apple varieties are more accurately predicted for small than for large fruits. The authors conclude that increase in estimations for large “Royal Gala” and “Braeburn” suggest that the shape of varieties changed with commodity size. They also indicate that the sphere, ellipsoid and FEM models are considerably poorer predictor of actual surface area than non-linear regression model, and that fruit volume based on non-linear equation gives best estimation.

The relationship between mean fruit weight and dimensions (surface area) can be used for harvest time prediction (Minchin, et all, 2003). The fruit *Actinidia chinensis* HORT16A was a new yellow fleshed cultivar in New Zeland. Over five seasons the fruits were destructively harvested at various times after blooming, therefore the weight and tree linear measurements of fruit size were obtained. Mathematical function was fitted for estimation the mean fruit weight dependent on height, width and thickness of commodity and also the curve was used for interpolation between two observation times during fruit growing season.

Fruit surface area is an important physical property in physiological, entomological and psychopathological research too. Bovi and Spiering (2002) established several relationships to estimate peach palm Bactris gasipaes surface area. They involve image digitalization of commodities and compare obtained equation with traditional methods output, that’s mean the fruit weight and size. The method based on image digitalization is as twice fast as traditional ones. Curve fitting independent and dependent variable pairs is better with the image method. Authors selected exponential type of function Y= a xb, although the linear model was also adequate. The best correlation (R2= 94.8%) of the fruit surface area (Y) was obtained using the product of fruit length and width (x) in exponential form:

$$Y = 2.077\ x^{1.189}$$

Or as linear correlation (R^2= 94.5%):

$$Y = -6.261+3.961\ x$$

The aim of this study is to develop method for apricot halves surface area estimation. The resemblance of real apricot halves geometric will be approximated by ellipsoid. Ellipsoid model is complementing by measured values of tree fruit axes A, B and C and stone axes values a, b and c.

MATERIAL AND METHOD

An apricot fruits are growing on Faculty of Agriculture nearby property and are cultivated by Department of fruit growing, viticulture and horticulture. The sample of 30 apricot fruits is picked up from pile, as representative commodities of “Novosadska rodna” cultivar. Selected fruits were in good condition, had typical color and shape. The dimensions A – length, B – height and C – width were measured by hand caliper (Fig 1). After that each fruit was halved by hand with knife along the suture. The stones were withdrawn from the flesh. Stone dimensions a – length, b – height and c - width were measured too by the same measurer device. The results are presented in Table 1.

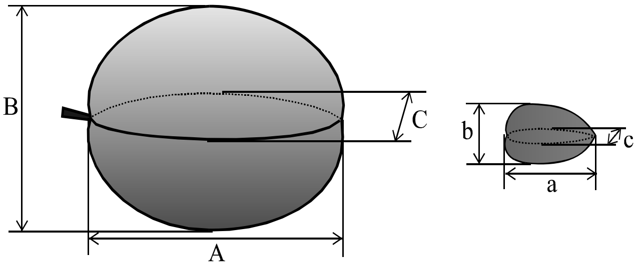

Fig. 1 Three perpendicular dimensions of apricot fruit and stone
Sl. 1 Tri osnovne dimenzije ploda kajsije i koštice

Table 1. Length (A), height (B) and width (C) of apricot fruit cultivar „Novosadska rodna“; length (a), height (b) and width (c) of apricot stone

Tabela 1. Dimenzije ploda kajsije sorta „Novosadska rodna“ dužina (A) visina (B) i širina (C); dimenzije koštice kajsije: dužina (a), visina (b) i širina (c)

FRUIT (*mm*) PLOD (*mm*)			STONE (*mm*) KOŠTICA (*mm*)			FRUIT (*mm*) PLOD (*mm*)			STONE (*mm*) KOŠTICA (*mm*)		
A	B	C	a	b	c	A	B	C	a	b	c
48.1	49.0	44.0	35.0	25.6	10.0	49.3	48.0	40.0	34.7	24.8	10.7
48.0	48.6	44.0	35.2	25.7	10.4	47.6	46.8	40.9	33.0	24.4	10.0
45.7	52.7	45.8	34.0	26.0	10.6	45.7	46.0	40.7	33.0	25.6	9.4
45.7	45.4	42.3	32.2	25.0	12.2	49.1	48.5	39.4	32.7	24.0	10.9
47.3	48.7	42.7	34.1	25.2	9.6	46.0	47.5	40.9	32.4	25.9	11.1
49.6	52.1	43.9	33.6	25.1	10.0	46.4	45.3	38.7	32.8	23.0	10.8
46.0	48.2	40.2	33.5	24.8	10.2	49.8	51.2	43.4	35.3	26.6	10.4
48.5	50.8	42.7	34.8	26.8	10.6	50.0	48.6	40.0	35.6	25.0	10.6
44.6	45.0	40.0	32.5	23.0	9.2	45.7	47.4	41.2	31.5	23.8	9.2
44.4	43.0	39.2	32.3	22.8	9.9	50.2	48.8	42.5	35.0	26.0	10.2
46.3	48.8	43.2	34.1	23.9	9.9	48.1	48.6	43.4	34.8	25.6	9.8
52.0	51.5	43.0	32.8	26.8	10.0	46.8	46.5	44.5	30.7	23.4	10.0
46.9	46.8	38.9	34.5	24.4	9.9	50.8	53.1	44.9	34.6	27.5	10.6
43.3	46	40.8	31.3	24.1	10.0	45.4	48.2	42.4	32.8	25.0	9.7
49.0	47.0	40.0	32.9	23.7	9.6	50.0	51.4	45.0	35.0	25.7	10.0

The mean values (underline values) of all dimensions were calculated as well and are given in Table 2.

Table 2. Mean values of apricot fruit and stone dimensions (mm), cultivar „Novosadska rodna“

Tabela 2. Srednje vrednosti dimenzija (mm), ploda kajsije sorte „Novosadska rodna“

A=47.5	B=48.3	C=42.0	a=33.6	b=25.0	c=10.2

Five apricot halves and their belonging stones were used again for real surface area measurement. Half apricot surface Five apricot halves and their belonging stones were used again for real surface area measurement. Half apricot surface was covered by narrow adhesive tapes with millimeter square printing network. When the tapes were removed from the halves surface, the real data were obtained by counting square millimeters (Table 3).

Table 3. Measured values of apricot halves and stones surface area (cultivar "Novosadska rodna")
Tabela 3 Izmerene vrednosti dimenzija i spoljnih površina polutki kasija i koštica (sorta "Novosadska rodna")

FRUIT HALVES POLOUTKE PLODA (*mm*)			STONE KOŠTICA (*mm*)			SURFACE AREA SPOLJNA POVRŠINA (cm^2)			
A	B	C	a	b	c	SURFACE	STONE	FLAT CROSS SECTION	TOTAL
48.1	48.6	43.4	34.8	25.6	9.8	36.3	7.0	9.5	52.8
46.8	46.5	44.5	30.7	23.4	10.0	35.4	6.2	9.0	50.6
50.8	53.1	44.9	34.6	27.5	10.6	40.5	7.9	10.0	58.4
45.4	48.2	42.4	32.8	25.0	9.7	32.3	6.5	9.7	48.5
50.0	51.4	45.0	35.0	25.7	10.0	39.1	7.2	10.5	56.8

The total area of apricot half is a sum (Table 3) of outside and inside semi-ellipsoid surface area and flat cross section area bounded by the differences of A-a and C-c, the distinctions between fruit and stone length and width. The estimation has been made that inside apricot semi-ellipsoid surface is equal to stone semi-ellipsoid surface area.

RESULTS AND DISCUSSION

The shape of apricot half is irregular. The resemblance of this body is necessary in order to describe it mathematically. An ellipsoid model (Mohsenin, 1980; Clayton, et all 1995) is chosen. The results of surveying three axial dimensions A, B and C, as well as stone dimension a, b and c provides the authors with enough information. The surface area of apricot half P_1 is expressed by equation (Hadžić, 1998):

$$P_1(A,B,C,a,b,c) = \pi/2 \cdot [(ABC)^{2/3} + (abc)^{2/3} + (AB-ab)/2] \qquad (1)$$

The data of three axial dimensions of fruit half and stone obtained on 5 apricot observations (Table 2) are inserted into equation (1). The results are presented in Table 4. The comparison of the row P1- calculated values and P which are the real surface area values of 5 samples, show there are no errors larger then 2%. The disadvantage of this model is the necessity of six values measurement in tree axial. This method is destructive also, because the fruit need to be halved for stone values surveying.

The objective of this study is to carry out the model with satisfactory prediction of apricot surface area, but the number of function's arguments should be as less as possible. The assumption is made that the linear correlation between apricot fruit and stone dimensions exists. The similar idea is presented in Bovi and Spiering (2002) where linear equation describes fruit surface area as a function of product length and width. The equations with independent variable were fruit length or width, fruit weight or cross sectional area had determination coefficient lesser than previous statement.

Table 4. Real apricot half surface area P and the surface based on the first model P_1
Tabela 4. Izmerena spoljna površina polutki P i izračunata površina na osnovu prvog matematičkog modela P_1

SURFACE AREA SPOLJNA POVRŠINA (cm^2)		ERRORS GREŠKA (%)
P	P_1	Error 1
52.8	52.16	–1.212
50.6	50.39	–0.415
58.4	59.46	1.815
48.5	49.17	1.381
56.8	57.17	0.651

The linear regression between fruit and stone dimensions is confirmed by Statistica 7 for Windows (StatSoft, 2006). The correlation matrix is in Table 5, the bold numbers represent significant correlation. The fruit dimension B – height has a strong relationship with

Table 5. Correlation matrix of apricot dimensions
Tabela 5. Korelaciona matrica izmerenih veličina kasije

Correlations

A	B	C	a	b	c	
1.00	**0.67**	0.32	**0.59**	**0.58**	0.15	A
	1.00	**0.72**	**0.56**	**0.78**	0.10	**B**
		1.00	0.30	**0.61**	0.04	C
			1.00	**0.58**	0.11	a
				1.00	0.26	b
					1.00	c

Marked correlations are significant at $p < 0,05$

all other dimensions, except for c – the stone width. When linear correlation of A, C, a, and b dimensions with B – height is established, the new values are labeled as A*, C*, a* and b*.The suitable equations are:

$$A^*(B) = 19,1205+0,5882 \cdot B \qquad (2)$$
$$C^*(B) = 13,1942+0,5952 \cdot B \qquad (3)$$
$$a^*(B) = 18,9414+0,3025 \cdot B \qquad (4)$$
$$b^*(B) = 6,2295+0,3879 \cdot B \qquad (5)$$

The smallest dimension of stone c – width has a lowest relative variance of all other apricot values, therefore it will be of low relevance on apricot half surface area estimation. The dimension c will be assume as constant and will be replace with mean value $\underline{c}$ = 10.2 mm, the mean value of 30 fruit measurements (Table 2).

The graphical view of stone height – b and fruit width –C versus fruit height –B relationship is on Figure 2. The dots are the values of B and C or B and b, matched from measure of 30 apricot pieces (Table 1). The unbroken line on both graphs represent equation [5] and [3] respectively, dashed red lines are the limits of 95% confidence in both cases.

En ellipsoid model of apricot half surface area (equation 1) will be reorganized according to correlation equations [2], [3], [4] and [5]. The independent variables will be replaced with A*(B), C*(B), a*(B) and b*(B), the third stone dimension will be assumed as $\underline{c}$ = 10.2 mm. Therefore, surface area $P_2(B)$ is calculated using software Mathematica for Windows (Wolfram Research, 2003) with independent variable B, as follow:

$$P_2(B) = \pi/2 \, [(63645B^2+9657.95B^3+543.036B^4+13.4026B^5+0.122568B^6)^{1/3} + (1.44854 \times 10^6 + 226664B + 11747.9B^2 + 225.404B^3 + 1.43249B^4)^{1/3} - 58.9977 + 4.94435B + 0.23543B^2] \qquad (6)$$

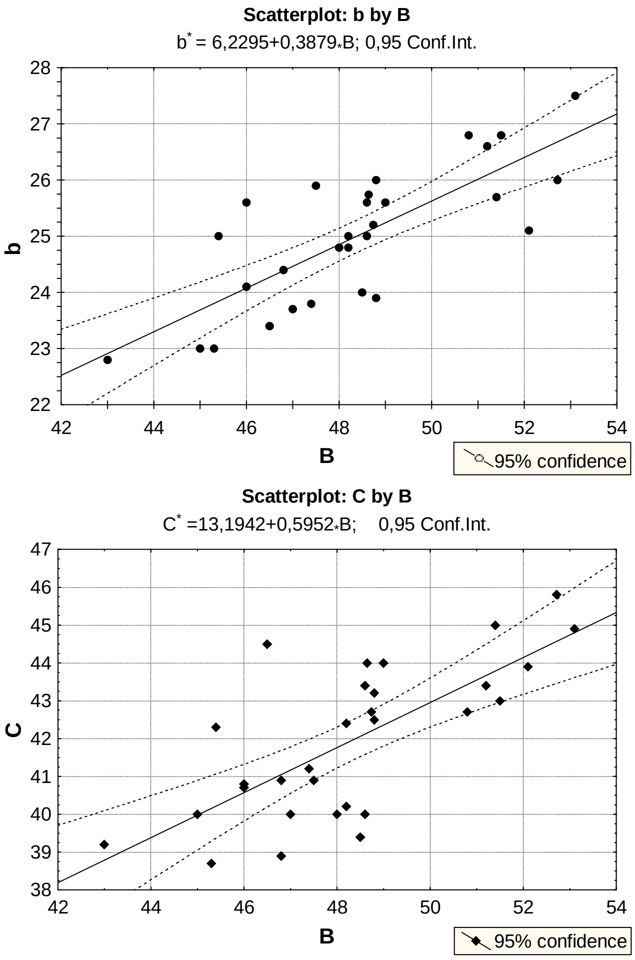

Fig. 2. Linear correlation of stone height b and friut width C from fruit height B

Sl. 2. Linearna korelacija visine koštice b i širine ploda C u zavisnosti od visine ploda B

This second model is easier for everyday application. The apricot surface area can be predicted by only one fruit measurement. That surveying is non destructive and easy to be done.The surface ares for the sample of 5 apricot pieces calculated by second reorganized ellipsoid model – $P_2(B)$ are given in Table 6.

Table 6. Real apricot half surface area P and surface based on the second model P_2

Tabela 6. Izmerena spoljna površina ploda kajsije P i površna izračunata na osnovu drugog matematičkog modela P_2

SURFACE AREA (cm^2)		ERRORS (%)
P	P_2(B)	Error 2
52.8	51.46	−2.538
50.6	48.17	−4.802
58.4	58.84	0.753
48.5	50.82	4.790
56.8	55.99	−1.426

If the the real surface area measurements-P compare with this ellipsoid model surface area prediction, the errors are not larger that 4.8%. It means that the second model has larger dispersion, but the model is good centered on average area value.

CONCLUSION

Two mathematical equations for estimation of apricot halves surface area is presented in this paper. The ellipsoid is adopted as a shape resemble to apricot fruit shape. The first ellipsoid model equation fits the measure apricot halves surface area very well, there are no errors larger than 2%. The destructive method of cutting each commodity is nescessary to be involved, in order to achieve three axis values of fruit and stone. Therefore, the correlation between fruit lenght A and width C, as well as the stone lenght a and height b, from fruit height B are found. The third stone dimension width – c is not in correlation with dimension B, this value will be adopted as a mean value od 50 commodity measurements. The new, rearanged ellipsoid model is assembled, much easier for everyday application in the form:

$$P_2(B) = \pi/2 \; [(63645B^2+9657.95B^3+543.036B^4+13.4026B^5+0.122568B^6)^{1/3} + (1.44854x10^6 + 226664B + 11747.9B^2 + 225.404B^3 + 1.43249B^4)^{1/3} - 58.9977 + 4.94435B + 0.23543B^2] \quad (6)$$

The apricot halves surface area variety „Novosadska rodna" is predicted by measure only one fruit's dimension, the height.

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