

Fruit Mass of *Carica papaya* L. from Cultivars Aliança and THB from the Width and Length of the Fruit

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Abstract

Papaya (*Carica papaya* L.) is a typical plant with a tropical climate, but also grown in subtropical regions. Using mathematical models well-adjusted allows with good precision to estimate characteristics of interest. The objective was to adjust an equation that estimates the fruit mass for each cultivar of papaya, Aliança and THB, using only one measure, length or width. The experiment was conducted in the municipality of Linhares in the state of Espírito Santo, Brazil. Seedlings were planted on the same day, spaced 3.6×1.5 m and in rows side by side. Initially, the equations were modeled, they were linearized and then the covariance analysis was performed in order to verify the possibility of an equation that would serve both cultivars. As the covariance was significant, it was necessary to develop equations for each cultivar. To obtain the growth equations, 350 fruits of cultivar Aliança and 550 of THB were used. The validation was performed with 50 fruits of each. The characteristics evaluated were the largest width (W in mm), the longest fruit length (L, in mm) and the observed mass (OM in g). The equations that best fit were those of the power model that use width (W) as an independent variable.

Keywords

Non-Destructive Method, Regression, Validation, Mathematical Equations, Growth, Modeling

1. Introduction

Papaya (*Carica papaya* L.) belongs to the Caricaceae family and is a large and

perennial herbaceous plant [1]. Typical of tropical climate, but also cultivated in the Mediterranean region, like Spain [2], for example. According to [3], papaya fruits are excellent sources of calcium, pro-vitamin A and vitamin C (ascorbic acid). [4] and [5] affirm that the concentration of vitamin C varies between cultivars and fruit ripening stages.

In 2018, an average of 38.91 tons of papaya per hectare were harvested in Brazil, in an area of 27,250 hectares, totaling 1,060,392 tons [6]. In 2019, Brazil exported 44,238.067 tons of papaya, with the three largest buyers being Portugal, Spain and Germany [7]. The production of this fruit in the country has great economic, social and nutritional importance. Crops are constantly renewed, with a cultivation cycle of about 18 to 24 months [8]. Therefore, it requires and employs a large amount of labor, generating many direct and indirect jobs.

Currently in Brazil, there are 58 papaya cultivars registered with the Ministério da Agricultura, Pecuária e Abastecimento [9]. The cultivars Aliança and THB are both registered, part of the “Solo” group. In this group, “Solo”, most cultivars belong, which have pyriform fruits, of small size and weight ranging from approximately 300 to 650 g [10].

The fruit growth curve can point to the most critical phase in its development and thus highlight the period of greatest demand for nutrients [11] and still allow an estimate of production [12].

In their study using the equatorial diameter of the blueberry fruit (*Vaccinium* spp.), using a power-type equation, [13] estimated its mass, [14] estimated an equation that, based on the diameters of the babassu fruit, can estimate its volume. [15] adjusted a quadratic equation that estimates the mass of pear (*Pyrus communis* L.) using the diameter of the fruit.

There are also some studies of papaya fruit growth. [16] related the diameter, the length of papaya fruits and the growth rate with degrees accumulated days. [17] related the papaya growth to the number of days required until harvest. And yet [18] they adjusted the quadratic equation for the growth of mountain papaya (*Vasconcellea cundinamaricensis* B.), which is a species that also belongs to the family Caricaceae.

No studies were found in the literature on papaya fruit growth in which they related the length and/or width of the fruit to its mass. The objective of this work was to adjust an equation that estimates the fruit mass for each papaya cultivar Aliança and THB, which uses only one measure, length or width.

2. Material and Methods

The experiment was carried out at Fazenda Santa Terezinha of the company Caliman Agrícola SA, located in the municipality of Linhares, Northern Espírito Santo State, Brazil, with latitude 19° 11' 49" S, longitude 40° 04' 20" W and altitude of 33 m. The region's climate is of the tropical Aw type by the Köppen classification, with rain in the summer and drought in the winter [19].

For the preparation of the experimental area, plowing, harrowing and the ne-

cessary correction indicated by the soil analysis were carried out. The seedlings were produced with Bioplant[®] substrate in tubes of 50 cm³ of polyethylene in the seedling nursery of the farm itself. The planting of the seedlings of both cultivars was carried out on the same day, in July 2018, at a spacing of 3.6 × 1.5 m. They were allocated in lines side by side, thus guaranteeing maximum equality in environmental and management conditions. Drip irrigation was performed. Fertilization, fertigation and management against pests and diseases were in accordance with the company's cultural treatment.

During planting, three papaya seedlings were allocated per pit, remaining until flowering, at approximately 90 days, when sexing was carried out, trying to leave only one hermaphrodite plant in each pit, these produce fruits with a peripheral shape, which is what is required by the market.

400 fruits of cultivar Aliança and 600 of THB were collected from various stages of development, harvested at 8 and 16 months after planting. To model the equations, 350 and 550 fruits of "Aliança" and "THB" were used respectively.

The mathematical models tested for obtaining the growth curve were linear first degree (Equation (1)), potential (Equation (2)) and exponential (Equation (3)). The potential and exponential equations were linearized in the parameters to then perform the covariance analysis in order to verify the possibility or not of adjusting an equation that would suit both cultivars; verifying the length and also the width of the transformed fruit of the logarithm between cultivars, where the tested hypotheses were $H_0: \beta_0 = 0$ versus $H_a: \beta_0 \neq 0$ and $H_0: \beta_1 = 0$ versus $H_a: \beta_1 \neq 0$. The model was not used quadratic due to the impossibility to linearize it, which is a necessary step in the analysis of covariance.

$$OM = \hat{\beta}_0 + \hat{\beta}_1 X \quad (1)$$

$$OM = \hat{\beta}_0 X^{\hat{\beta}_1} \quad (2)$$

$$OM = \hat{\beta}_0 e^{\hat{\beta}_1 X} \quad (3)$$

where OM is the observed mass (dependent variable) as a function of X (independent variable) which is the largest width (W) and the length (L). Six equations were obtained, two from each model for each cultivar, using the least squares method, and their respective coefficients of determination (R^2).

The validation of the equations was performed with 50 fruits of each cultivar. The characteristics evaluated were the largest width (W) and the largest length of the fruit (L), measured with a digital caliper in millimeters and the observed mass (OM), obtained with an analytical digital scale in grams. In the validation, the values of length (L) and width (W) were replaced in each equation obtained in the modeling, thus obtaining the estimated mass (EM) in grams. Each equation was adjusted in simple linear regression and Student's t test was performed at 5% probability to verify the coefficients, the hypotheses were: $H_0: \beta_0 = 0$ with $H_a: \beta_0 \neq 0$ and $H_0: \beta_1 = 1$ with $H_a: \beta_1 \neq 1$. The mean absolute error (MAE) (Equa-

tion (4)), the root mean square error (*RMSE*) (Equation (5)) and the Willmott *d* index [20] (Equation (6)) were also determined.

$$MAE = \frac{\sum_{i=1}^n |EM - OM|}{n} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (EM - OM)^2}{n}} \quad (5)$$

$$d = 1 - \left[\frac{\sum_{i=1}^n (EM - OM)^2}{\sum_{i=1}^n (|EM - \overline{OM}| + |OM - \overline{OM}|)^2} \right] \quad (6)$$

The criteria for defining the best equation were: linear coefficient ($\hat{\beta}_0$) not different from zero; slope ($\hat{\beta}_1$) not different from one; *MAE* and *RMSE* closer to zero; determination coefficient (R^2) and Willmott *d* index [20] closest to one.

Descriptive statistics of the fruits were also performed. The making of graphs and statistical analyzes were performed using the R software [21] using the *Expdes.pt* package version 1.2 [22].

3. Results and Discussion

In **Table 1**, it can be seen that papaya fruits of various sizes were used to model the equations. The coefficient of variation (CV), which is a measure of variability, is considered very high for all measures (width, mass and length) in both cultivars according to the classification by [23] and [24] respectively. In studies of growth modeling, it is necessary to use elements of all sizes, so that it represents growth in the most realistic way possible, thus obtaining more accurate equations. This can be seen by a very high coefficient of variation.

The adjusted equations in the modeling are shown in **Table 2**. It can be seen that for the same type of equation, those that use the width of the fruit (*W*) as an independent variable have a higher coefficient of determination (R^2) compared to those that use the length (*L*). Given this fact, it can be seen that the width of the papaya fruit has a greater relationship with the mass. [15] in their study with pear state that the best adjustment in relation to the width may be associated with the piriform characteristic of the fruits, where there is a greater accumulation of mass in the medial-basal region, favoring the relationship between these characteristics. In other growth studies, the equations that best fit with the mass were also those that used the width of the fruit [13] [15]. The analysis of covariance was significant for the linear and angular coefficients ($p < 0.05$), showing that the two cultivars show different growth and, therefore, there was a need to adjust equations for each cultivar separately.

The equation must be chosen not only by the high coefficient of determination (R^2), but by several criteria as well as performed by [25] and [15]. The criteria for the validation of the equations are presented in **Table 3**. For the two cultivars, the model that met all adjustment norms was the potential that uses fruit

width (W) as an independent variable. [18] in their study with mountain papaya (*Vasconcellea cundinamarcensis* B.), which is a species of the same family as the papaya, adjusted the quadratic equation for fruit growth.

Table 1. Descriptive statistics of length (L , in mm) and width (W , in mm), and mass in grams (M , in g) of the fruits of *Carica papaya* L. from cultivars Aliança and THB used in modeling the equations.

Cultivar Aliança			
	Length (L)	Width (W)	Mass (M)
Mínimum	16.72	10.53	1.72
Máximo	174.03	103.77	826.25
Mean	104.29	59.60	247.94
CV (%)	34.80	38.38	82.09
Cultivar THB			
Mínimum	12.61	10.11	1.31
Máximo	164.67	94.46	687.93
Mean	94.03	54.96	182.90
CV (%)	38.24	42.55	84.70

Table 2. Linear, potential and exponential equations adjusted from the observed mass (OM , in grams) of fruits of *Carica papaya* L. from cultivars Aliança and THB as a function of the length (L , in mm) and width (W , in mm) of the fruit and their respective coefficients of determination (R^2).

Cultivar Aliança		
Model	Equation	R^2
Linear	$EM = -277.043 + 5.034L$	0.8059
Linear	$EM = -247.501 + 8.312W$	0.8728
Potential	$EM = 0.0001L^{3.0227}$	0.9166
Potential	$EM = 0.0011W^{2.9355}$	0.9723
Exponential	$EM = 16.6892 * e^{0.0232L}$	0.8857
Exponential	$EM = 16.4480 * e^{0.0400W}$	0.9580
Cultivar THB		
Linear	$EM = -182.82 + 3.89L$	0.8149
Linear	$EM = -160.374 + 6.246W$	0.8888
Potential	$EM = 0.0003L^{2.8789}$	0.9101
Potential	$EM = 0.0018W^{2.7927}$	0.9771
Exponential	$EM = 13.6456 * e^{0.0244L}$	0.8790
Exponential	$EM = 12.9924 * e^{0.0413W}$	0.9662

Table 3. Linear coefficient ($\hat{\beta}_0$), slope ($\hat{\beta}_1$) of the simple linear model equations of validation and determination coefficient (R^2), adjusted between the estimated mass (EM) by the length (L) and the width (W) as a function of the observed mass (OM) and also the mean absolute error (MAE), root mean square error ($RMSE$) and Willmott's d index obtained individually for the fruit mass of *Carica papaya* L. from Aliança cultivars and THB.

Cultivar Aliança							
Model	Variable	$\hat{\beta}_0^{(1)}$	$\hat{\beta}_1^{(2)}$	R^2	MAE	$RMSE$	d
Linear	L	-38.1800*	1.3500*	0.8447	66.39417	73.23896	0.9206919
Linear	W	-53.9560*	1.3940*	0.8766	67.95106	73.61276	0.9221594
Potential	L	6.2076*	0.6724*	0.9704	21.02387	42.71063	0.9443800
Potential	W	-0.0266^{ns}	0.9878^{ns}	0.9960	4.82407	6.88070	0.9989603
Exponential	L	42.1110*	0.8340*	0.9705	34.86750	37.32508	0.9650740
Exponential	W	30.8967*	0.8386*	0.9969	24.15321	25.41689	0.9835546
Cultivar THB							
Linear	L	102.7876*	0.6552*	0.8013	64.71077	70.77960	0.9118268
Linear	W	67.1740*	0.7273*	0.8991	45.10899	51.24379	0.9555987
Potential	L	49.2393*	0.9623 ^{ns}	0.9355	44.78347	54.38947	0.9624298
Potential	W	-0.3768^{ns}	0.9809^{ns}	0.9875	11.94517	16.30100	0.9965178
Exponential	L	48.2852*	0.8654*	0.9459	30.59454	38.86922	0.9781387
Exponential	W	1.2837 ^{ns}	0.9439*	0.9812	18.71388	22.89691	0.9928871

(1) ns: the linear coefficient does not differ from zero by the Student's t test, at the level of 5%; * linear coefficient differs from zero by the Student t test, at the level of 5%; (2) ns: the slope does not differ from one, by Student's t test, at the level of 5%; * angular coefficient differs from one, by Student's t test, at the level of 5%.

An equation that can accurately estimate the mass of a fruit using only one measure, in this case, the width, and yet without detaching it from the parent plant, is a good tool in growth and physiological monitoring studies, as evaluations require methods non-destructive. The producer can also use these equations to estimate the mass of fruits and still obtain an approximation of production. The use of potential equations is much simpler and faster to solve compared to non-linear models, especially if the researcher or the producer is in the field with only the smartphone in hand.

It is possible to estimate the growth of the fruit using these equations. They still have an advantage in relation to the use of equations that need to use degree days, since they use only a linear measure of the fruit. The equations that require degrees days require planning to be used, since one must know how many degrees have been accumulated since the opening of the flowers or withering of the petals until the moment, so that only this can estimate the growth of the fruit.

In **Figure 1** are the equations indicated to estimate the mass of papaya fruits of cultivars Aliança and THB, where W is the largest width of the fruit measured

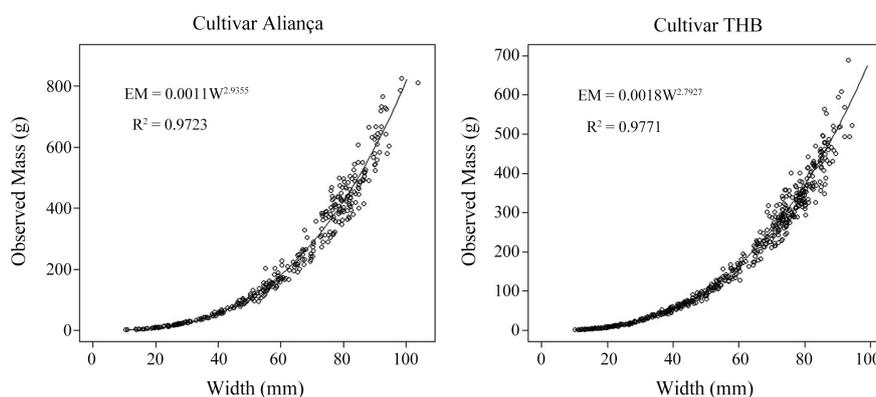


Figure 1. Power equations adjusted to obtain the estimated mass (EM) of the cultivars Aliança and THB of *Carica papaya* L. from the largest width (W) of the fruit and their respective coefficients of determination (R^2).

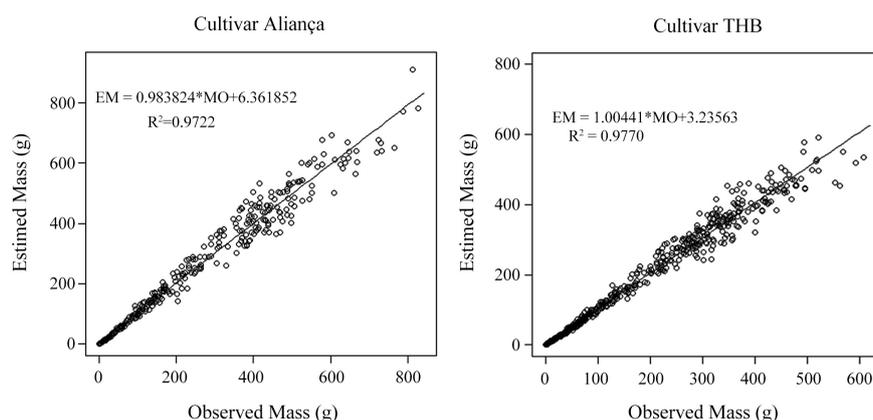


Figure 2. Estimated mass (EM) as a function of observed mass (OM) in papaya fruits (*Carica papaya* L.) THB and Aliança.

in millimeters. It is worth mentioning that when using regression models for estimates, the values should not extrapolate from those used in the construction of the regression equation [26].

In **Figure 2**, the relationship between the observed mass (OM) and the estimated mass (EM) was very close, with a very high determination coefficient (R^2) in both cultivars.

4. Conclusions

It was possible to estimate the mass of the fruits of *Carica papaya* L. from cultivar Aliança and THB.

To estimate the mass of the fruit of *Carica papaya* L. from the Aliança cultivar, the equation $EM = 0.0011W^{2.9355}$ is indicated and for THB $EM = 0.0018W^{2.7927}$, where W represents the largest width of the fruit in mm.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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