

## Modeling Fruit Growth of ‘Triunfo’ Pear Grown in North Espírito Santo State

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### Abstract

The objective of this study was to obtain mathematical models to estimate non-destructively the fruit mass of pear cv. ‘Triunfo’. To this end, 128 fruits from all developmental stages collected at three different times were used. Fruits were measured for maximum length (L), maximum width (W) and observed mass (OM). For the adjustment, with a sample of 100 fruits, the models first degree linear, quadratic and power were tested, in which the OM was used as the dependent variable in function of L and W. From a sample of 28 fruits, separated for this purpose the equations were validated. Thus, it indicates an equation of the quadratic model represented by  $EM = 36.020218 - 3.067232(W) + 0.082568(W)^2$  using from the measurement of the largest fruit width (W), as the most accurate to estimate the fruit mass of pear cv. ‘Triunfo’.

**Keywords:** *Pyrus communis* L., non-destructive method, mathematical equations

### 1. Introduction

Belonging to the Rosaceae family, the pear (*Pyrus communis* L.) is the third most consumed temperate fruit in Brazil, with a production of 22,108 tonnes in 2017, with standing out the states of Rio Grande do Sul (12,839 t), Santa Catarina (7,334 t), Paraná (1,341 t), São Paulo (300 t) and Minas Gerais (294 t) (IBGE, 2018). However, Brazil is unable to meet all the demand for supplying the national market, making it necessary to import a large part of the fruits consumed in the country (Oliveira et al., 2015). In part, the insufficient Brazilian production is linked to the lack of studies that seek to adapt new cultivars to regions with productive potential (Fachinello et al., 2011).

The pear tree is a plant of the temperate climate, which requires temperatures of 7.2 °C or less for a good vegetative and reproductive development (Oliveira et al., 2015). There are cultivars that require a high amount of cold hours (700 to 1200 h) and there are those with less accumulated cold hours (less than 500 h), which are more interesting for Brazilian producers (Nakasu & Faoro, 2003).

Among the cultivars with little demand for accumulated cold hours, we can highlight the cv. ‘Triunfo’ which presents large fruits, with an oblong shape, thick film, green color, and peel scores, the pulp is firm, granulated, with an acidic sweet flavor and of regular quality (Nakasu et al., 2007). This cultivar has been shown to have great potential for the tropical and subtropical regions of Brazil (Bettiol Neto et al., 2014; Oliveira et al., 2015). However, there are few studies that prove its productive effectiveness (Bettiol Neto et al., 2014).

In relation to the knowledge of the fruit growth patterns, this practice facilitates the decision making of the cultural treatments, allowing the adoption of appropriate techniques in the management, harvesting and post-harvesting of the fruits, in addition to indicating maturation and quality (Muianga et al., 2016).

In this context, modeling to estimate fruit growth has been shown to be an important tool in helping researchers and producers. This method relates characteristics such as width, length, diameter and/or height as the fruit mass allowing, through simple equations, to estimate the fruit mass without the need for its destruction (Jorquera-Fontena et al., 2017).

Thus, the aim of this study was to obtain, test and calibrate mathematical models to estimate non-destructively the mass of pear fruits cultivar ‘Triunfo’ from their length and width.

## 2. Method

The present work was carried out with pear fruits cv. ‘Triunfo’, collected from Boa Vista farm, in the municipality of Montanha, North of the State of Espírito Santo, Brazil, located with the geographical coordinates of 18°07’48” South Latitude and 40°13’08” East Longitude. The region’s climate according to the Köppen classification is Tropical Aw, with dry winter and summer rain (Alvares et al., 2014).

The orchard is made up of 300 trees, planted in September 2014. For irrigation, a system located by microjet was used with a flow rate of 20 L/h, and a watering shift of 1 h per day. Fertilization was done with organic fertilizer Minho Fértil®.

128 fruits were collected from all stages of development (Figure 1) in three different seasons: September 2018; January 2019 and March 2019. The fruits were packaged and transported to the laboratory where they were measured at maximum length (L) and maximum width (W) (Figure 2), as a digital caliper (Fowler®), in millimeters. The observed mass (OM, in g) of each fruit was also obtained with an electronic precision scale (MARTE®).



Figure 1. Different stages of development of pear fruits of cv. ‘Triunfo’ used for modeling

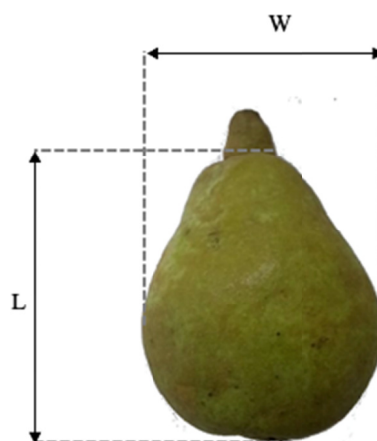


Figure 2. Representation of the length (L) and width (W) measures of pear fruits of cv. ‘Triunfo’

To estimate the equations, 100 fruits were used and the first degree linear model represented by  $EM = \hat{\beta}_0 + \hat{\beta}_1 x$ , quadratic represented by  $EM = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2$  and power represented by  $EM = \hat{\beta}_0 x^{\hat{\beta}_1}$ , was tested, in which OM was used as a dependent variable in function of L and W as an independent variable. Six models of equations were obtained to estimate the mass of pear cv. ‘Triunfo’ and its respective coefficients of determination ( $R^2$ ).

The validation was done based on 28 fruits, where the values of L and W were replaced in the proposed equations for modeling, thus obtaining the estimated mass (EM, in g). A simple linear regression model ( $EM = \hat{\beta}_0 + \hat{\beta}_1 x$ ) was fitted for each model, where EM was the dependent variable as a function of OM as an independent variable. For each of the simple regression adjustments, the hypotheses  $H_0: \hat{\beta}_0 = 0$  versus  $H_a: \hat{\beta}_0 \neq 0$  and  $H_0: \hat{\beta}_1 = 1$  versus  $H_a: \hat{\beta}_1 \neq 1$  were tested, using the Student's t test at 5% probability. Also determined for all equations the mean absolute error (MAE), by the expression:  $MAE = \frac{\sum_{i=1}^n |EM - OM|}{n}$ , the root of the root mean square error (RMSE) by the expression:  $RMSE = \sqrt{\frac{\sum_{i=1}^n (EM - OM)^2}{n}}$  and the Willmott index (d) (Willmott, 1981) by the expression:  $d = 1 - \left[ \frac{\sum_{i=1}^n (EM - \overline{OM})^2}{\sum_{i=1}^n (|EM - \overline{OM}| + |\overline{OM} - \overline{OM}|)^2} \right]$ . Where, EM are the estimated mass values; OM are the values of the observed mass;  $\overline{OM}$  is the average of the observed mass values; n is the number of fruits used in the validation (n = 28).

The best equation was defined by the following criteria: linear coefficient ( $\hat{\beta}_0$ ) not different from zero; slope ( $\hat{\beta}_1$ ) not different from one; MAE and RMSE closer to zero, and Willmott's d index (Willmott, 1981) closer to one. Statistical analyzes were performed with the aid of the R software (R Core Team, 2018), using the data package ExpDes.pt version 1.2 (Ferreira et al., 2018).

### 3. Results and Discussion

The equations resulting from the measures of the length and width of the fruits are shown in Table 1. The width, in general, presented a greater relationship with the mass of the fruits in all the models studied. 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. However, the quadratic and power model equations showed coefficient of variation values above 0.90, which according to Rojas-Lara et al. (2008) is indicative of a good correlation between the variables under study.

Table 1. First degree linear model equations, quadratic and power adjusted using the observed mass (OM) in function of length (L) and width (W) and coefficient of determination ( $R^2$ ), to estimate the mass of pear fruits cv. 'Triunfo'

Model	Equation	$R^2$
Linear	$EM = -95.0410 + 2.8363 (L)$	0.8101
Linear	$EM = -101.1943 + 4.0731(W)$	0.8538
Quadratic	$EM = 21.843750 - 1.560683 (L) + 0.036666(L)^2$	0.8840
Quadratic	$EM = 36.020218 - 3.067232(W) + 0.082568(W)^2$	0.9474
Power	$EM = 0.0013(L)^{2.6342}$	0.8780
Power	$EM = 0.0013(W)^{2.8365}$	0.9472

Based on the validation criteria (Table 2), only the quadratic model and the power model, obtained from the largest fruit width, had results not different from zero and not different from one by the Student's t test ( $p < 0.05$ ) for the linear coefficients ( $\hat{\beta}_0$ ) and slope ( $\hat{\beta}_1$ ) respectively (Table 2). The non-significance of these parameters is an excellent indicator of the accuracy of these equations, since when the observed mass is zero, the mass estimated by the model will also be zero and as there is a gradual increase in the observed mass, the estimated mass will follow the same behavior. However, the quadratic model equation presented mean absolute error (MAE) and root mean square error (RMSE) values closer to zero and d index value closer to one, in addition, this equation had a value of determination coefficient ( $R^2$ ) slightly higher than the power model equation, being the same equation with higher values of  $R^2$  in the modeling adjustment, thus, this model was the one that best met the statistical criteria established in this study.

Table 2. Linear coefficient ( $\hat{\beta}_0$ ), slope ( $\hat{\beta}_1$ ) of simple linear model equations and coefficient of determination ( $R^2$ ), adjusted between the estimated mass (EM) by the length (L) and the width (W) in function of the observed mass (OM), in addition to the mean absolute error (MAE), root mean square error (RMSE) and Willmott's d index obtained individually to estimate the mass of pear fruits cv. 'Triunfo'

Model	Variable	$\hat{\beta}_0$	$\hat{\beta}_1$	$R^2$	MAE	RMSE	d
Linear	L	19.8071*	0.6653*	0.8807	17.6950	20.8103	0.9333
Linear	W	-1.6253*	0.8404*	0.8960	14.5610	16.5895	0.9471
Quadratic	L	13.8863*	0.8007*	0.8621	12.9459	15.9064	0.9513
Quadratic	W	-2.3632 <sup>ns</sup>	1.0053 <sup>ns</sup>	0.9534	5.4531	7.5983	0.9868
Power	L	11.7411*	0.8017*	0.8668	11.3522	14.9284	0.9569
Power	W	-5.2825 <sup>ns</sup>	1.0745 <sup>ns</sup>	0.9530	5.8751	7.8649	0.9849

Note. <sup>(1)</sup> <sup>ns</sup> Value of  $\hat{\beta}_0$  does not differ from zero by Student's t-test, at a level of 5%; <sup>(1)</sup> \* Value of  $\hat{\beta}_0$  differs from zero by Student's t-test, at a level of 5%; <sup>(2)</sup> <sup>ns</sup> Value of  $\hat{\beta}_1$  does not differ from one, by Student's t-test, at a level of 5%; <sup>(2)</sup> \* Value of  $\hat{\beta}_1$  differs from one, by Student's t-test, at a level of 5%.

In several countries, characteristics such as pulp firmness, soluble solids, color and amount of starch are used as parameters to determine the ripeness of pear fruit, however, in places with moderate winter, no parameters are found to indicate the maturation of these fruits, considering the days between flowering and the characteristic harvest, which can be variable according to climatic conditions (Bettiol Neto et al., 2014).

As it is a fruit that does not reach the stage of ripening outside the plant, the pear needs new technology to assist the producer, since there are great losses of this fruit in the post-harvest. In this way, mathematical modeling of the pattern of fruit growth can facilitate crop management. This type of model has the function of helping in decision-making in relation to crop treatment, especially in the harvest, estimating exactly the fruit growth habit (Cunha & Volpe, 2011).

Thus, we indicate the quadratic model equation represented by  $EM = 36.020218 - 3.067232(W) + 0.082568(W)^2$  (Figure 3) obtained from the largest width (W) measure of the fruits as the most accurate to estimate the mass of pear fruits cv. 'Triunfo'. It should be noted that this model should be used in edaphoclimatic situations similar to those mentioned in this study. Always respecting the limits of the values used for the adjustment (Levini et al., 2017). Another important fact to be taken into account is that the fruits developed from the process of parthenocarp, thus, the seeds are absent from these fruits and may directly influence its shape. If the researcher or producer wishes to use these equations in other types of conditions, different from those of this study, these equations must be calibrated again using appropriate statistical criteria, in order not to generate an imprecise estimate of the fruit mass.

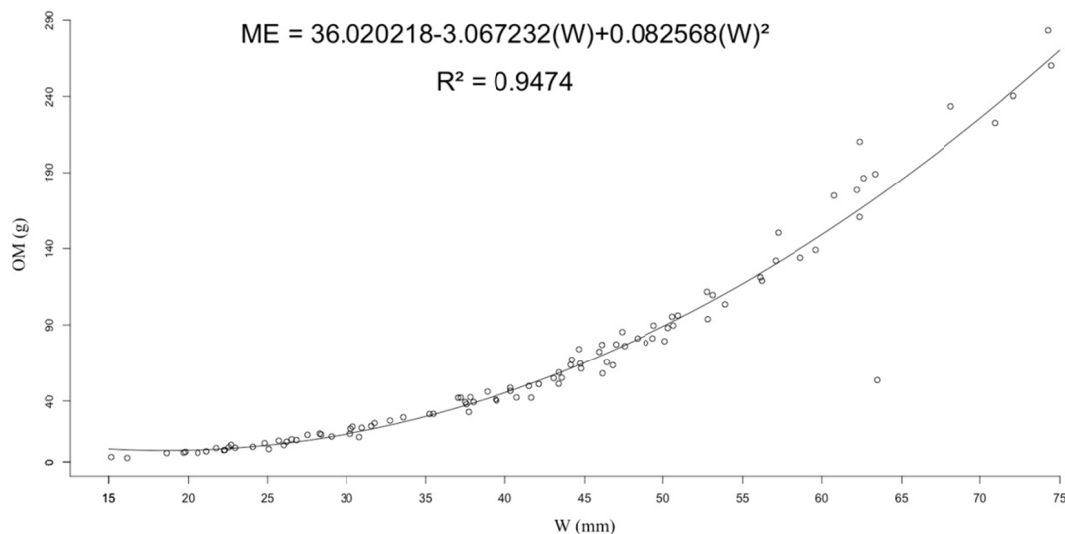


Figure 3. Quadratic model equations adjusted using the observed mass (OM) in function of the largest width (W) and determination coefficient ( $R^2$ ) to estimate the mass of pear fruits of cv. 'Triunfo'

#### 4. Conclusion

The pear fruits of the cultivar ‘Triunfo’, can have their mass estimated through their greater width (W) by the quadratic model equation represented by  $EM = 36.020218 - 3.067232(W) + 0.082568(W)^2$ , in a simple, precise and non-destructive way.

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