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Modeling the growth of 'Isabel' grape fruits

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Abstract: The modeling of fruit growth is important mainly in physiological and plant growth studies, allowing the monitoring of fruit growth and the follow-up of their development in a non-destructive way. Since no studies were found in the literature to model the growth of 'Isabel' vine fruits, the objective of this work is to adjust a growth curve for the fruits, verifying if the same equation can be applied to two production seasons. year in the north of the state of Espírito Santo. To adjust the growth curves, simple linear, quadratic, cubic, power and exponential models were used, with the weight of the berries as a function of the diameter and length of the berries. The validation of the equations was carried out using the same berries as the estimates of the equations through Pearson's linear correlation, 1ze, Willmott's agreement index and required sample size to estimate the equation. The power model using the diameter as an independent variable is the equation that best explains the weight of the fruit of the 'Isabel' grape.

Keywords: *Vitis labrusca*; Experimental precision; Experimental planning; Data analysis; Statistical analysis; Growth curve.

Adherence to the BJEDIS' scope: This work is in line with the scope of BJEDIS as it presents information related to data analysis and mathematical modeling.

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1. INTRODUCTION

Viticulture was introduced in Brazil by the Portuguese, using fine grapes *Vitis vinifera* grown in Europe and selected according to information obtained through the personal experience of European winegrowers. However, the grape culture only came to be consolidated in Brazilian territory in the 19th century, thanks to Italian immigrants who brought an American grape cultivar known as 'Isabel', of the *Vitis labrusca* species (1).

The 'Isabel' grape is a species originally from the southern United States, from where it was spread to other regions. In the 1850s, it aroused the interest of European winegrowers due to resistance to powdery mildew, a disease that at that time caused enormous damage to world viticulture (2). Therefore, researchers claim that 'Isabel' was the basis for the development of commercial viticulture in the South and Southeast regions of Brazil.

The cultivation of American grapes provided an expansion of Brazilian viticulture, as they are rustic grapes adapted to local soil and climate conditions. This expansion led to a technification of national viticulture, whose priority was to prevent the attack of pests and diseases (3). Currently, vines are cultivated in almost the entire Brazilian territory, with emphasis on the southern region with the production of grapes for processing juices, wines and sparkling wines and, in the warmer regions (northern Paraná, São Paulo, Minas Gerais, Bahia and Pernambuco) the production of fine table grapes (Italy, Ruby, Red Globe).

According to Embrapa (4), 'Isabel' is a very rustic and highly fertile red grape cultivar, providing abundant harvests with few management interventions. It has the characteristic flavor of labruscas, adapting to uses such as table grapes, making white, rosé and red wines, vinegar, sweets, jellies and, especially, for making juices, being the main basis of Brazilian juice for export. According to Incaper (5), the state of Espírito Santo has enormous potential for growing grapes and producing wine, and the expansion of the market makes the activity extremely promising. However, producers still face challenges such as the high cost of setting up the crop and the lack of tradition.

Despite being a rustic cultivar and having been cultivated for a long time in Brazil, most of the planted area is located in southern Brazil where there is only one annual crop. In warmer regions, such as the São Francisco valley and the north of the state of Espírito Santo, two annual crops are produced, working on plant physiology, through pruning and application of growth regulators to induce flowering. Due to the importance of this cultivar, there is a need for more in-depth research regarding the phenotype of the fruits, especially in areas with two annual crops, and the study of growth curves is an important tool that makes it possible to know the different phenological phases, the time of greatest mass gain. of the fruit, the most suitable period for fertilization, pest control and determination of the optimal harvest point (which is usually done subjectively through the external color and size of the fruit) (6).

The growth curve study via allometric models has a great capacity to synthesize the information present in the data set, summarizing them in just a few parameters with practical interpretations. The use of allometric models makes it possible to monitor the growth of fruits and allows monitoring their development in physiological studies without the need to detach them from the mother plant, thus being a non-destructive method (7), providing economy and, if well adjusted, a good precision in the estimation of the characteristic of interest. Modeling from allometric measurements can relate the length, width or the product of both to some characteristic of interest, such as fruit mass (7, 8).

Several authors have studied fruit growth of various crops of economic interest (9, 10, 11, 7, 8). Berilli *et al*. (9) related the diameter, length of papaya fruits and growth rate with accumulated degree days. Fernandes *et al*. (6) compared nonlinear model fits for arabica coffee (*Coffea arabica* L.), relating fresh fruit mass with days after flowering. Muniz *et al*. (10) compared the fit of nonlinear regression models in cocoa (*Theobroma cacao* L.), related fruit length, diameter and volume with its age. Jorquera-Fontena *et al*. (7) obtained an equation that relates the diameter of the blueberry (*Vaccinium* spp.) to its mass. Oliveira *et al*. (8) studied the modeling of the growth curve of 'Triunfo' pear fruits. However, no studies were found in the literature on growth curves using allometric models to estimate the mass of 'Isabel' vine fruits.

Jorquera-Fontena *et al*. (7) in their study using the equatorial diameter of the blueberry fruit (*Vaccinium* spp.), through a power-type equation, estimated its mass. According to the author, monitoring fruit growth is a widely used measure in physiology and agronomy studies. This is typically done with highlighted fruits, which can lead to erroneous results when the fruits grow asynchronously in clusters as in blueberry plants. Thus, estimating fruit weight from equations using fruit diameter measurements can represent a quick and inexpensive alternative for weight assessment.

Santos *et al*. (11) state that an equation that can accurately estimate the mass of a fruit using only a measure such as a width, but without detaching it from the parent plant, is a good tool in studies of growth and physiological monitoring, as the evaluations require non-destructive methods. In addition, it states that the use of potential equations is much simpler and faster to solve compared to non-linear models, especially if the researcher or producer is in the field with only a smartphone in hand.

Bearing in mind that the adoption of adequate statistical criteria is extremely important to explain the natural phenomena that take place according to some model, the objective of this work was to determine the growth curve to estimate the mass of vine fruits. Isabel' using allometric measurements.

2. MATERIALS AND METHOD

The present work was carried out on an experimental crop, installed on the experimental farm of Centro Universitário Norte do Espírito Santo (CEUNES), located in the municipality of São Mateus. The equipment and consumables used for the execution are available at the Plant Improvement Laboratory (PIL) and Viticulture (LV) of CEUNES. The climate in the region, according to the Köppen classification, is AW, with rain in the summer and dry in the winter (12).

The 'Isabel' grape crop (Figure 1) where the two crops were evaluated, was implemented in 2016 in the experimental area, being of productive age. The planting of the experiment was carried out in a 2m x 3m spacing, with automatic irrigation by the micro-sprinkler system. The cultural treatments performed in the experiment were: a fertilization of NPK 20-25-20 one week before pruning, 15 days after pruning and 30 days after pruning. Fruiting pruning carried out in August 2020 and February 2021 in which, after each pruning, applications of dormex® were made for floral induction. Fungicide applications were performed weekly for 90 days after pruning, acaricide applications in the first month after pruning, and insecticide application after pruning. Two potassium sulfate fertilizations occurred 90 days after pruning and one week after the first fertilization. After 90 days of pruning, Bordeaux mixture was applied weekly, until one week before harvest.

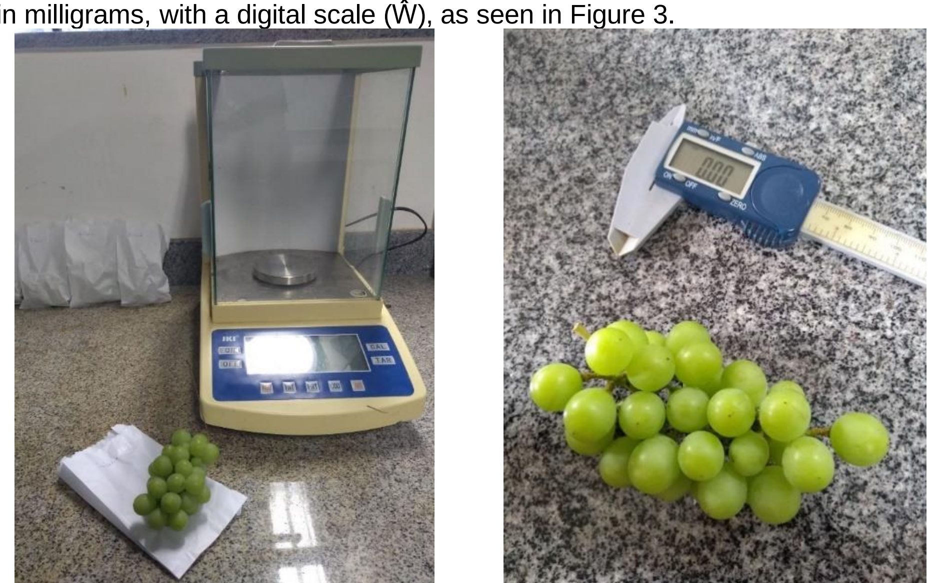
(A) (B)

Figure **1.** 'Isabel' grape plantation located on the CEUNES experimental farm, being plowed during the production season (a) and plowing after pruning and application of Dormex® (b).

The grape bunches were harvested randomly, biweekly, from after anthesis until the fully developed fruits, about four months after pruning, obeying the visual criterion for the change in the color of the berry skin. Five bunches were harvested each time, in each production season, totaling about 30 bunches per production season. The grape bunches were harvested in the field, packed in boxes with bubble wrap and transferred to the LMP/CEUNES where the evaluations were carried out, as shown in Figure 2.

Figure **2**. Box used for packaging and transporting bunches of 'Isabel' grapes.

All berries of all bunches of the two evaluation seasons (summer and winter harvest) were evaluated, and the characteristics evaluated in each berry were: diameter (D) and length (L), measured in mm, with a caliper digital; the observed weight, in milligrams, with a digital scale ($\hat{W}$), as seen in Figure 3.



(A) (B)

Figure **3**. Digital scale (a) and digital caliper (b) used to measure the observed weight, diameter and length of the berries.

For modeling the growth of grape berries (*Vitis labrusca*) 'Isabel', a total of 1885 berries were used. Model equations were fitted: simple linear represented by $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x$; quadratic represented by $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2$; cubic represented by $\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x + \hat{\beta}_2 x^2 + \hat{\beta}_3 x^3$; power represented by $\hat{Y} = \hat{\beta}_0 x^{\hat{\beta}_1}$ and exponential represented by $\hat{Y} = \hat{\beta}_0 e^{\hat{\beta}_1 X}$. For the simple linear model, the observed weight (OW) was used as the dependent variable ($\hat{Y}$) as a function of D, L, D^2 and L^2 as independent variables (x). For the other models, OW was used as a dependent variable ($\hat{Y}$) as a function of D and L as independent variables (x). A total of 12 equations were fitted.

The estimated equations of the different models were validated using the same 1885 berries of the equations estimate, using Pearson's linear correlation (r), the coefficient of determination (R^2) as the square of Pearson's linear correlation (14), the root mean square error (RQME), the Willmott agreement index (d) (15) and the required sample size to estimate the equation (neq) through of the following expressions:

$$r = \frac{\sum_{i=1}^{n}(\hat{W})(OW) - -\frac{(\sum_{i=1}^{n}\hat{W})(\sum_{i=1}^{n}OW)}{n}}{\sqrt{\sum_{i=1}^{n}\frac{(\sum_{i=1}^{n}\hat{W})^2}{n}}\sqrt{\sum_{i=1}^{n}\frac{(\sum_{i=1}^{n}OW)^2}{n}}}$$

$$R^2 = \left\{\frac{\sum_{i=1}^{n}(\hat{W})(OW) - -\frac{(\sum_{i=1}^{n}\hat{W})(\sum_{i=1}^{n}OW)}{n}}{\sqrt{\sum_{i=1}^{n}\frac{(\sum_{i=1}^{n}\hat{W})^2}{n}}\sqrt{\sum_{i=1}^{n}\frac{(\sum_{i=1}^{n}OW)^2}{n}}}\right\}^2$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(\hat{W} - OW)^2}{\sum_{i=1}^{n}(|\hat{W} - \overline{OW}| + |\hat{W} - \overline{OW}|)^2}\right]$$

$$RQME = \sqrt{\frac{\sum_{i=1}^{n}(\hat{W} - OW)^2}{n}}$$

$$n_{eq} = \frac{t_{\alpha/2}^2 RQME^2}{e^2 \overline{OW}^2}$$

Where: $\hat{W}$ is the estimated weight values of the berries; OW are the values of the observed weight of the berries; $\overline{OW}$ is the average of the observed weight values of the berries; n is the number of berrie used in the validation (n=1885); $t_{\alpha/2}$ is the critical value of Student's t distribution, whose area to the right is equal to $\alpha/2$ with (n–1) degrees of freedom, and with a 5% error probability; *e* is the error in the estimate of the mean, assumed to be 5%.

The best equation estimating the weight of grape fruit berries (*Vitis labrusca*) 'Isabel' for the summer and winter seasons was defined by the following selection criteria: r, R^2 and d closest to one; RQME closest to zero; neq<n. Additionally, the selected equation must not present values of $\hat{W}$< 0, which was checked graphically.

Statistical analyzes were performed using the R software version 3.6.1. (16), in RStudio environment version 1.2.1335.

3. RESULTS AND DISCUSSION

Table 1 shows the descriptive statistics for the variables diameter (D), length (L), and observed weight (OW) used to model the growth of 'Isabel' grapes. According to Rizzon *et al*. (2) the berry of the 'Isabel' grape is large, weighing on average 3.0g, 1.67cm long and 1.57cm wide. Thus, it appears that satisfactory values were found for the same variables in the two production seasons.

Table **1.** Minimum, maximum, mean, amplitude, standard deviation (SD) and coefficient of variation (CV) of diameter (D), length (L) and observed weight (OW) of berries of grape fruits (*Vitis labrusca*) 'Isabel' used in fruit growth modeling.

Variable	Unit	Minimum	Maximum	Average	Amplitude	SD	CV%
981 2020/2021 summer crop berries							
D	mm	0.34	18.79	11.30	18.45	6.31	55.83
L	mm	1.01	21.02	12.93	20.01	6.75	52.21
OW	mg	0.5	4380.1	1711.06	4379.6	1285.22	75.11
904 2021 winter crop berries							
D	mm	1.11	18.59	11.78	17.48	5.04	42.77
L	mm	1.44	20.27	13.61	18.83	5.59	41.09
OW	mg	2.6	4209.4	1690.30	4206.8	1097.76	64.94

[1/] D, diameter of the berries, in mm; L, length of berries mm; OW, observed weight, in mg.

The coefficients of variation (CV) found were considered 'very high' for all measures evaluated, in both seasons, according to the criteria of Pimentel-Gomes (16). This is an expected result, since the berries were evaluated soon after anthesis until the fruits were fully developed, following the entire growth process. According to Santos *et al*. (12) it is necessary to use elements of all sizes in growth modeling studies, so that it represents growth as realistically as possible, obtaining more accurate equations, and this can be seen by a very high coefficient of variation.

Adjustments of six equations were performed using the simple linear (SL), quadratic (Q), cubic (C), power (P) and exponential (E) models, using the estimated weight of the berries as a function of their diameter (D) and length (L). For the simple linear model, D^2 and L^2 were also used as independent variables, finally obtaining a total of twelve equations, as shown in figures 4 and 5. It was found that the equations have the same response for the summer season and for the winter season, making it possible to adjust a single equation for both seasons.

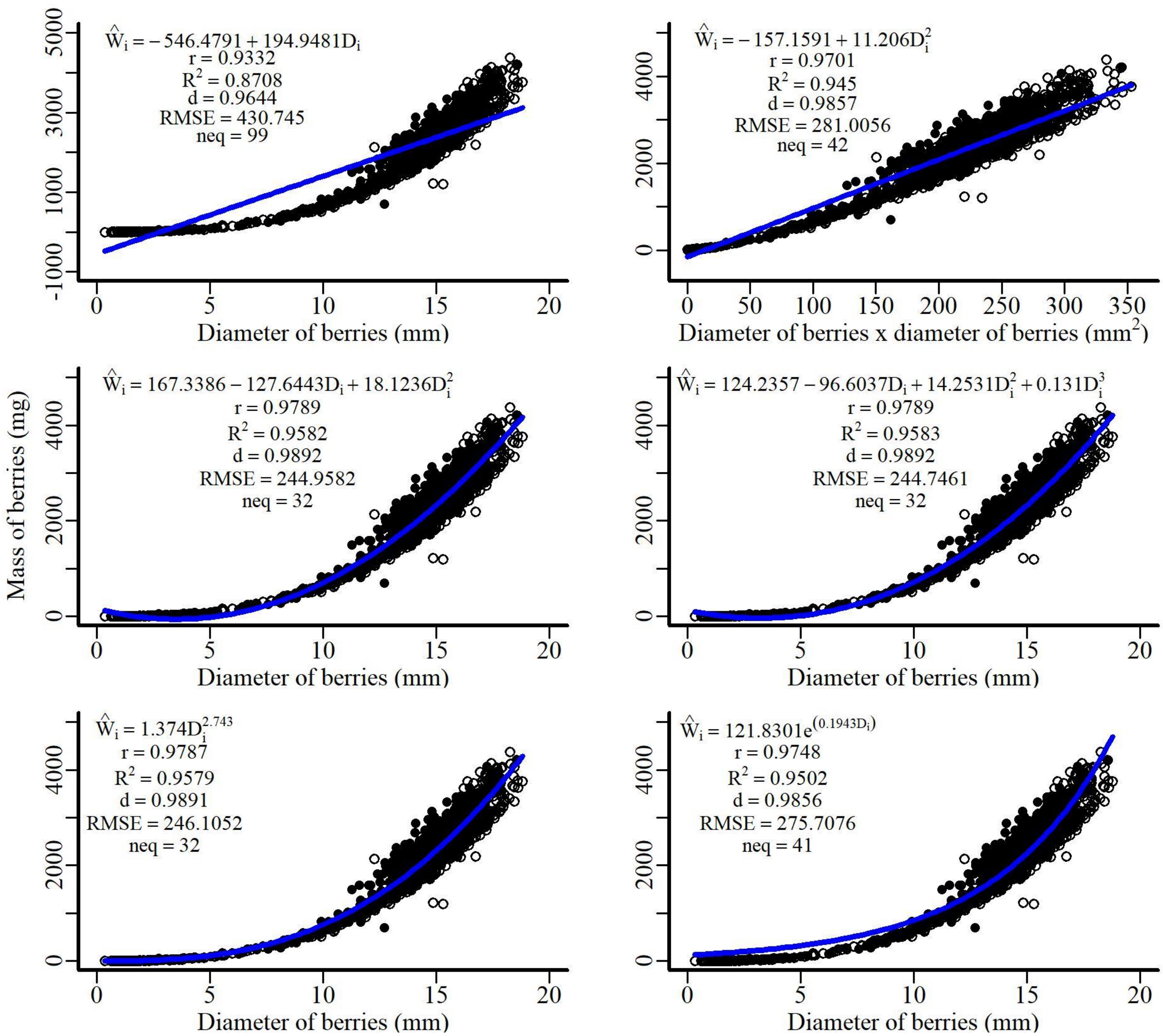


Figure **4**. Equation adjustment (Ŵ) through simple linear (SL), quadratic (Q), cubic (C), power (P) and exponential (E) models with their respective coefficients of determination (R^2) from fruit berries grape (*Vitis labrusca*) 'Isabel', using the weight measurement as a function of the diameter (D) of the berries (Validation criteria: RQME=root mean square error; d=Willmott agreement index; neq=necessary sample size to estimate the equation).

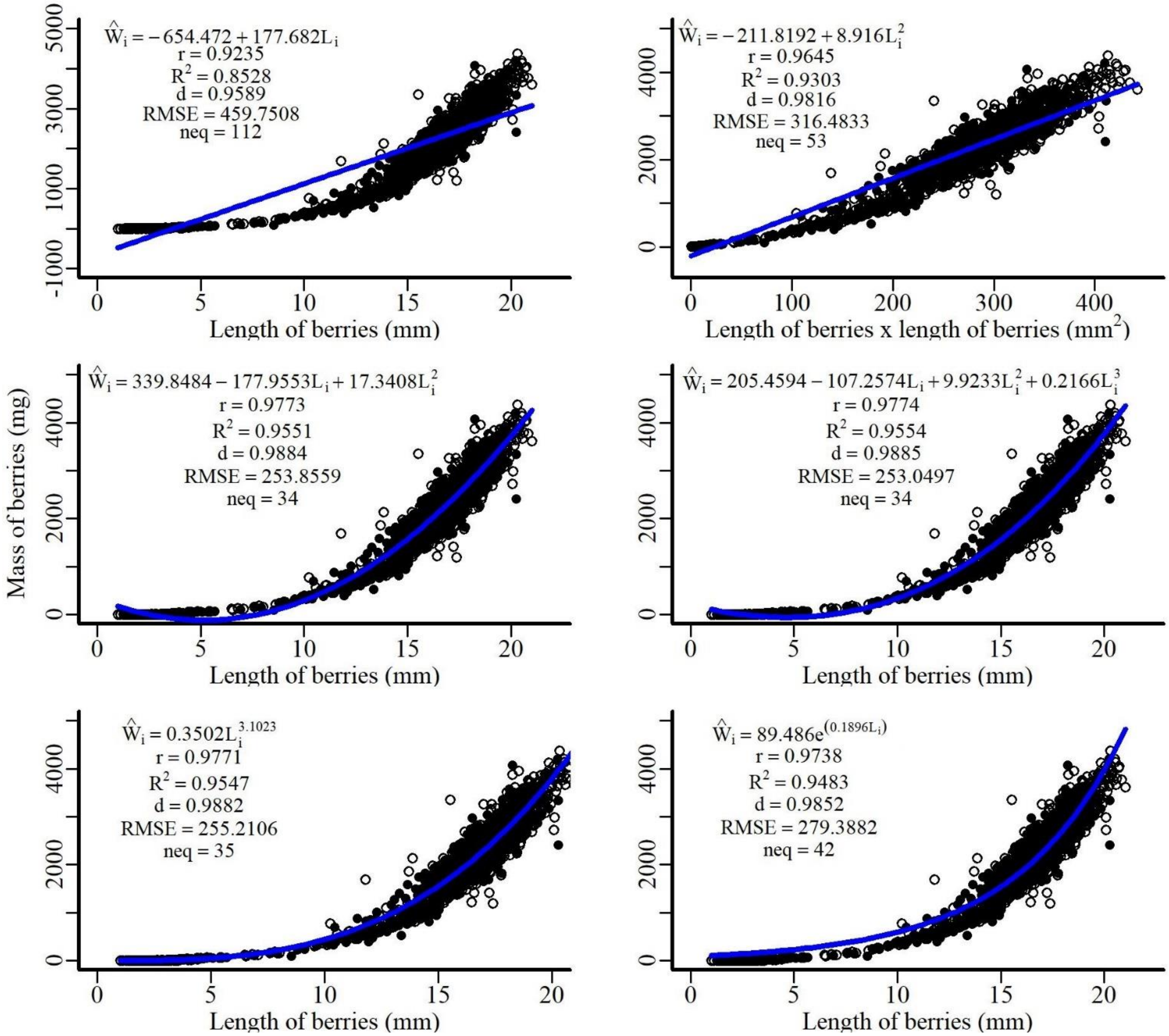


Figure **5**. Equation adjustment (PE) through simple linear (SL), quadratic (Q), cubic (C), power (P) and exponential (E) models with their respective coefficients of determination (R^2) from fruit berries grape (*Vitis labrusca*) 'Isabel', using the weight measurement as a function of the length (L) of the berries (Validation criteria: RQME=root mean square error; d=Willmott agreement index; neq=necessary sample size to estimate the equation).

For the same type of equation, it is verified that those that use the fruit diameter (D) as an independent variable have a coefficient of determination (R^2) closer to one, when compared to those that use the length (L). Thus, it can be seen that the diameter of the berries has a greater relationship with the estimated weight. This result was also observed by Santos *et al*. (12) in their study with papaya; Jorquera-Fontena *et al*. (7) in their study with blueberry, in which fruit weight was satisfactorily estimated based on diameter; and by Oliveira *et al.* (8), where the width, in general, showed a greater relationship with the mass of pear fruits in all models studied.

Among the equations that use the diameter as an independent variable, it is observed that those of the quadratic, cubic and power model presented a slight emphasis in the values of R^2, RQME closer to zero and value of the d index closer to one. However, it is observed that the simple linear, quadratic and cubic models present negative fruit mass values, which is not a possible fact. Thus, according to the criterion established in the methodology that the selected equation should not present $\hat{W} < 0$, it can be seen graphically that the model that best adheres to the statistical criteria established in this study is the power that uses diameter as an independent variable.
From the defined equation, it is possible to estimate the mass of the berries in a non-destructive way, that is, without detaching them from the mother plant, which is a simple alternative that helps in the studies of growth and physiological monitoring. In this way, the mathematical modeling of the fruit growth pattern can facilitate crop management, helping in decision making regarding treatment, especially at harvest, accurately estimating the fruit growth habit (17). As stated by Santos *et al*. (12) the producer can also use these equations to estimate fruit mass and obtain an approximation of production.

CONCLUSION

It was possible to adjust the growth curve of 'Isabel' grapes using linear and non-linear models, adopting a single equation that estimates the fruit mass for the two production seasons. The equation that best explains the weight of the fruit of the 'Isabel' grape is the power model using the diameter as an independent variable, being represented by $\hat{W}_i=1.374D_i^{2.743}$.

CONFLICT OF INTEREST

There is no conflict of interest.

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Sample CRediT author statement

Édlen S. Bonela: Conceptualization, Bibliographic research, Data analysis, Preparation of the original draft, Editing and Revision. **Lucas B. Moreira Junior:** Preliminary Studies, Data Analysis, Editing and Review. **Vinicius S. Oliveira:** Conceptualization, Supervision, Editing and Review. **Omar Schmildt:** Data Collection, Conceptualization, Supervision and Review. **Edilson R. Schmildt**: Conceptualization, Supervision, Data Analysis and Review. **Márcio P. Czepak:** Conceptualization, Supervision and Review.

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