

## Modeling the growth and production of *Physalis angulata* L.

## Modelagem do crescimento e produção de *Physalis angulata* L.

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**ABSTRACT** - The species *Physalis angulata*, belonging to the Solanaceae family, has potential growth in the berry market and pharmaceutical industry. However, technical information about its production cycle is still limited. This study aimed to fit and compare the Logistic and Gompertz nonlinear regression models to identify which one best describes the biological relationship between fruit production and seedling nursery time. The experiment was carried out in a completely randomized design, consisting of five periods of permanence of the seedlings in the nursery (22, 26, 30, 34 and 38 days), each treatment with five replicates and 12 plants per replicate. After transplanting, the plants were evaluated weekly for up to 70 days for survival, height, stem diameter and yield. Autoregressive logistic and logistic models showed better performance in fitting to the data of growth in height and stem diameter of *P. angulata* L. seedlings. According to parameter “c”, seedlings that remained for 34 days in the nursery showed faster growth in the field for both height and diameter. Seedlings that remained in the nursery for 38 days had higher fruit production compared to those of younger ages.

**RESUMO** - A espécie *Physalis angulata*, pertencente à família Solanaceae, apresenta potencial crescimento no mercado de pequenas frutas e indústria farmacológica. Porém, informações técnicas sobre seu ciclo de produção ainda são limitadas. Este estudo teve como objetivo ajustar e comparar os modelos de regressão logística não linear e de Gompertz para identificar qual deles melhor descreve a relação biológica entre a produção de frutos e o tempo de viveiro das mudas. O experimento foi realizado em delineamento inteiramente casualizado, constituído de cinco períodos de permanência das mudas no viveiro (22, 26, 30, 34 e 38 dias), cada tratamento com cinco repetições contendo 12 plantas por repetição. Após o transplante, as plantas foram avaliadas semanalmente até 70 dias quanto à sobrevivência, altura, diâmetro do colo e produtividade. Os modelos Logístico autorregressivo e Logístico apresentaram melhor desempenho no ajuste dos dados de crescimento em altura e diâmetro do caule das mudas de *P. angulata* L. O parâmetro “c”, tanto para altura quanto para diâmetro das mudas que permaneceram por 34 dias no viveiro, apresentaram crescimento mais acelerado em campo. Mudas que permaneceram no viveiro por 38 dias resultaram em maior produção de frutos em relação àquelas de menores idades.

**Keywords:** Propagation. Development. Cycle. Nonlinear models.

**Palavras-chave:** Propagação. Desenvolvimento. Ciclo. Modelos não-lineares.

**Conflict of interest:** The authors declare no conflict of interest related to the publication of this manuscript.



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## INTRODUCTION

Producing vigorous seedlings is a decisive step for the success of cultivation, directly impacting the yield and initial development of plants in the field. In the case of *Physalis angulata* L., a species with growing potential in Brazilian cuisine and pharmacology (SAAVEDRA et al., 2019; SILVA et al., 2022), the time of permanence in the nursery determines the ideal physiological stage for transplanting the seedlings, influencing both the efficiency of the production process and the quality of the final product (FREITAS et al., 2021).

Despite the adaptability and medicinal prominence of *Physalis angulata*, technical information on seedling production is still limited (OLIVEIRA et al., 2023). In addition, most evaluations of agronomic traits of cultivated species often use linear models, which are not always able to adequately represent plant growth dynamics, especially in the face of biological phenomena that are complex and autocorrelated over time (XU et al., 2014).

Thus, nonlinear regression models are proposed, such as the Logistic and Gompertz models, which have stood out for providing parameters of easy biological interpretation and greater precision in the description of growth (PERIPOLLI et al., 2024). Nonlinear growth models allow the estimation of essential parameters, such as asymptotic value, growth rate, and critical points, including inflection and maximum acceleration or deceleration (SILVA et al., 2021). Fitting these models to the growth of *P. angulata* can provide practical support for decisions made by nurserymen, optimizing resources and improving cultivation efficiency for producers.

Recent research has demonstrated the efficiency of nonlinear regression models, such as Logistic and Gompertz, to describe crop growth and development, optimizing management decisions (LUCIO; NUNES; REGO, 2016). For example, Sari et al. (2018) proposed a guide for nonlinear modeling of multi-harvest data from *Solanum melongena* L., demonstrating the importance of

nonlinearity measures in model selection. When analyzing the production of *Capsicum chinense* L., Diel et al. (2020) found that the use of the Logistic growth model allows the identification of critical points throughout the cycle, providing a more complete view of production performance compared to conventional analyses.

In this context, the present study aimed to obtain fits and compare the performance of the Logistic and Gompertz nonlinear regression models, aiming to identify the one that best describes the biological pattern of the estimated parameters, relating fruit production to the time of permanence of the seedlings in the nursery.

## MATERIAL AND METHODS

### Characterization of the experimental site

The experiment was carried out at the Center for Agrarian, Environmental and Biological Sciences, Federal University of Recôncavo da Bahia, located in the municipality of Cruz das Almas, Bahia, Brazil, at an altitude of 220 m above sea level, latitude of 12°40'19" S and longitude of 39° 06'23" W of Greenwich. The climate of the region is As type (ALVARES et al., 2014), hot and humid tropical, with an average annual temperature of 25 °C and relative humidity of 80%. In the experimental period, rainfall in the months of April, May and June was 313.9, 83.6 and 93.9 mm, respectively (INMET, 2022).

The soil was classified as a cohesive *Latossolo Amarelo* (Oxisol), flat relief, medium texture (RODRIGUES

et al. 2009), with 791 g kg<sup>-1</sup>, 69 g kg<sup>-1</sup> and 140 g kg<sup>-1</sup> of sand, silt and clay, respectively.

### Treatments and experimental design

The experiment was carried out in a completely randomized design, consisting of five periods of permanence of the seedlings in the nursery (22, 26, 30, 34 and 38 days). Each treatment consisted of five replicates, with 12 plants in each replicate.

### Experiment setup and execution

*P. angulata* seedlings were produced in a greenhouse. Sowing was carried out directly in 55 cm<sup>3</sup> containers (12.5 cm length x 2.9 cm internal diameter), with substrate composed of 30% humus and 70% Plantmax®. The sowing dates were March 2, 6, 10, 14, and 18, 2022, for which the seedlings remained in the nursery for 38, 34, 30, 26, and 22 days, respectively, being transplanted to the field on April 10, 2022.

Soil chemical analysis (Table 1) was performed prior to plowing and harrowing. Subsequently, a manual digger was used to open the holes (20 x 30 cm), with a spacing of 0.8 m between plants in the row and 1.8 m between rows. Fertilization was carried out in each hole, with 200 grams of humus, whose chemical analysis is presented in Table 1.

The plants were irrigated by a drip system in the morning and afternoon, according to the water requirement of the crop. Cultural practices, such as combating leaf-cutting ants (weekly rounds) and biweekly weeding, were carried out. The last harvest was performed on June 21, 2022.

**Table 1.** Chemical analysis of the soil and humus substrate used in the cultivation of *Physalis angulata* L.

|       | pH    | P                               | K     | Ca  | Mg  | Al  | H+Al                               | SB  | CEC  | OM            | V  |
|-------|-------|---------------------------------|-------|-----|-----|-----|------------------------------------|-----|------|---------------|----|
|       | water | ----- mg dm <sup>-3</sup> ----- |       |     |     |     | cmol <sub>c</sub> dm <sup>-3</sup> |     |      | ----- % ----- |    |
| Soil  | 5.4   | 9.6                             | 545.4 | 3.4 | 1.0 | 0.1 | 11.7                               | 5.8 | 17.5 | 2.4           | 33 |
| Humus | 7.3   | 901.2                           | 782.0 | 5.4 | 1.8 | 0.0 | 2.6                                | 9.2 | 11.8 | 2.2           | 78 |

P, K, and Na were determined using the Mehlich-1 extractant; Al, Ca, and Mg using KCl 1 M; O.M. = organic matter; E.C. = electrical conductivity; SB = sum of bases; V = base saturation; CEC = cation exchange capacity.

### Evaluations carried out

On the day of planting in the field, the seedlings were measured for height, using a millimeter ruler, and stem base diameter, with a digital caliper.

Fruit count per plant started seven days after planting in the field and was performed every week up to 70 days after transplanting. To evaluate yield (kg of ripe fruits), harvests were carried out at three non-equidistant times: the first harvest at 28 days after planting, the second harvest at 15 days after the first harvest, and the third harvest at 22 days after the second harvest. Ripe fruits were harvested based on their visual appearance, which includes the presence of dry calyx around them. The total production of fruits harvested per treatment was quantified. Yield (kg ha<sup>-1</sup>) was estimated considering a density of 6944 plants per hectare and measuring the weight of 60 fruits per treatment using an analytical scale with precision of 0.001 g.

### Data analysis

Mixed linear models were employed for traits obtained from repeated measures, such as height, diameter, and number of fruits per plot, using the *lme4* package (BATES et al., 2022) in R software (R CORE TEAM, 2022), following the residual maximum likelihood method. Six models were used to analyze the fixed- and random-effects structures (Table 2).

After defining the models for verifying the significance of the influencing factors on the response variables, using the AKAIKE (Akaike Information Criterion - AIC) and Schwarz Bayesian (Bayesian Information Criterion - BIC) criteria, regression equations were fitted to study the behavior of the variables as a function of the time of permanence in the nursery and evaluation periods. Regression model fitting methods were used according to the results of the interactions and nature of the data.

**Table 2.** Summary of the models studied with fixed- and random-effects structures for the variables growth in height, diameter and number of fruits of *Physalis angulata* L..

| Models | Fixed effects                         | Random effects |
|--------|---------------------------------------|----------------|
| M1     | Age, Time and Interaction: Age x Time | Time           |
| M2     | Age, Time and Interaction: Age x Time | Plot           |
| M6     | Age, Time and Interaction: Age x Time | Time and Plot  |
| M3     | Age and Time                          | Time           |
| M4     | Age and Time                          | Plot           |
| M5     | Age and Time                          | Time and Plot  |

In order to fit the growth curves, the Logistic and Gompertz models were tested (PEREIRA; FERNANDES; SCALCO, 2016) and the least squares method and Gauss-Newton iterative procedures were employed, using the *nls* function of R software (R CORE TEAM, 2022). The assumptions of the models were tested as follows: residual normality by the Shapiro-Wilk test, homoscedasticity by the Breusch-Pagan test, using *bptest* function of the *lmtest* package (HOTHORN et al., 2022), and residual autocorrelation by the Durbin-Watson test, using *Durbin-Watson Test* function in the *car* package (FOX et al., 2023). When the assumptions were not met, the generalized least squares method was used, incorporating the first-order autocorrelation parameter (AR1) into the residuals, using the *gnls* function of the *nlme* package (PINHEIRO et al., 2022) of R software (R CORE TEAM, 2022). AIC and BIC criteria were used to assist in the choice of the fitted equations; the lower the values of these criteria, the more appropriate the fit.

A) Fitted Logistic model (PEREIRA; FERNANDES; SCALCO, 2016):

$$Y = \frac{a}{1 + \exp(-b(t - c))}$$

where: Y = dependent variable (Height, Stem Diameter); t = time; x = value of the independent variable; exp = base of the Napierian logarithm; a = superior asymptote; b = growth rate; c = inflection point (time required to reach 50% of the maximum variable).

B) Fitted Gompertz model (PEREIRA; FERNANDES; SCALCO, 2016):

$$Y = a * \exp(-\exp(-b(T - c)))$$

where: Y = dependent variable (Height, Stem Diameter); t = time; x = value of the independent variable; exp = base of the Napierian logarithm; a = superior asymptote; b = growth rate; c = inflection point (time required to reach 34% of the maximum variable).

The effect of age on yield was evaluated based on the average weight and total number of fruits per plot. Analysis of variance and regression were performed.

## RESULTS AND DISCUSSION

For height and diameter, model 1 was selected, with the lowest AIC and BIC (Tables 2 and 3). The interaction between nursery time (Seedling age) and field time (Post-transplanting time) was significant for all variables studied (p-value < 0.0001) (Table 4).

Evaluating the quality of seedlings removed from the nursery is a crucial aspect to be considered to ensure the success of transplanting to the field. Among the main variables to be evaluated are seedling height and stem diameter, as well as fruit production in the post-transplanting period, for fruit species (ZACCHEO; AGUIAR; STENZEL, 2013; BERTOLINI; BRUN, 2015; MENDONÇA; SOUZA, 2018).

**Table 3.** Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) values for the fitted mixed models.

| Model | Height |        | Diameter |        |
|-------|--------|--------|----------|--------|
|       | AIC    | BIC    | AIC      | BIC    |
| M1    | 1475.6 | 1497.3 | 808.15   | 829.85 |
| M2    | 1636.6 | 1658.3 | 962.72   | 984.42 |
| M6    | 1628.2 | 1657.1 | 950.87   | 976.19 |
| M3    | 1513.4 | 1531.5 | 868.93   | 887.01 |
| M4    | 1657.0 | 1675.0 | 996.92   | 1015.0 |
| M5    | 1638.6 | 1658.3 | 938.44   | 967.37 |

**Table 4.** Significance of the analysis of variance for height and stem diameter of *P. Physalis angulata* from the selected mixed models.

|            | Height                  |          | Diameter                |          |
|------------|-------------------------|----------|-------------------------|----------|
|            | F <sub>calculated</sub> | P-value  | F <sub>calculated</sub> | P-value  |
| Age        | 88.3                    | < 0.0001 | 49.98                   | < 0.0001 |
| Time       | 310.5                   | < 0.0001 | 282.15                  | < 0.0001 |
| Age x Time | 42.7                    | < 0.0001 | 70.33                   | < 0.0001 |

The results of the fits to the growth curves are presented in Tables 5 and 6. The AIC and BIC criteria were used to assist in the choice of equations; the lower their values, the more appropriate the fit.

For 22 and 30 days of permanence in the nursery, the most suitable model to describe growth in height in the field

was the Logistic-AR1. Silva et al. (2021), when analyzing the longitudinal diameter of dwarf coconut fruits, concluded that the assumption of independence was violated, which led to the incorporation of a first-order autoregressive model (AR1) for both models (Gompertz and Logistic).

**Table 5.** Estimated parameters from growth curve fits for the height of *P. Physalis angulata* seedlings produced with different nursery permanence times (age), according to the analysis model.

|                      | Parameters |       |        | SD    | Shapiro-Wilk | Breusch-Pagan | Durbin Watson | AIC     | BIC     | R <sup>2</sup> |
|----------------------|------------|-------|--------|-------|--------------|---------------|---------------|---------|---------|----------------|
|                      | a          | b     | c      |       |              |               |               |         |         |                |
| 22-day-old seedlings |            |       |        |       |              |               |               |         |         |                |
| Logistic             | 68.298     | 0.093 | 32.152 | 7.71  | 0.440        | 0.011         | 0.026         | 275.034 | 283.063 | 0.98           |
| Gompertz             | 75.398     | 0.053 | 27.108 | 8.61  | 0.024        | 0.184         | 0.002         | 287.220 | 295.250 | 0.98           |
| Logistic (AR1)       | 68.166     | 0.093 | 32.069 | 7.71  |              |               |               | 273.819 | 283.856 | 0.98           |
| Gompertz (AR1)       | 74.825     | 0.053 | 26.834 | 8.64  |              |               |               | 281.028 | 291.065 | 0.98           |
| 26-day-old seedlings |            |       |        |       |              |               |               |         |         |                |
| Logistic             | 72.623     | 0.079 | 31.135 | 8.34  | 0.124        | 0.097         | 0.602         | 292.785 | 300.814 | 0.98           |
| Gompertz             | 82.649     | 0.043 | 26.090 | 9.32  | 0.277        | 0.462         | 0.058         | 305.027 | 313.057 | 0.97           |
| Logistic (AR1)       | 72.628     | 0.079 | 31.139 | 8.34  |              |               |               | 294.779 | 304.816 | 0.97           |
| Gompertz (AR1)       | 82.919     | 0.043 | 26.201 | 9.33  |              |               |               | 305.161 | 315.198 | 0.97           |
| 30-day-old seedlings |            |       |        |       |              |               |               |         |         |                |
| Logistic             | 74.391     | 0.073 | 30.705 | 8.27  | 0.575        | 0.000         | 0.246         | 295.257 | 303.286 | 0.97           |
| Gompertz             | 86.049     | 0.039 | 25.710 | 9.24  | 0.135        | 0.001         | 0.712         | 307.536 | 315.565 | 0.97           |
| Logistic (AR1)       | 74.305     | 0.073 | 30.704 | 8.32  |              |               |               | 292.593 | 302.629 | 0.97           |
| Gompertz (AR1)       | 86.058     | 0.039 | 25.721 | 9.25  |              |               |               | 309.461 | 319.498 | 0.97           |
| 34-day-old seedlings |            |       |        |       |              |               |               |         |         |                |
| Logistic             | 72.033     | 0.063 | 30.166 | 9.57  | 0.140        | 0.095         | 0.600         | 308.463 | 316.493 | 0.96           |
| Gompertz             | 85.200     | 0.033 | 25.297 | 10.37 | 0.070        | 0.090         | 0.403         | 317.261 | 325.290 | 0.96           |
| Logistic (AR1)       | 72.039     | 0.063 | 30.169 | 9.57  |              |               |               | 310.457 | 320.493 | 0.96           |
| Gompertz (AR1)       | 85.467     | 0.033 | 25.394 | 10.37 |              |               |               | 318.102 | 328.138 | 0.94           |
| 38-day-old seedlings |            |       |        |       |              |               |               |         |         |                |
| Logistic             | 75.843     | 0.061 | 30.773 | 8.73  | 0.120        | 0.230         | 0.670         | 302.613 | 310.642 | 0.97           |
| Gompertz             | 91.858     | 0.031 | 26.535 | 9.82  | 0.116        | 0.597         | 0.056         | 315.572 | 323.601 | 0.96           |
| Logistic (AR1)       | 75.849     | 0.061 | 30.776 | 8.73  |              |               |               | 304.608 | 314.645 | 0.96           |
| Gompertz (AR1)       | 92.251     | 0.031 | 26.677 | 9.81  |              |               |               | 315.433 | 325.470 | 0.96           |

R<sup>2</sup> = coefficient of determination; SD = standard deviation; AIC = Akaike information criterion; BIC = Bayesian information criterion. a = upper asymptote; b = growth rate; c = inflection point.

**Table 6.** Estimated parameters of growth curve fits for root collar diameter of *Physalis angulata* seedlings, produced under different nursery stay times (age), according to the analysis model.

|                      | Parameter |       |        | SD    | Shapiro-<br>Wilk | Breusch-<br>Pagan | Durbin<br>Watson | AIC     | BIC     | R <sup>2</sup> |
|----------------------|-----------|-------|--------|-------|------------------|-------------------|------------------|---------|---------|----------------|
|                      | a         | b     | c      |       |                  |                   |                  |         |         |                |
| 22-day-old seedlings |           |       |        |       |                  |                   |                  |         |         |                |
| Logistic             | 18.063    | 0.090 | 29.327 | 7.62  | 0.186            | 0.003             | 0.096            | 134.478 | 142.507 | 0.98           |
| Gompertz             | 19.932    | 0.051 | 24.075 | 8.87  | 0.086            | 0.003             | 0.056            | 151.175 | 159.205 | 0.98           |
| Logistic (AR1)       | 18.057    | 0.089 | 29.300 | 7.67  |                  |                   |                  | 134.203 | 144.24  | 0.98           |
| Gompertz (AR1)       | 19.912    | 0.050 | 23.963 | 8.89  |                  |                   |                  | 143.065 | 153.102 | 0.98           |
| 26-day-old seedlings |           |       |        |       |                  |                   |                  |         |         |                |
| Logistic             | 18.722    | 0.083 | 28.798 | 9.71  | 0.245            | 0.011             | 0.798            | 166.412 | 174.442 | 0.97           |
| Gompertz             | 20.979    | 0.045 | 23.443 | 11.22 | 0.230            | 0.011             | 0.812            | 182.268 | 190.297 | 0.96           |
| Logistic (AR1)       | 18.703    | 0.083 | 28.748 | 9.71  |                  |                   |                  | 167.990 | 178.026 | 0.97           |
| Gompertz (AR1)       | 21.118    | 0.045 | 23.651 | 11.23 |                  |                   |                  | 182.644 | 192.681 | 0.96           |
| 30-day-old seedlings |           |       |        |       |                  |                   |                  |         |         |                |
| Logistic             | 18.587    | 0.066 | 27.942 | 9.83  | 0.000            | 0.026             | 0.452            | 167.397 | 175.426 | 0.96           |
| Gompertz             | 21.279    | 0.036 | 22.208 | 10.70 | 0.000            | 0.026             | 0.41             | 176.685 | 184.715 | 0.95           |
| Logistic (AR1)       | 18.618    | 0.066 | 28.060 | 9.85  |                  |                   |                  | 166.901 | 176.938 | 0.96           |
| Gompertz (AR1)       | 21.301    | 0.036 | 22.253 | 10.70 |                  |                   |                  | 178.604 | 188.640 | 0.95           |
| 34-day-old seedlings |           |       |        |       |                  |                   |                  |         |         |                |
| Logistic             | 17.895    | 0.055 | 27.930 | 10.43 | 0.039            | 0.000             | 0.004            | 168.389 | 176.419 | 0.95           |
| Gompertz             | 21.269    | 0.029 | 22.589 | 11.10 | 0.094            | 0.000             | 0.002            | 175.176 | 183.205 | 0.94           |
| Logistic (AR1)       | 17.843    | 0.054 | 27.809 | 10.44 |                  |                   |                  | 163.724 | 173.761 | 0.94           |
| Gompertz (AR1)       | 21.193    | 0.029 | 22.384 | 11.13 |                  |                   |                  | 167.332 | 177.368 | 0.94           |
| 38-day-old seedlings |           |       |        |       |                  |                   |                  |         |         |                |
| Logistic             | 18.430    | 0.062 | 28.310 | 10.20 | 0.085            | 0.358             | 0.358            | 169.445 | 177.475 | 0.96           |
| Gompertz             | 21.671    | 0.033 | 23.082 | 11.22 | 0.053            | 0.253             | 0.352            | 179.983 | 188.012 | 0.95           |
| Logistic (AR1)       | 18.455    | 0.062 | 28.366 | 10.20 |                  |                   |                  | 171.168 | 181.205 | 0.95           |
| Gompertz (AR1)       | 21.930    | 0.032 | 23.491 | 11.22 |                  |                   |                  | 179.117 | 189.154 | 0.95           |

R<sup>2</sup> = coefficient of determination; SD = standard deviation; AIC = Akaike information criterion; BIC = Bayesian information criterion; a = upper asymptote; b = growth rate; c = inflection point.

For 26, 34 and 38 days, the Logistic model without incorporation of the autocorrelation parameter was better fitted to the data. According to Reis et al. (2014), the Logistic model was essential to interpret the dry mass accumulation in the parts of garlic plants over time. However, it was observed that parameter “a”, corresponding to the maximum asymptotic mass, was reached around 130 days after planting, which highlights the importance of nonlinear modeling and its parameters to accurately describe the development stages of agricultural crops.

Parameter “c” corresponds to the time at which the seedling reaches 50% of its maximum height. Seedlings that remained for 34 days in the nursery (Figure 1A) resulted in a lower value of the parameter “c”, which corresponds to faster growth in height compared to the other permanence times. Pereira, Fernandes and Scalco (2016) observed that lower estimates of the growth rate in non-irrigated coffee plants resulted in slow development, which highlights the sensitivity of the growth rate parameter as a descriptor of performance under different management conditions. Thus, the incorporation of precise biometric parameters, such as the

time to reach 50% of the maximum height, represents a relevant tool for monitoring and decision-making in production processes.

In relation to diameter, for the permanence times of 22, 26, 30 and 34 days in the nursery, the Logistic AR1 model better represented the means, while for 38 days the Logistic model without incorporation of the autocorrelation parameter showed better performance. Given the residual dependence observed, the models are fitted including the first-order autoregressive term. The approach follows the recommendations of Ribeiro et al. (2017), who highlight the importance of properly modeling residual autocorrelation to ensure more accurate estimates when there is autocorrelation in the errors. Frühauf et al. (2020) compared the Brody, Gompertz, Logistic, and von Bertalanffy models for cedar growth in diameter and observed that all models demonstrated good fit when using the first-order autoregressive error structure.

Based on parameter “c”, as observed for height, the growth in diameter of plants in the field (Figure 1B) was faster for seedlings that remained for 34 days in the nursery

(Table 6). Nonlinear models have a greater capacity to describe biological processes, standing out for providing superior fits compared to linear models in the study of plant

growth. In addition, these models allow estimating parameters that have biological relevance and interpretation, as reported by Sousa et al. (2014).

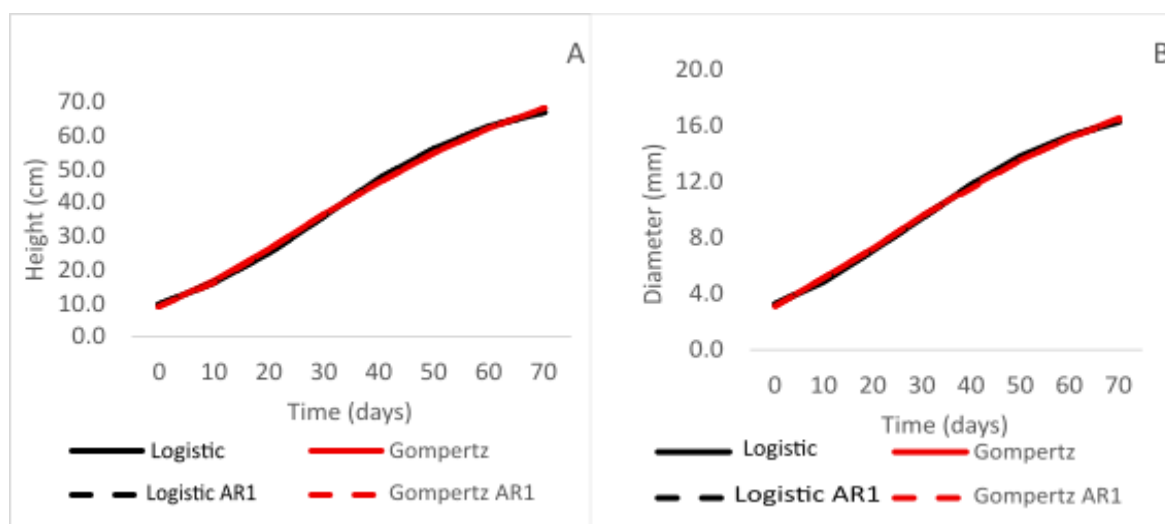


**Figure 1.** Height (A) and stem diameter (B) of *Physalis angulata* seedlings that remained in the nursery for 34 days, assessed 70 days after transplanting to the field.

Fruit yield ( $\text{kg ha}^{-1}$ ) was influenced by the time of permanence of the plants in the nursery phase ( $p\text{-value} < 0.0001$ ). For each day that the seedling remained in

the nursery, considering the maximum tested time of 38 days, there was an increase of 50.6 kg of fruits per hectare (Figure 2).

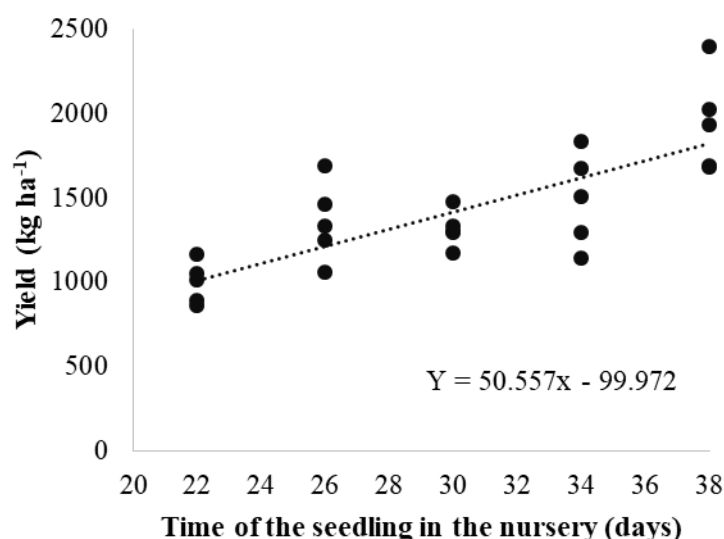


**Figure 2.** Fruit yield ( $\text{kg ha}^{-1}$ ) of *Physalis angulata* in response to the permanence time of the seedling in the nursery.

The definition of quality for fruit seedlings is a topic of great relevance for farmers and producers, as it is directly related to the success of production in the field. Tanan, Nascimento and Leite (2018) observed, in their studies on *P. angulata*, in the semi-arid region of Bahia, that each plant produced, on average, 140.5 fruits at 54 days of cultivation, highlighting the production capacity of the species even under adverse conditions. The long fruiting period is interesting for

farmers, who can count on this species as an alternative for cultivation throughout the year.

Machado et al. (2024) found that *Physalis angulata* seedlings kept in the nursery for 38 days, with a minimum height of 12.8 cm and stem diameter of at least 4.2 cm, reached production of more than 200 fruits per plant in the reproductive stage. This performance represented a production increase of approximately 20% compared to

seedlings with shorter time of permanence in the nursery.

Seedling age is directly related to the plant's ability to adapt to its new environment. The rapid vegetative establishment of 34-day-old seedlings and the higher yield of 38-day-old seedlings are attributed to their initial physiological vigor. Younger seedlings have higher photosynthetic and transpiration rates soon after transplanting (JANKAUSKIENĖ; LAUŽIKĖ, 2023). However, the additional time in the nursery for the treatment of 38 days allowed higher dry mass accumulation and larger leaf area, morphological support that is decisive to sustain fruit weight, which results in an increase in yield (JANKAUSKIENĖ; LAUŽIKĖ, 2023).

In other words, seedlings kept for 38 days in the nursery suffered less stress in the initial establishment, which contributed to the higher yield of the plants.

## CONCLUSION

Autoregressive Logistic and Logistic models showed better performance in fitting to the data of growth in height and stem diameter of *Physalis angulata* L. seedlings compared to the Gompertz model.

Both height and diameter of seedlings that remained for 34 days in the nursery showed faster growth in the field. On the other hand, permanence for 38 days in the nursery resulted in a greater increase in fruit production per hectare.

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