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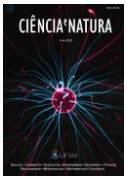

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Statistics

Description of the growth curve of the biquinho-type pepper plant under water stress

Descrição da curva de crescimento da planta de pimenta do tipo biquinho sob estresse hídrico

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ABSTRACT

The consumption of pepper is quite common in Brazil, being used not only in food, but also in the pharmaceutical and hygienic segment, providing health benefits for having antibiotic effects, anti-inflammatory action and several vitamins. The objective of this work was to characterize the growth curve of the biquinho-type pepper plant, using the nonlinear regression models logistic, Gompertz and von Bertalanffy, to the plant's height data subjected to irrigation of 20% of its water requirement. The experiment was conducted in a greenhouse, belonging to the Agricultural Engineering Academic Unit (UAEAg) of the Federal University of Campina Grande - UFCG. All the models used proved to be appropriate, but the von Bertalanffy model was the most adequate to fit the data according to the AIC statistics, estimating a maximum growth of 7.58cm for the plants in 163 days after sowing the crop. with the highest speed of growth per day obtained up to 38 days after sowing, when the height reached was 2.27cm.

Keywords: Nonlinear model; Logistic model; Gompertz model

RESUMO

O consumo da pimenta é bastante comum no Brasil, sendo utilizada não somente na alimentação, mas também no segmento farmacêutico e higiênico, tendo benefícios à saúde por ter efeitos antibióticos, ação antiinflamatória e diversas vitaminas. O objetivo do trabalho foi caracterizar a curva de crescimento da planta da pimenta biquinho, por meio dos modelos de regressão não linear logístico, Gompertz e von Bertalanffy, aos dados de altura da planta submetida à irrigação de 20% de sua

necessidade hídrica. O experimento foi conduzido em casa de vegetação, pertencente a Unidade Acadêmica de Engenharia Agrícola (UAEAg) da Universidade Federal de Campina Grande – UFCG. Todos os modelos utilizados demonstraram-se apropriados, porém o modelo de von Bertalanffy foi o mais adequado ao ajuste aos dados de acordo com a estatística do AIC, estimando um crescimento máximo de 7,58cm para as plantas em 163 dias após a semeadura da cultura com a maior velocidade de crescimento ao dia obtida até 38 dias após a semeadura, quando a altura atingida foi de 2,27cm.

Palavras-chave: Modelo não linear; Modelo logístico; Modelo Gompertz

1 INTRODUCTION

The increase in the consumption and use of pepper in several segments, such as pharmaceutical, food and hygiene, has been expanding the cultivation of pepper to supply market demand. According to Alvarenga Neto *et al*. (2016), Capsicum-type pepper provides health benefits because it has antibiotic effects, anti-inflammatory action and several vitamins. Some research confirms that red peppers are called thermogenic for raising metabolism, helping with weight loss (MATIELLO, 2013).

Brazil has approximately 13 thousand planted areas, with an average production of 280 tons of pepper, one of the 10 main vegetables produced (ALVARENGA NETO *et al*., 2016). In São Paulo pepper is the 56th best-selling product at CEAGESP, in 2017, more than 6 thousand tons were sold. The most sought-after types are: red, green, American green and Cambuci (CEAGESP, 2020). According to AFEIRA (2020) in the Northeast region, the states of Ceará, Pernambuco and Bahia stand out, in Ceará the use of peppers in small establishments, usually in processing industries, adding value to the product.

The cultivation of pepper plants by small farmers is important because it generates income and keeps people in the countryside. The sale to the processing industry allows a higher price, when compared to the price of fresh pepper. Pepper culture is widely observed in family farming, due to its practical management and cultivation. As demand has been higher than the supply, there is a shortage of the product, mainly because its production is destined for industry (SANTOS *et al*., 2018). According to Barbieri *et al*. (2011) to produce 1 kg of dehydrated pepper approximately 7 kg of fresh pepper are used, adding value by raising the producer's income.

Considering the pepper varieties of the Capsicum genus, the biquinho-type pepper (Capsicum Chinense), due to its characteristics, such as lack of pungency and fruit shape, is considered a sweet pepper, they are preferred for seasoning, fresh consumption, among others, being ideal for salad composition (DANTAS *et al*., 2017). During the production chain of this pepper it is essential to know all the stages, mainly the management of water and soil, applied organic substrates, which influence the growth of this cultivar and directly affect its production. In this way, evaluating the type of treatment applied and the growth of this cultivar is essential for decision making and for implementing the cultivation in the field.

Nonlinear models, especially growth models, are often used to describe and understand growth over time, mainly for fruits, plants and animals. In particular for plant growth, these models can be useful to obtain knowledge of the phenological stages of the plant, consequently having knowledge and carrying out adequate management of the crop, times for fertilization, harvest and pest control. Nonlinear growth models bring in their parameters useful biological interpretations to obtain the mentioned information. The estimation of the parameters can be performed using the least squares method, adapting the situations of assumptions for each case. Due to the nonlinearity of the parameters, iterative methods are added to find the solutions of the systems of normal equations. The most used nonlinear models for studies of growth curves are the logistic, Gompertz, Brody, von Bertalanffy and Richards models.

Maia *et al*. (2009) used the Brody, Gompertz, logistic and von Bertalanffy models to describe the growth curve of banana trees. The authors concluded that the logistic model was the most adequate for adjusting the data. Mangueira *et al*. (2016) studied the growth of the corn plant using the logistic model considering different characteristics for the error vector and concluded that the logistic model with normal asymmetric errors obtained the best fit to the data. The pepper of the cultivar doce-type was evaluated by Jane *et al*. (2019) who used polynomial and nonlinear logistic and Gompertz models. The authors concluded that the logistic

model was the most adequate according to the quality criteria of adjustment residual standard deviation, corrected Akaike criterion and determination coefficient.

Several other plant growth studies can be found in Lyra *et al*. (2003), Lyra *et al*. (2008), Moura *et al*. (2008), Puiatti, *et al*. (2013), Tsumanuma, *et al*. (2010), Kleinpaul (2018), etc. In this context, this work was carried out aiming to characterize the growth curve of the biquinho-type pepper plant, using the nonlinear models: logistic, Gompertz and von Bertalanffy, fitting them to the plant height data measured over the days after sowing.

2 MATERIAL AND METHODS

The experiment was conducted in a greenhouse, belonging to the Agricultural Engineering Academic Unit (UAEAg), Campus I, of the Federal University of Campina Grande - UFCG, located in the municipality of Campina Grande, Paraíba State, at the geographical coordinates 7º15'18" south latitude and 35º52'28" west longitude, at an altitude of 550m (ANDRADE, 2008).

In this experimental trial, the seeds of pepper BRS Moema (Capsicum chinense), developed by the company ISLA Seeds, were used, following sowing recommendations suggested by the company, 0.5 cm deep, directly at the place of cultivation. The soil used in the composition of the substrate was classified as Eutrophic Grayish Clay, collected in the district of São José da Mata in the municipality of Campina Grande - PB, in the proportion 7: 3 of soil and tanned bovine manure, 30% of the total volume of the pot.

In the treatments, five irrigation depths and two types of water were applied (water supply and wastewater treated by an anaerobic sludge blanket urea flow reactor - UASB + WETLAND) based on the water requirement (NH) of the crop, which are 100% NH, 80% NH, 60% NH, 40% NH and 20% NH.

For this study, only data were used considering the condition of 20% NH in the water per supply, i.e., the data refer to the average height of the pepper plant,

which received water supply with 20% NH on each day measurement performed. Therefore, growth was only considered when the plant is subjected to the least amount of water, being under water stress. The evaluations were carried out every seven days, totaling 21 evaluations, 163 days after sowing (DAS).

The following models were fitted to assess the growth of the biquinho-type pepper plants:

$$logistic: Y_i = \frac{\alpha}{1 + exp(\gamma - k * x_i)}$$

$$Gompertz: Y_i = \alpha * exp\{-exp(\gamma - k * x_i)\} + \varepsilon_i$$

$$von\ Bertalanffy: Y_i = \alpha * \left(1 - y\left(exp(-k * x_i)\right)\right)^3 + \varepsilon_i$$

Y_i represents the i-th height of the plant, x_i represents the i-th day of height collection; α is the growth stabilization value, i.e., the asymptotic value; γ it is a parameter without practical interpretation, but it is associated with the inflection point of the growth curve; k is the maturity index, interpreted as the higher its value, the faster the plant reaches its maximum growth; ε_i is the error associated with the i-th observation with the assumption that the errors are independent and follow a normal distribution with zero mean and constant variance. The inflection points (PI) of the curves are given $(\gamma/k;\ \alpha/2), (\gamma/k; \alpha/e)$ and $(log(3\gamma)/k; 8\alpha/27)$ for the logistic, Gompertz and von Bertalanffy models, respectively. This point indicates the change in the curve's concavity, i.e., the point at which growth ceases to be increasing to decreasing and indicates a deceleration in the speed of growth (FREITAS, 2007) and (MISCHAN *et al*., 2014).

With the equations for each model, it is possible to obtain other relevant information for the study. The instantaneous absolute growth rate (TCI), calculated from the model derivative in relation to time, estimates the increase in plant height at each unit of time (FREITAS, 2007). The absolute maturity rate (TMA) indicates the

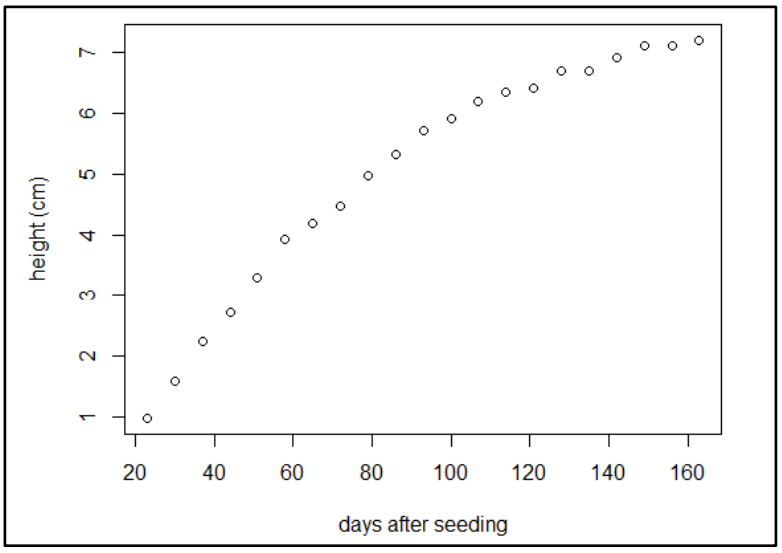
proportion of daily growth relative to the asymptotic value, where it is obtained by dividing the TCI by the estimated asymptotic value α (FREITAS, 2007).

The assumption of normality was assessed by the Shapiro-Wilk test, with a significance level of 5%. All data analysis was performed using the free software R Core Team (2019), using the gnls function of the nmle package. The model with the best fit was selected according to the Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (BIC), (Akaike, 1974) and (Schwarz, 1978), where the model with the lowest value of the AIC and BIC statistics being considered as the best fit.

3 RESULT AND DISCUSSION

The data of the average height in each day of observation of the biquinho-type pepper plant, in centimeters, are shown in Figure 1. The data represent an increase in the average height of the plants over the evaluated days, which stabilizes as it approaches the end of the evaluation days. This is a characteristic in studies with growth measures carried out over time, being ideal situations for the use of nonlinear growth models.

Figure 1 - Dispersion graph of the average height plant of the biquinho-type pepper as a function of time (days)



Source: Author's (2021)

Table 1 shows the parameter estimates for each of the models used. All adjusted models have normal residues according to the Shapiro-wilk normality test considering a significance level of 0.05.

Table 1 - Estimates of the parameters for the logistic, Gompertz and von Bertalanffy models fitted to the height data of the biquinho-type pepper plants

Models	**Parameters**					**AIC**[***]	**BIC**[****]
	α	**γ**	***k***	**PI**[*]	**TMA**[**]		
Logistic	7.12	2.30	0.04	(3.56;58)	3.92%	-7.90	-3.73
Gompertz	7.39	1.23	0.03	(2.72;41)	4.17%	-29.12	-24.94
von Bertalanffy	7.58	0.81	0.02	(2.25;44)	4.25%	-38.84	-34.66

[*]PI(X,Y) is the Inflection point.
[**]TMA is the absolute maturity rate.
[***]AIC is the Akaike criterion.
[****]BIC is the Schwarz Bayesian Criterion.
Source: Author's (2021)

Similar results were obtained by Jane *et al*. (2019) when they checked the polynomial and nonlinear models in pepper growth, obtaining normal residues at 5% significance in their results, with the logistic model being suitable to be applied.

According to Table 1, the asymptotic heights of the estimated plants were 7.12 cm; 7.39 cm and 7.58 cm in the logistic, Gompertz and von Bertalanffy models, respectively. These estimates are lower than those found by Jane *et al*. (2019) for the logistic and Gompertz models, which were 7.73 cm and 7.90 cm, respectively, but using the cultivar Doce in the experiment. In Table 1, the estimated maximum TMA was 3.92%, 4.17% and 4.25%, i.e., these are the proportions of growth relative to the estimated asymptotic value per unit of time in each fitted model.

Silva *et al*. (2019) researching various types of substrates in the cultivation of yellow biquinho-type pepper and chili pepper, reached maximum heights of 3.33cm and 1.69cm, respectively, at 41 days after sowing. Smaller pepper plants are known to facilitate management and are suitable for the ornamental plant sector. Almeida *et al*. (2017) studying concentrations of bovine tannery sludge in

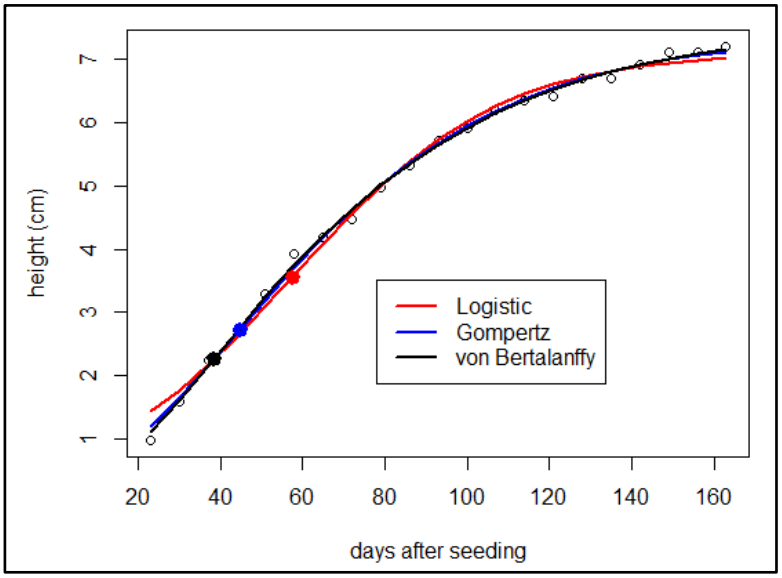
the development and quality of seedlings of biquinho-type pepper found an average height of 1.77cm, at 45 days after sowing, a result lower than that obtained in this research.

In Figure 2, it is possible to verify the fit of the models to the plant height data. The three models used showed satisfactory fit according to the graph, however, according to the AIC and BIC statistics (TABLE 1), the lowest estimated value was from the von Bertalanffy model, i.e., according to the AIC statistic = -38.84 and according to the BIC statistic = -34.66, the von Bertalanffy model was the most adequate to fit the data. Divergent results were obtained by Lima *et al*. (2019) when evaluating the nonlinear modeling of dry bean biomass, in which, according to their results, the estimates of the AIC criterion were lower for the logistic model.

The inflection point (PI) of the logistic, Gompertz and von Bertalanffy models were 3.56cm, 2.72cm and 2.25cm, respectively. This estimate indicates that the pepper plant had greater speed of growth until it reached those heights estimated in the PI, after that time, the growth becomes slower. These estimated heights were reached approximately 58.41 and 44 days after sowing, for the logistic, Gompertz and von Bertalanffy models, respectively. The inflection point can be seen in Figure 2.

In this way, it is clear that at 44 days after sowing, pepper plants of greater height are obtained. This is interesting since the objective for both production and ornamental purposes, is that the faster the plant goes through the growth phase, the flowering and fruiting phases are also anticipated. It is evidenced in Figure 2, by the von Bertalanffy model and justified by the amount of water applied to the plant, stimulating a greater speed in its development, due to the water stress to which it is submitted.

Figure 2 - Dispersion graph of the average height of the plant (cm) as a function of time (days) with the curves of the fitted models and the inflection points estimated with each adjustment



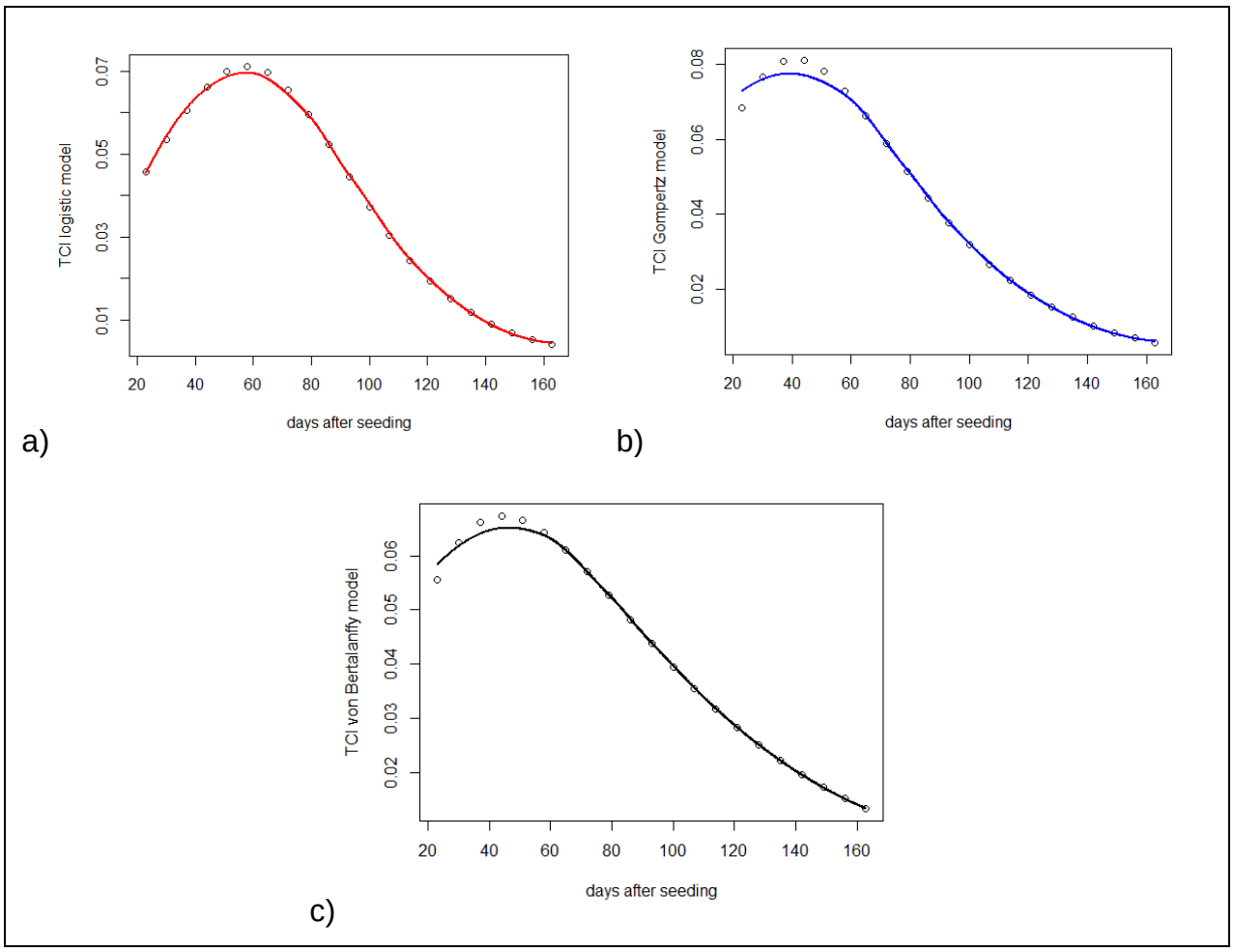
Source: Author's (2021)

Using the logistic, Gompertz and von Bertallanfy models to the height of the papaya plant, Silva Neto (2014), obtained similar results in relation to the behavior of the curve and states that the nonlinear models through the growth curve and its characteristics of fast and easy interpretation have been framed to represent the cultures, as being the Gompertz model the indicated one to evaluate the curve of the average height of the plant in papaya culture.

Figure 3 shows the Instantaneous Growth Rate (TCI) for each model. The estimated maximum daily growth for the logistic, Gompertz and von Bertallanfy models were approximately 0.07cm, 0.08cm and 0.065cm, respectively. Note that in the logistic model there is a peak in the TCI at 60 days after sowing and then a progressive drop over the days, i.e., there is a decrease in the TCI over the days. In the Gompertz model, the peak of the TCI is seen in about 50 days after sowing, with a higher value than the logistic model, with a daily reduction in all the studied models. A similar result was obtained by Mangueira (2015) when applying the logistic model to the height of the corn plant.

TCI levels are high in the pepper plant growing phase, Figure 3, resulting from a high energy expenditure phase for the production of phytomass, reaching the appropriate plant height to start flowering, justifying the continuous drop throughout the season, since the energy will be released for the production of flowers and later fruits, leaving the plant with general architecture within the parameters for commercialization, in the case of ornamental plants, or in suitable conditions to resist the production with no tipping.

Figure 3 - Graphs of instantaneous absolute growth rates (TCI) for the logistic (a), Gompertz (b) and von Bertalanffy (c) models



Source: Author's (2021)

4 CONCLUSIONS

According to the fit of the logistic, Gompertz and von Bertalanffy models to the height data of the biquinho-type pepper plant under water stress, the von Bertalanffy model was the most appropriate, considering the statistics of the AIC and BIC.

The fit estimated a maximum growth of 7.58cm for the plants in 163 days after sowing the crop. In addition, the highest speed of growth per day was obtained up to 44 days after sowing, when the reached height was 2.25cm.

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