Production of biquinho pepper in different growing seasons characterized by the logistic model and its critical points

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ABSTRACT: *The objective of this study was to characterize the production of biquinho pepper through the interpretation of parameter estimates from the logistic model and its critical points obtained by the partial derivatives of the function, and to indicate the best cultivar and growing season for subtropical climate sites. For this, a 2x3 factorial experiment was conducted with two cultivars of biquinho pepper (BRS Moema and Airetama biquinho) in three growing seasons (E1: October 2015, E2: November 2015, E3: January 2016). The logistic non-linear model for fruit mass was specified as a function of the accumulated thermal sum, and the critical points were calculated through the partial derivatives of the model, in order to characterize the productive performance of the crop by the biological interpretation of the estimates of the three set parameters. In E3, temperatures close to 0 ºC during the experiment were lethal to the plants, and a linear regression model was used in this case. The production of the cultivars in E1 and E2 were well characterized by the estimated logistic models, and the most productive cultivar was Airetama biquinho in all evaluated seasons. This cultivar also presented higher concentration of production. The two cultivars did not differ significantly with regards to productive precocity. For E3, it was not possible to interpret the parameters in the same way as for E1 and E2, since the use of the linear model did not allow the same interpretations performed for the nonlinear model, reaffirming its applicability horticultural crops of multiple harvests.*

Key words: *Capsicum chinense, temperature, fruit mass, non-linear model.*

Produção de pimenta biquinho em diferentes épocas de cultivo caracterizadas pelo modelo logístico e seus pontos críticos

RESUMO: *O objetivo deste estudo foi caracterizar a produção de pimenta biquinho através da interpretação dos parâmetros do modelo Logístico e seus pontos críticos obtidos pelas derivadas parciais da função, bem como indicar qual a melhor cultivar e a melhor época de cultivo para locais de clima subtropical. Conduziu-se um experimento em esquema fatorial 2x3 sendo duas cultivares de pimenta biquinho (BRS Moema e Airetama biquinho), em três épocas de cultivo (E1: outubro de 2015, E2: 01 de novembro 2015 e E3: janeiro de 2016). Ajustou-se o modelo logístico para massa de frutos em função da soma térmica acumulada, e calculou-se os pontos críticos através das derivadas parciais do modelo com a finalidade de caracterizar o desempenho produtivo da cultura através da interpretação biológica destes parâmetros. Temperaturas próximas a 0 ºC durante o experimento foram letais às plantas, e por isso, para a época 3, ajustou-se um modelo de regressão linear. A interpretação dos parâmetros do modelo Logístico e seus pontos críticos permitiram que a produção das cultivares nas épocas 1 e 2 fossem caracterizadas, sendo que a cultivar mais produtiva é Airetama biquinho em todas as épocas de transplante. Essa cultivar também apresenta maior concentração de produção no período. Quanto a precocidade produtiva as duas cultivares não diferiram significativamente. Sobre a época 3, não foi possível interpretar da mesma forma, pois o ajuste do modelo linear não permite as mesmas interpretações realizadas para o modelo não linear, reafirmando a sua aplicabilidade em cultura olerícolas de múltiplas colheitas.*

Palavras-chave: *Capsicum chinense, temperatura, massa de frutos, modelo não-linear.*

INTRODUCTION

       Capsicum is a genus that comprises several species of peppers, with different color, flavor and shapes (KIM, et al., 2014; PAULUS et al., 2017). These peppers are of great economic and social importance in several regions of the world with Vietnam, Indonesia, India, Brazil and China as leading producers (FAOSTAT, 2019). The biquinho pepper (*Capsicum chinense* Jacq.) is a species that has small round fruits forming a beak. The fruits have low pungency and are characterized as sweet fruits that can be consumed *in natura* or processed (HEINRICH et al., 2015).

The biquinho pepper is multiple-harvest crop. That is, it can be harvested several times from the same plant during the production cycle. Because it is a species found in tropical climates, it is temperature dependent. Its base temperature is 16.5ºC (VALERA, 2017), and at lower temperatures, growth is paralyzed. As a result of this, it is possible to simulate the consequence of the air temperature on the growth and development of the plants as a function of the accumulated thermal sum (MENDONÇA et al., 2012).

Plant growth responds non-linearly to temperature (PAINE et al., 2012) and, thus, the use of non-linear models is promising for modeling the growth of plants (YIN et al., 1995; PAINE et al., 2012), allowing biological interpretations of the critical points of the adjusted function (MISCHAN et al, 2011; SARI et al., 2018; SARI et al., 2019). Peppers respond to the accumulated thermal sum, and the crop cycle is associated with the amount of degree-days for each stage of development (FILGUEIRA, 2003).

For multiple-harvest crops, logistic regression models can efficiently describe fruit production which is the appropriate for crops such as *Capsicum annuum, Cucurbita pepo*, *Solanum melongena*, *Phaseolus vulgaris* and *Fragaria ananassa* (DIEL et al., 2019; LUCIO et al., 2016; LÚCIO; NUNES; REGO, 2015; SARI, et al., 2018; SARI et al., 2019). For *Fragaria ananassa*, DIEL et al. (2019) modeled the fruit production as a function of STa (accumulated thermal sum) for the logistic, Gompertz and von Bertalanffy models in different parameterizations and concluded that the Logisitic model described fruit production best while the models of Gompertz and von Bertalanffy overestimate the parameter that represent the production.

The objective of this study was to characterize the production of the biquinho pepper through interpretation obtained estimates of the parameters of the logistic model and its critical points obtained by the partial derivatives of the function, as well as to indicate the best cultivar and the best growing season for subtropical climate sites.

MATERIALS AND METHODS

Site of cultivation and experimental design

The experiment was conducted in the experimental area of the Federal University of Santa Maria - Frederico Westphalen *Campus* (27º 23'40" S, 53º25'45" W, at 493 m above sea level). The climate of the region, according to the Köeppen classification, is Cfa (ALVARES et al., 2013).

The experiment was conducted in a randomized complete block design in 2x3 factorial, composed of four replicates. The two cultivars of biquinho pepper (*C. chinense*) tested were BRS Moema ISLA® and Airetama biquinho ISLA® (of red and yellow color respectively, and intermediate growth) and the three cultivation periods evaluated were on October 21, 2015 (E1), November 20, 2015 (E2) and January 9, 2016 (E3). Replicates consisted of 10 plants for the cultivar BRS Moema and 12 plants for the cultivar Airetama biquinho.

Conditions for cultivation and preparation of the study area

Seeds of the two cultivars were sown in three seasons (E1: August 24, 2015, E2: October 1, 2015, E3: November 13, 2015), in expanded polystyrene trays with 128 cells, filled with commercial substrate Carolina®, with two seeds deposited per cell. After the first true leaves were emitted, thinning was performed, with only the most vigorous seedling remaining in each cell.

After 22 days of germination for the E1 and E2 seasons, and 20 days for the E3 season, the seedlings were transferred to a floating type system, in benches at 1.5 m above ground, and irrigation maintained with nutrient solution by Hidrogod®, Calcinit® and chelated iron (mixed mineral fertilizer) at concentrations of 0.5, 0.4 and 0.06 g L-1, respectively. Irrigation was performed daily from 8am to 10am in the morning shift and from 3pm to 5pm in the afternoon shift to the transplant point, which occurred when the seedlings had 60 days for the E1 and E2 seasons, and 40 days for the season E3.

Preparation of the area for seedling transplantation and experimental conditions

The soil of the experimental area in which the seedlings were transplanted was plowed. Correction of acidity and soil fertilization was performed according to the recommendation of the Committee on Soil Chemistry and Fertility (COMISSÃO DE QUÍMICA E FERTILIDADE DO SOLO - CQFSRS/SC, 2004). After this stage, the beds were covered with black mulching, to maintain soil moisture and avoid competition with weeds.

Seedlings were transplanted at a recommended spacing by the company producing the seed with 0.80 m between rows and 0.50 m between plants for BRS Moema and 1.20 m between rows and 0.80 m between plants for Airetama biquinho in addition to the border. Irrigation was carried out via drip irrigation according to crop needs and

meteorological conditions, and phytosanitary control was performed when necessary.

Temperature data were collected from the automatic meteorological station of the National Institute of Meteorology (INMET), located approximately 50 m away from the experiment site. The average air temperature was calculated (Tave). The accumulated thermal sum (STa) was calculated using the following equation: $STa = \sum STd$ in ºC day (ARNOLD, 1960) where: $STd=(Tave-Tb)$ ºC day, for base temperature (Tb) was used 16.5 °C (VALERA, 2017).

Fruits were harvested when more than 50% of the fruits of the plot were ripe. For BRS Moema 16 harvests were carried out for the E1 seasons, 12 harvests for the E2 season and 12 harvests for the E3 season. For the cultivar Airetama biquinho, 15 harvests were realized for E1, 13 harvests for E2 and 12 for E3. The fruits harvested in each plot were weighed using a digital scale (grams), and the mass of fruits per plant was calculated as the total mass of fruits harvested divided by the number of plants of the plot.

Statistical analyzes

The values of average mass of fruits per plant (g plant⁻¹), obtained in each harvest, were accumulated successively in each plot: H1, H1+H2, H1+H2+H3, ..., H1+H2+H3+H4+H5+H6+H7+H8+H9+H10…. The logistic model was selected a priori since it presents lower intrinsic and parametric nonlinearity values when compared with other nonlinear growth models. In addition, the logistic model was selected in other researches with multiple-harvested crops (LÚCIO et al., 2015; DIEL et al., 2019; SARI et al., 2018). The logistic model for the cultivars in the E1 and E2 seasons was specified as

$$yi^1 = \frac{\beta_1}{1+e^{(\beta_2 - \beta_3 x_i)}} + \varepsilon_i$$

Where ^1y_i is the dependent trait (accumulated number or weight of fruits per plant); x_i is accumulated thermal sum (STa), in degree days, elapsed from time of transplant of seedlings to harvest (independent trait) and equidistant; β_1 represents the horizontal asymptote, that is, the point of stabilization of production; β_2 is the parameter that indicates the distance (in relation to abscissa) between the initial value and the asymptotes; β_3 is a parameter associated with the growth rate; and ε_i represents random error.

Parameter estimates were obtained by the ordinary least squares method, using the Gauss-Newton iterative process. Normality, heteroscedasticity and residual independence were verified by the Shapiro-Wilk, Breusch-Pagan and Durbin-Watson tests, respectively. Subsequently, the coefficient of determination (R²) and intrinsic (c^I) and parametric (c^θ) nonlinearity were estimated by the curvature method proposed by Bates and Watts, (1988) $c^I \times \sqrt{F_{(\alpha;p,n-p)}}$ e $c^\theta \times \sqrt{F_{(\alpha;p,n-p)}}$, where $F_{(\alpha,p,n-p)}$ = the value of tabulated F, α = 5%, p = number of model parameters and n = number of observations. When these values are less than 0.3 and 1.0, the model has a response close to linear (unbiased), a desirable feature in non-linear models (FERNANDES et al., 2015; MISCHAN; PINHO, 2014; RATKOWSKY,, 1993; SEBER; WILD, 2003). After adjusting the model, the bootstrap confidence interval (CI) was calculated, with 10,000 resampled data sets, in this methodology the distribution of the estimated parameters is empirical (obtained by the resampling), and the confidence interval is constructed through the percentiles of the distribution. Due to non-compliance with the assumptions of the models, was decided to obtain the parameter confidence intervals through bootstrap resampling. This technique allowed to study the distributional properties of the estimators (Souza et al., 2010), being this technique the most indicated to solve problems of not attending to the presuppositions according to Ratkowski, (1983). The 95% confidence intervals (CI 95%) were computed as the difference between 97.5 and 2.5th percentile of the 10,000 parameter.

The coordinates (x, y) of the critical points of the logistic growth curve known as maximum acceleration point (MAP), inflection point (PI), maximum deceleration point (MDP) and asymptotic deceleration point (ADP) were obtained by zeroing the derivatives $\frac{d^2Y}{dx^2}, \frac{d^3Y}{dx^3}$ and $\frac{d^4Y}{dx^4}$, according to methodology described by Mischan et al. (2011).

For E3, a linear regression model was fitted for both cultivars, because the logistic model had high parametric non-linearity and crops did not present sigmoidal behavior due to the occurrence of frost at the end of April which proved lethal to plants as they were in full fructification. Statistical and graphical analyzes were performed using MASS (VENABLES; RIPLEY, 2002), lmtest (ZEILEIS; HOTHORN, 2002), car (FOX; WEISBERG, 2017), manipulate (ALLAIRE, 2014) and ggplot2 (WICKHAM, 2016) packages R software (R CORE TEAM, 2019).

RESULTS

The absolute minimum and maximum air temperatures recorded in the evaluation period

Diel et al.

were 2.0 and 35.2 °C, respectively. The average temperature showed peaks between 20 and 30 ºC, but most of the cycle remained stable (Figure 1). It can be noticed that there were periods with temperatures very close to 0 ºC, with frost occurrence. There was frost on April 28, 2016, which, by its intensity, was lethal to the plants, causing the complete death of transplanted cultivars in all seasons (Figure 2C, 2D and 2E).

The maximum temperatures remained, for a longer period of time, between 25 and 35ºC, and these are ideal for tropical climate crops with biquinho pepper; however, the minimum temperatures that occur in a shorter period of time can compromise the whole crop. The logistic model was fit to data for seasons E1, E2 and E3 (Table 1).
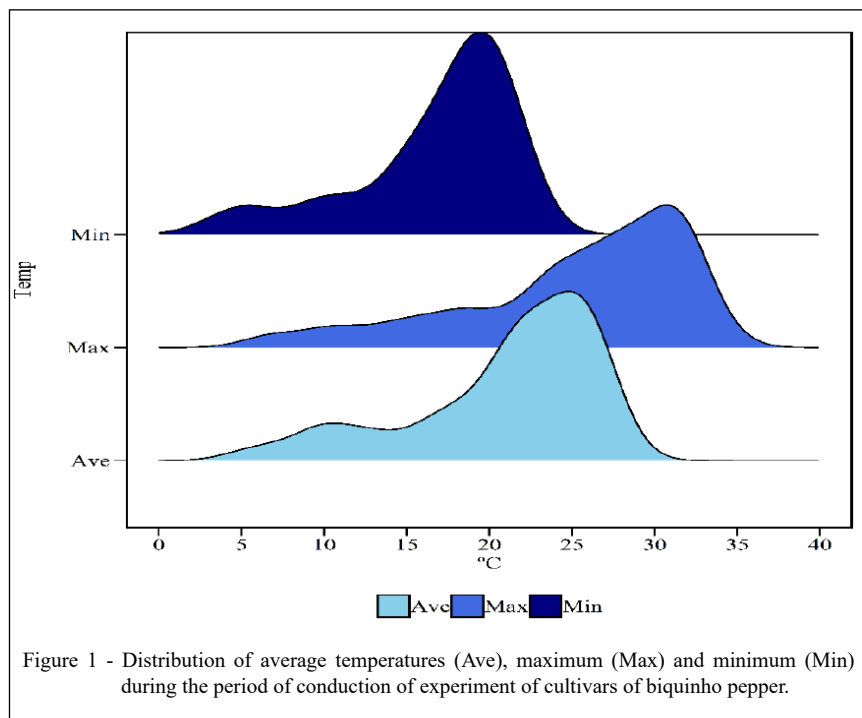
The assumptions of normality and heteroscedasticity were met; however the results demonstrated the existence of autocorrelated residuals. Due to the violation of one of the assumptions of the statistical model (independence of residuals), it was decided to generate intervals by the bootstrap resampling method. The coefficient of determination indicated good fit of the model in all treatments; however, the model can only represent the growth of a plant when it is close to linear, in this case, represented by the intrinsic nonlinearity (c^l) and parametric (c^θ). For seasons E1 and E2, c^l was lower

than 0.3 in all treatments, as well c^θ presented results lower than 1 for both cultivars in the E1 and E2 seasons, indicating that the model has a good linear approximation and its parameters are reliable. For the E3 season the same tendency was not observed, since c^θ was higher than 1 indicating that the results of the parameters were biased. Consequently, the cultivars BRS Moema and Airetama biquinho cultivated at this season, cannot be described by the nonlinear model due to the plants having been pass by lethal temperatures when in full production resulting in no sigmoid response but linear growth.

The estimates of the parameters of the adjusted logistic model and the critical points of the function allow for explaining the productive performance of the cultivars at each growing season (Table 2) and the interpretation of the differences between treatments are performed through the confidence intervals of the model parameters (β_1, β_2, β_3) (Figure 3).

We can observe that the cultivar Airetama Biquinho was the most productive in seasons E1 and E2 (highest asymptote, β_1) reaching 1047.69 and 792.65 g plant^{-1}, respectively, while BRS Moema reached 612.81 and 308.16 g plant^{-1} for seasons E1 and E2, respectively (Table 2 and Figure 3).

Still for the confidence intervals, the parameters β_2 and β_3 do not have significant

Figure 1 - Distribution of average temperatures (Ave), maximum (Max) and minimum (Min) during the period of conduction of experiment of cultivars of biquinho pepper.
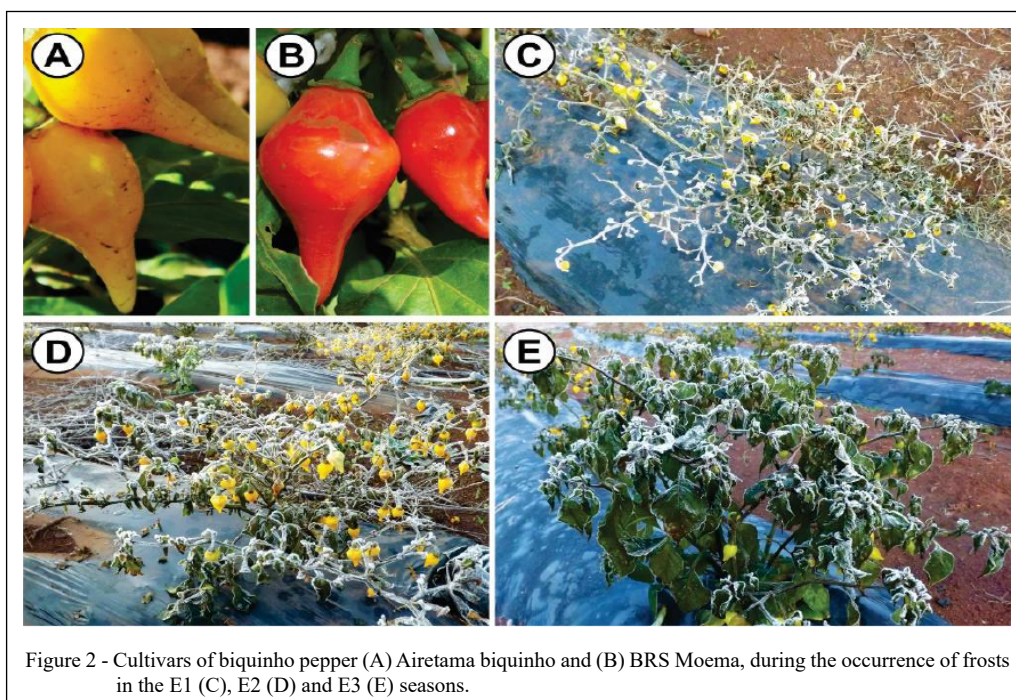
Figure 2 - Cultivars of biquinho pepper (A) Airetama biquinho and (B) BRS Moema, during the occurrence of frosts in the E1 (C), E2 (D) and E3 (E) seasons.

differences between the evaluated cultivars and cultivation seasons, that is, the precocity and the rate of fruit production are similar regardless of the cultivar chosen and the growth season (Figure 3).

The highest production values in the E1 season may also be due to the highest number of harvests to which the cultivars were submitted (16 and 15 harvest for the cultivars BRS Moema and Airetama biquinho, respectively) compared to the E2 season (12 and 13 harvest for the cultivars BRS Moema and Airetama biquinho, respectively) (Figure 4A and 4B). The stabilization of the production in the E1 season for both cultivars occurred after accumulation of more than 1000 ºC day. For the E2 season the stabilization of the production was reached at around 900 ºC day. Thus although, season E1 had higher production, the cultivars took longer to reach the point of stabilization of fruit production (Figure 4C and 4D).

As for the interpretation of the critical points of the logistic function (MAP, ADP, MDP, PI), it can be observed that in the E1 season both cultivars took longer time (STa) to reach each the points due to higher production and longer harvest time (Figure 4E and 4F). At the E1 season, the maximum acceleration point (MAP) presented higher value for the BRS

Table 1 - p values for the tests of normality, heteroscedasticity and independence of errors, nonlinearity estimates and coefficient of determination of the logistic model for fruit mass (g plant^{-1}) for two cultivars of biquinho pepper in three seasons of cultivation. SW (Shapiro-Wilk), BP (Breusch Pagan), DW (Durbin Watson, C^I (intrinsic nonlinearity) C^θ (parametric nonlinearity) and R^2 (coefficient of determination).

Season	Cultivars	SW	BP	DW	C^I	C^I	R^2
E1	Airetama biquinho	0.67	0.24	0.03	0.09	0.26	0.995
E1	BRS Moema	0.73	0.90	0.00	0.12	0.72	0.986
E2	Airetama biquinho	0.34	0.11	0.30	0.10	0.63	0.994
E2	BRS Moema	0.59	0.33	0.87	0.07	0.73	0.996
E3	Airetama biquinho	0.86	0.49	0.06	0.10	2.15	0.992
E3	BRS Moema	0.67	0.49	0.01	0.09	8.24	0.991

Table 2 - Parameters of the estimated logistic model for mass of fruits of two cultivars of biquinho pepper cultivated in two growing seasons (β_1: represents the production, β_2: represents the precocity of production and β_3: represents the rate of fruit production) and your critical points (PI: inflection point, MAP: maximum acceleration point, MDP: maximum deceleration point, ADP: asymptotic deceleration point).

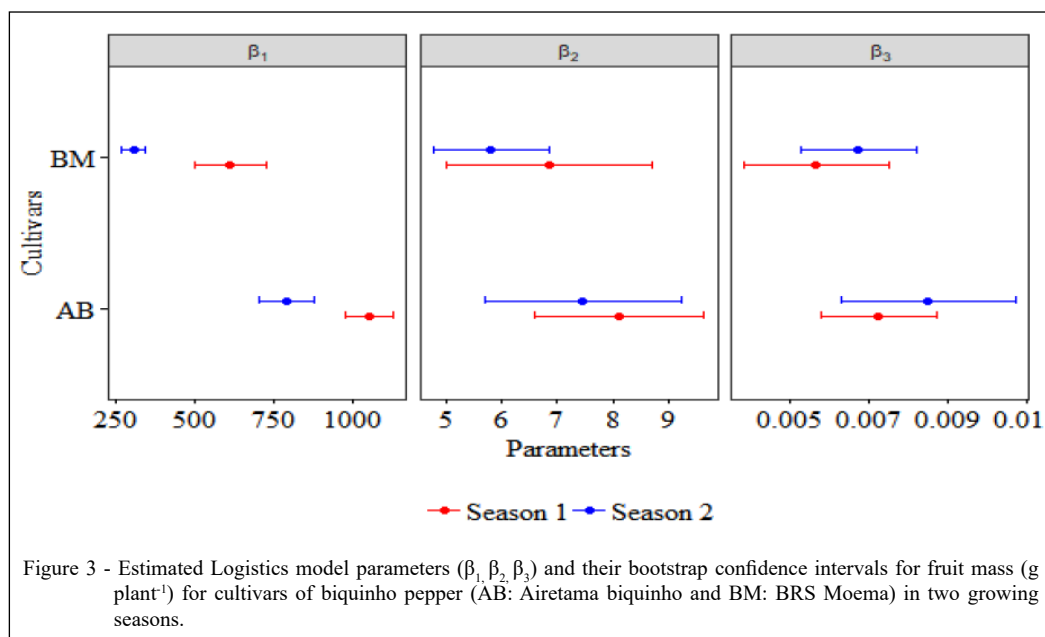| Seasons	Cultivars	β_1	β_2	β_3	PI	MAP	MDP	ADP
E1	Airetama biquinho	1047.69	8.11	0.0072	1119.56	937.70	1301.41	1436.10
E1	BRS Moema	612.81	6.84	0.0057	1209.32	976.35	1442.29	1614.84
E2	Airetama biquinho	792.65	7.44	0.0085	876.39	721.24	1031.54	1146.45
E2	BRS Moema	308.16	5.82	0.0067	862.83	667.50	1058.16	1202.82

Moema cultivar, indicating that the auto acceleration period was higher until reaching the maximum growth rate in comparison to the Airetama biquinho. In the E2 season, the highest MAP value was for the cultivar Airetama.
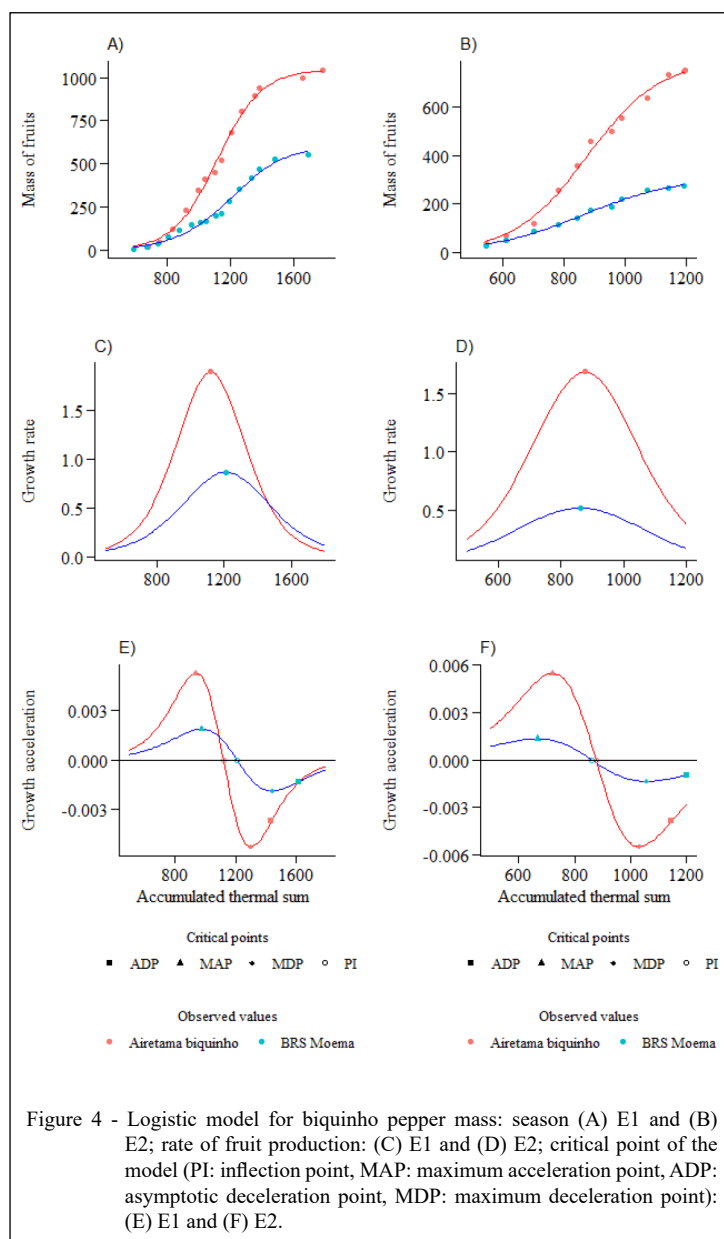
For the inflection point (PI), which means the transition in growth from increasing to decreasing rates, during the E1 season both cultivars took longer to reach the maximum rate of fruit production than during the E2 season. The cultivar Airetama biquinho arrived at the PI before BRS Moema in the E1 season; however, this behavior was reversed in the E2 season. As the production was lower in the E2 season, the PI was reached in a shorter time of thermal accumulation compared to E1. The maximum deceleration points (MDP) and asymptotic deceleration point (ADP) were also higher in the E1 season, and did not show large differences between the cultivars (Figure 4E and 4F).

The interval between the MAP and MDP points indicate the concentration of production. The cultivar Airetama biquinho had a higher concentration of production compared to BRS Moema (Figure 4E and 4F).

For the E3 season, which had its cycle interrupted at 129 days, during full fruit production, a linear model was estimated for both cultivars, which presented high coefficients of determination ($R^2 > 0.99$) (Figure 5), and the assumptions of the mathematical model were met. The cultivar Airetama biquinho showed higher production compared to the cultivar BRS Moema, indicating that independent of the growing season Airetama biquinho is more productive.

Figure 3 - Estimated Logistics model parameters (β_1, β_2, β_3) and their bootstrap confidence intervals for fruit mass (g plant^{-1}) for cultivars of biquinho pepper (AB: Airetama biquinho and BM: BRS Moema) in two growing seasons.

Figure 4 - Logistic model for biquinho pepper mass: season (A) E1 and (B) E2; rate of fruit production: (C) E1 and (D) E2; critical point of the model (PI: inflection point, MAP: maximum acceleration point, ADP: asymptotic deceleration point, MDP: maximum deceleration point): (E) E1 and (F) E2.
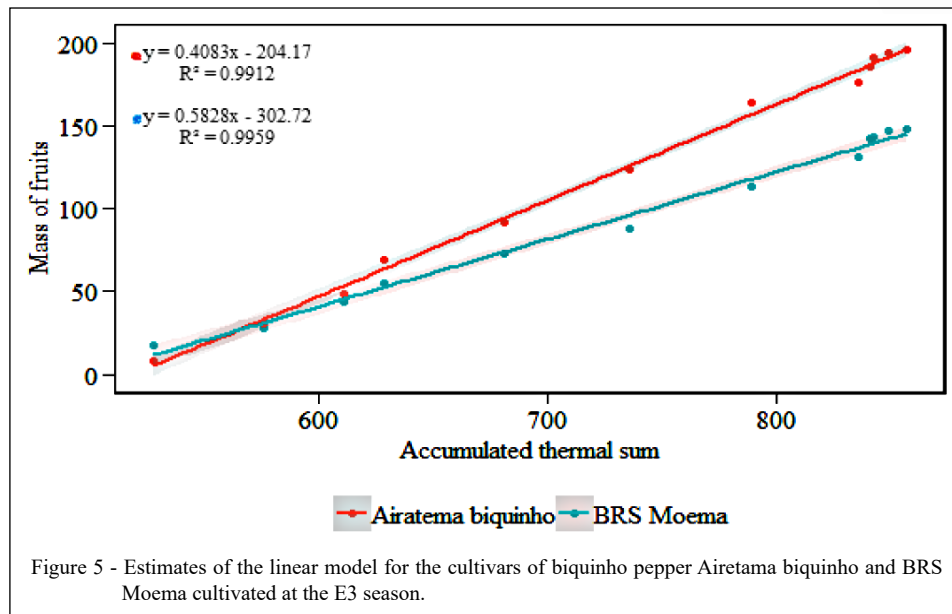
DISCUSSION

The low temperatures that the pepper plants were subjected to during the experiment caused the plants to die in all growing season. The effect of low plant temperatures depends on the intensity and degree of exposure (SHARMA, et al, 2005). Temperature is a factor that has great importance in the growth and development of plants, since it affects process from photosynthesis to the absorption of water and nutrients (AIRAKI et al., 2012), and temperatures around 0 ºC can also cause frost formation on plants (NIMER, 1979), which may be decisive for their survival.

According to the Sharma et al. (2005), the response of plants to low temperatures can be classified into three categories: sensitive, insensitive and tolerant. Sensitive plants, which included peppers, may suffer irreversible damage below 10 °C; in insensitive plants no damage occurs at temperatures above 0 ºC; and tolerant plants primary lesion occurs, but it tolerates secondary lesions.

Figure 5 - Estimates of the linear model for the cultivars of biquinho pepper Airetama biquinho and BRS Moema cultivated at the E3 season.

When low temperatures do not become lethal, they can still cause a number of negative effects on sensitive plants, such as reduced fruit quality (GUO et al., 2014), quality of seeds and the formation of the pollen tube for fruit formation (WU et al., 2012), causing significant productivity losses.

The base temperature of the biquinho pepper is 16.5 ºC (VALERA, 2017), below which the rate of development of plants decreases. In addition low temperatures can cause anthesis delays and leaf growth before the first flower (RYLSKI, 1972) and delays in fruiting and production declines such as what happened in the E2 and E3 seasons in relation to the E1 season that obtained the highest yields.

The reproductive period of the biquinho pepper fruits, described by the Logistic model, could be well characterized, because the parameters allowed biological interpretation, and the critical points of the model provide the trend of the production along the crop cycle (MISCHAN et al, 2011); which, for example, indicated precocity and rate of fruit production (DIEL et al., 2019; SARI et al., 2018; SARI et al., 2019). In addition, nonlinear growth models such as logistic are flexible enough to explain the variable performance of plants (PAINE et al., 2012) over the cycle.

The low non-linearity reported in the estimated model for the cultivars BRS Moema and Airetama Biquinho at E1 and E2 seasons indicated that the model parameters estimates are close to

being non-biased (RATKOWSKY, 1993; SARI et al., 2018) and can satisfactorily explain the productive performance of the crop. In addition to low parametric and intrinsic nonlinearity, the models presented normality and homogeneity of variances. According to the Ratkowsky (1993), when nonlinear models have parameters results close to linear, the estimators have normal distribution and only variations slightly above the minimum possible variation.

When modeling the production of the cultivars studied at the E3 season, the model was estimated; however, the parametric nonlinearity was much higher than 1 indicating that the results of the parameters of the model would have great bias (RATKOWSKY, 1983; SEBER & WILD, 2003), because the higher these values, the smaller the linear approximation of the model making the parameters less reliable (TJØRVE & TJØRVE, 2010). In this way the production of the E3 season cannot be explained by non-linear models, since it does not have sigmoid growth (PAINE et al., 2012), precisely because frost was lethal to plants during a period of full fruit production.

As for the difference in fruit yield between cultivars and growing seasons represented by the parameter β_1 of the logistic model, the cultivar Airetama biquinho had greater production compared to BRS Moema, and still, at the E1 season produced greater amount of fruits compared to the E2 season. This showed the differences between cultivars and

growing seasons, confirmed by Moreira et al. (2018), in which they emphasized the high genetic diversity and the foreseeable result of the cultivars in relation to the planting season.

Studies on yield of fruits of biquinho pepper cultivars are scarce. In the present study the production of both cultivars BRS Moema and Airetama biquinho in the E1 season were high (612.81 and 1047.69 g respectively). Heinrich et al. (2015) reported highest production averages of 1680 to 1730 g per plant in a cycle for cultivars of orange-colored biquinho pepper. In a study by Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (2012), cultivars with a red color, such as BRS Moema, with a population of 10,000 plants, can produce 20 t ha^{-1}, totaling 500 g plant^{-1}. For E2 season, both cultivars had lower production (308.16 and 792.65g for BRS Moema and Airetama biquinho, respectively). This lower production is related to the low temperatures that may have caused the reduction of flower formation and of the pollen tube (WU et al., 2012; GAO et al., 2014), as was observed for E3 season, in which production was interrupted by frost caused by temperatures close to 0 °C.

The parameters β_2 and β_3 that indicated the precocity and rate of fruit production (DIEL et al., 2019; SARI et al., 2018), are similar regardless of the cultivar chosen and growing season. In experiments that determine precocity, it is usually measured by counting days after the transplant until the beginning of the harvest. Grazia et al. (2007) determined the precocity in days of each *Capsicum annuum* plant when grown under different substrates, and observed significant differences for the early yield between treatments. Precocity analyses using the days between transplanting/planting are less informative than approaches using nonlinear models, since they allow the biological interpretation of the critical points (MISCHAN et al., 2011).

According to Sari et al. (2018), in the treatment in which the PI is reached in a smaller scale of accumulated thermal sum or time, the production of this genotype is greater precocity, even if it has not begun to produce fruits before. The same authors indicated that higher MAP indicated a low degree of maturation in the first harvests, and that a shorter interval between MAP and MDP indicated that the concentration of production was grouped in fewer days. For *Capsicum annuum*, Paulus et al. (2015) observed maximum yield in days for BRS Mari cultivars (194 DAT with 179 plant^{-1} fruits) and for the cultivar Páprica (144 DAT with 100 plant^{-1} fruits).

The estimation of the linear model in the E3 season indicated the cultivar Airetama biquinho as the most productive and, in this case, the production did not reach the PI nor the asymptote, necessary information from the point of view of the productive performance of the crop (MISCHAN et al., 2011; SARI et al., 2018). Thus, it is reinforced how a non-linear regression can show several components of information of the cycle and the productive performance of the crop which cannot be described by linear regression model or analysis of variance when you have only the production variable, for example.

CONCLUSION

The cultivar Airetama biquinho was more productive, independent of the growing season used, and should be grown in seasons where there is no occurrence of frost.

The model of logistic growth used to describe the productive performance of biquinho pepper has advantages when analyzing the production by usual methods, since the critical points of the model indicated the production performance throughout the crop cycle.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

OVSV, ADL and DS conceived and designed experiments. MID, OVSV, DS, PJM, FLT performed the experiments and data collection. MID, ADL, BGS performed statistical analyses of experimental data. MID, ADL, BGS, MVMP and TO prepared the draft of the manuscript. All authors critically revised the manuscript and approved of the final version.

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