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Nonlinear models for describing the Citrus Variegated Chlorosis in groves of two counties at northwestern Paraná state, Brazil

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ABSTRACT. In Brazil, the production of sweet oranges has been threatened by the Citrus Variegated Chlorosis (CVC) incited by the gram-negative bacterium *Xylella fastidiosa* (Wells). Commercial citrus groves in two counties at the Northwestern Paraná state were evaluated to estimate the disease progression by using parameterizations of nonlinear models. Groves of *Citrus sinensis* Osbeck, variety "Pêra", "Valência", "Natal" and "Folha Murcha" had all the plants evaluated for the presence of disease symptoms. Thereafter, different parameterizations of the Logistic and Gompertz models were fitted to these data. The goodness of fit was evaluated by the intrinsic (IN) and parameter-effects (PE) curvatures of Bates and Watts, the bias of Box and the Hougaard measures of skewness. In Loanda, the best model was the Fermi-Dirac, and in Nova Esperança the data were best fitted to the parameterization L_5, which is also a parameterization from the Logistic model.

Key words: growth curves, nonlinear models, Citrus Variegated Chlorosi.

RESUMO. Modelo não-linear para a curva de progresso de incidência da Clorose Variegada dos Citros (CVC) em dois municípios da região noroeste do Estado do Paraná. A citricultura é afetada por diversas doenças, dentre as quais a Clorose Variegada dos Citros (CVC) causada pela bactéria *Xylella fastidiosa* (Wells). Para a região noroeste do Estado do Paraná, onde foi avaliada a CVC, propõe-se encontrar modelos não-lineares de curvas de progresso de incidência da CVC que representem o percentual de plantas acometidas pela doença. Para avaliar o comprometimento dos pomares com relação à doença, foram escolhidos pomares comerciais em dois municípios, onde foi determinada a proporção de plantas doentes. Foram selecionados talhões de laranja doce (*Citrus sinensis* Osbeck) nas variedades "Pêra", "Valência", "Natal" e "Folha Murcha" e a avaliação de todas as plantas do talhão foi realizada visualmente em relação à presença ou à ausência de sintomas de CVC. Para estimar o modelo que melhor se ajustou aos dados de progresso da proporção da doença em cada talhão, foram considerados modelos não-lineares de crescimento sigmoidal, o logístico e o de Gompertz, conforme sugerido na literatura. A escolha do melhor modelo foi com base em medidas de curvatura intrínseca e paramétrica de Bates e Watts, viés de Box e medida de assimetria de Hougaard. O modelo que melhor ajustou aos dados de Loanda foi o modelo de Fermi-Dirac e aos dados de Nova Esperança foi outra reparametrização do Modelo Logístico, denominado de L_5.

Palavras-chave: curva de crescimento, modelos não-lineares, Clorose Variegada dos Citros.

Introduction

In Brazil, the sweet orange production has been threatened by the Citrus Variegated Chlorosis incited by *Xylella fastidiosa* (Wells) which is a gram-negative bacterium detected in the plant xylem (GARCIA JUNIOR et al., 1995; ROSSETTI; DE NEGRI, 1990). The CVC symptoms are foliar chlorosis that becomes dark-brown and necrotic, clusters with four up to ten small units of hard rind fruit, slowly plant growth, branch die-back, and premature leaf abscission (GARCIA JUNIOR et al., 1995; ROSSETTI; DE NEGRI, 1990).

In 1987, this disease was firstly detected in the north and northwestern São Paulo and also in the Triângulo Mineiro from where it rapidly spread to other states. In early 1993, Chang et al. (1993) and Lee et al. (1993) detected the pathogenicity of *Xylella fastidiosa* by using the Koch postulate (DE NEGRI; GARCIA JUNIOR, 1993).

Laranjeira et al. (1998) studied the spatial and temporal progression of the CVC in eleven groves of sweet orange. These groves were bi-monthly sampled, and the Logistic was considered the best model for representing the disease progression.

As similar studies are still lacking in the northwestern Paraná state, the purpose of this experiment was to find a nonlinear model for describing the disease progression by using proportional data from plants infected by the CVC.

Material and methods

The experiments were carried out in commercial groves at Nova Esperança (23°11'SL and 52°13'WL) and Loanda (22°55'SL and 53°08'WL) where the disease symptoms were counted for estimating the proportion of diseased plants.

In Nova Esperança, groves of sweet orange (*Citrus sinensis* Osbeck) cv "Pêra" with 946 plants, cv "Valência" with 927 plants, cv "Natal" with 1,047 plants, and cv. "Folha Murcha" with 1,042 plants spaced 4 m apart in the 10 rows established 7 m apart were evaluated 34, 33, 22 and 19 times from May 2000 to March 2004 in the Fazenda Laranjeira. In Loanda, groves of sweet orange cv. "Pêra" with 1,186 plants, cv. "Valencia" named here as Valência-1 with 954 plants and Valência-2 with 1,292 plants cultivated in the Fazenda Janete; the cv. "Valência" named here as Valência-3 with 437 plants and "Folha Murcha" with 609 plants spaced 4 m apart in the 10 rows established 7 m apart were evaluated 17, 30, 32, 17 and 31 times from October 2000 to December 2004 in the Fazenda Colorado.

In the present experiment, the independent variable is time (days) and the responses were the proportion of diseased plants in the grove. The best combination model data set was verified by fitting different nonlinear parameterizations of the Logistic and the Gompertz sigmoid growth curves according to Laranjeira et al. (2003) and Nunes et al. (2006).

In eleven parameterizations described in Table 1, six (y_1 to y_6) were presented by Ratkowsky (1983), the y_7 is the Fermi-Dirac parameterization, and the y_8 is the Germi model from Scharf and Seidel (1986) for describing seed germination; the y_9 and y_{10} are two parameterizations of the Gompertz model presented by Ratkowsky (1983), and the y_{11} is the model recommended by Freitas (2008).

To estimate the parameters of each model were initially used the program Table Curve 2D (JANDEL SCIENTIFIC, 1994), for to achieve the initial value and posteriorly, the NLIN procedure of SAS was utilized to determine the final estimates.

The parameter estimates and the Hougaard measures of skewness were obtained by using the NLIN procedure of the SAS (SAS, 2006), in which the Hougaard measures of skewness were calculated by the following expression

$$g_{1i} = \frac{E\left[\hat{\theta}_i - E\left(\hat{\theta}_i\right)\right]^3}{\left(\gamma_3 * L^{ii}\right)^{3/2}},$$

in which: L^{ii} are elements of $L = \left(J^T \cdot J\right)^{-1}$; J is the Jacobian matrix, $E\left[\hat{\theta}_i - E\left(\hat{\theta}_i\right)\right]^3 = n \cdot m_3$; in which m_3 is the third momentum; and n is the number of observations. The parameter estimator has a very close-to-linear behavior when $|g_{1i}| < 0.1$ (RATKOWSKY, 1990), if $0.1 < |g_{1i}| < 0.25$, the estimator is reasonably close-to-linear, if $|g_{1i}| \geq 0.25$ the skewness is very apparent, and if $|g_{1i}| > 1.0$ the behavior is highly nonlinear (RATKOWSKY, 1990). The best model has close-to-linear behavior. The measures of nonlinearity curvatures of Bates and Watts, and the bias of Box were evaluated by the IML procedure of the SAS as suggested by Souza (1998).

According to Bates and Watts (1988), the nonlinear behavior can be decomposed into intrinsic- and parameter-effect nonlinearity. The intrinsic measure of nonlinearity (IN) is the curvature of the solution locus in the sample space (BATES; WATTES, 1988; MAZUCHELI; ACHCAR, 2002; RATKOWSKY, 1983), where the solution locus is all possible solutions to the model. The minimum square solution is a point ascertaining the perpendicular distance of minimum length.

Table 1. Functions that represent the deterministic components of the re-parameterizations of the Logistics and Gompertz models used for fitting data on progress CVC.

Logistic Models		Gompertz models
L1: $y_1(t) = \frac{A}{1+\exp(B-Ct)}$	L5: $y_5(t) = \frac{1}{A+(\exp B)C^t}$	G1: $y_9(t) = A\exp(-\exp(B-Ct))$
L2: $y_2(t) = \frac{1}{A+B\exp(-Ct)}$	L6: $y_6(t) = \frac{A}{1+B\exp(-Ct)}$	G2: $y_{10}(t) = \exp(A-BC^t)$
L3: $y_3(t) = \frac{1}{A+BC^t}$	Fermi: $y_7(t) = \frac{A}{1+\exp(\frac{t-B}{C})}$	G3: $y_{11}(t) = A\exp(-B\exp(-Ct))$
L4: $y_4(t) = \frac{A}{1+(\exp B)C^t}$	Germi: $y_8(t) = \frac{A}{1+\exp(-B(t-C))}$	

t = time in days after the first evaluation. y(t) = proportion of affected plants in the plot at time t. A, B and C = model parameters.

In the linear models, the IN estimates is zero because the sample space is a straight line, a plane or a hyper-plane, but in nonlinear models this space is curvilinear, and the IN represents a measure of this curvature. Therefore, the high IN estimates are indicating a model far from the linearity.

The unequal spacing and the lack of parallelism of the parametric lines onto the tangent plane to the solution locus (PE) is the parameter-effect curvature (RATKOWSKY, 1983). This curvature is a scale which represents the maximum effect of the parameterization which is obtained from three-dimensional vectors of acceleration. In the linear case, the parameter-effect curvature is represented by parallel straight lines, the acceleration matrix is composed by zeros, and consequently the PE is zero. The significance levels of IN and PE are tested by comparing the estimates with the critical value $1/2\sqrt{F}$ in which F = F(p,n-p;α) is according to the F distribution with p and n-p freedom degrees at significance level α. The model is close-to-linear if it has IN and PE lower than $1/2\sqrt{F}$, and this linearity is highest under the lowest IN and PE. High PE values indicate, at least, one parameter far from the linear behavior.

Moreover, the bias of Box reveals which parameters are responsible for the non-linear behavior. The bias of Box is calculated by,

$$\text{Bias}(\hat{\theta}) = \frac{-\sigma^2}{2}\left[\sum_{i=1}^{n} F(\theta)F'(\theta)\right]^{-1} \sum_{i=1}^{n} F(\theta)\ \text{tr}\left[\left(\sum_{i=1}^{n} F(\theta)F'(\theta)\right)^{-1} H(\theta)\right],$$

in which: F(θ) is the matrix *px1* from the first derivatives of $f(x_t,\theta^0)$ and H(θ) is the matrix *pxp* from the second derivatives related to every element in θ^0, evaluated in x_t, where t = 1, 2, ..., n. The bias of Box is expressed in percentages which above 1% indicate a nonlinear behavior of every parameter.

Every model had the assumption of normal errors verified by using the UNIVARIATE procedure of the SAS (SAS, 2006), and the significance levels by using the Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling tests at $p < 0.05$.

The best model was chosen by the intrinsic and parameter-effect nonlinearity, bias of Box, Hougaard measure of skewness, normal errors, and the t values associated to the parameter estimates (MAZUCHELI; ACHCAR, 2002; RATKOWSKY, 1983).

Results and discussion

The coordinate p at the inflexion point (t,p) was located between 0.4 and 0.5 indicating that both models are adequate to describe data of disease proportion and growth rate of the disease versus time (Figure 1 and 2) for every variety and both locations.

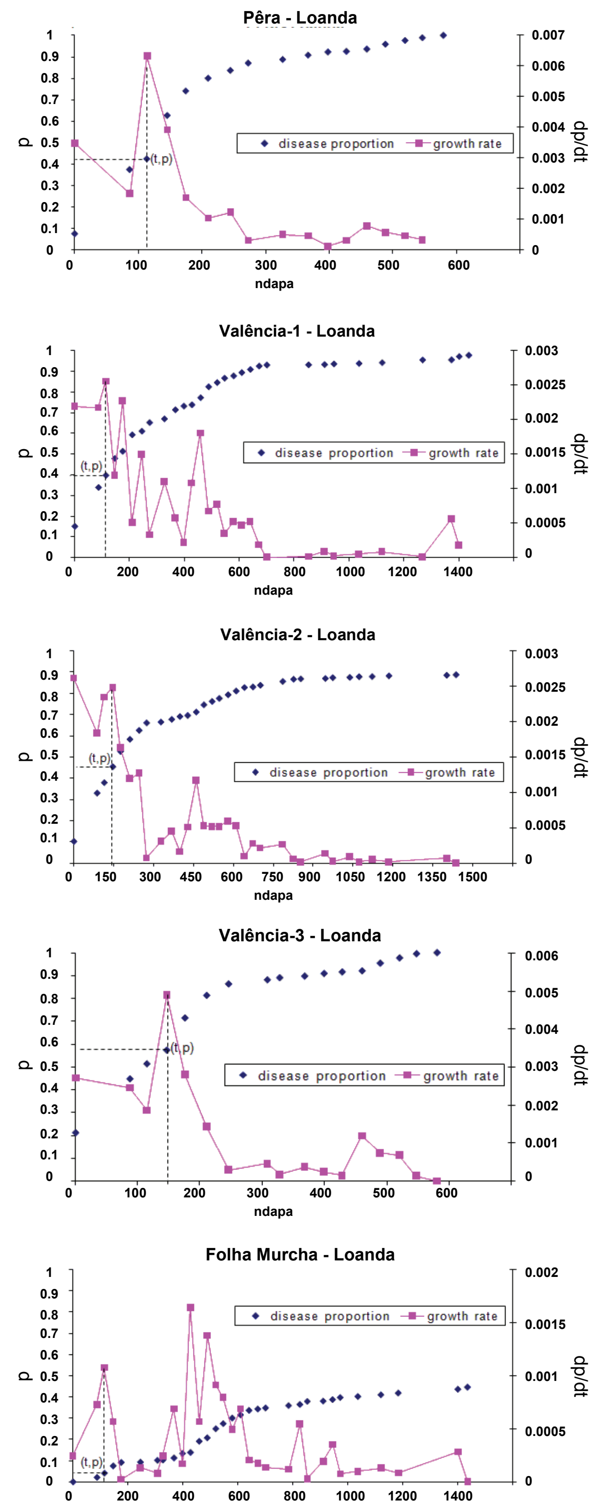

Figure 1. Disease proportion (p) and the growth rate of the disease (dp/dt) in plots of orange trees in the city of Loanda – Paraná state, (t,p) is the inflection point and ndapa is the number of days after the first evaluation.

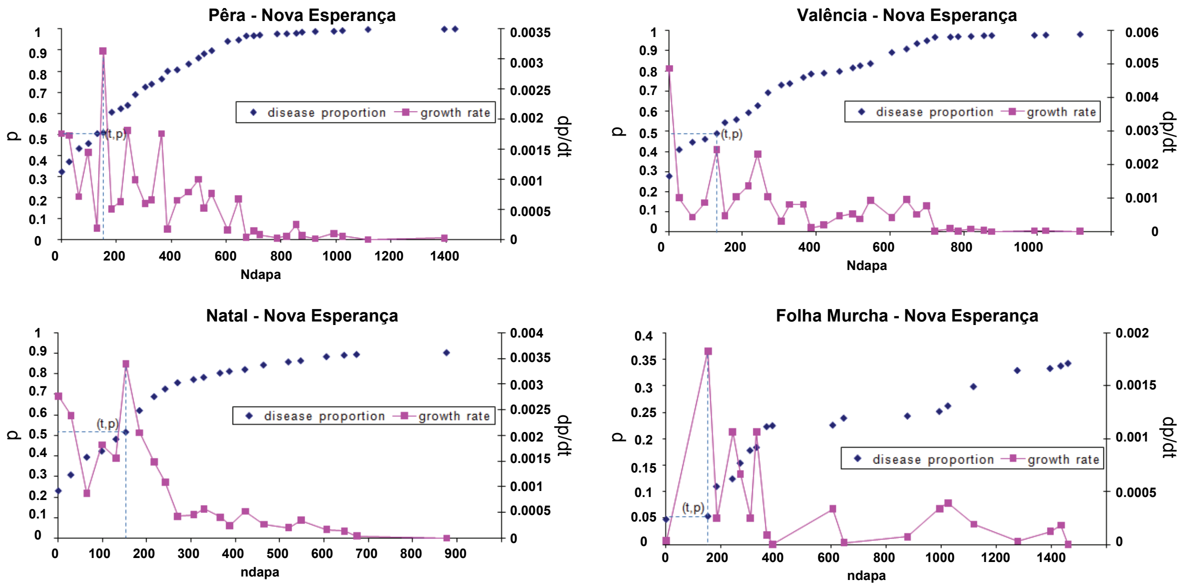

Figure 2. Disease proportion (p) and the growth rate of the disease (dp/dt) in plots of orange trees in the city of Nova Esperança – Paraná state, (t,p) is the inflection point and ndapa is the number of days after the first evaluation.

Loanda

In Loanda, the models L_1 and G_1 (RATKOWSKY, 1983) were fit to the proportional data collected from all the varieties. These models presented intrinsic-effect curvatures (IN) lower than $(1/2\sqrt{F})$ for all data sets, unlike the parameter-effect curvatures, except for data sets from the Valencia-1 (Table 2), which meant responses far from the linearity in most of the cases. Similarly, other logistic parameterizations had the parameter-effect curvatures higher than the critical level, except the Fermi-Dirac which presented goodness of fit from data from all the varieties (Table 3).

In this parameterization, the percentages of bias of Box were lower than 1% for all the parameters estimates from all data sets (Table 3).

Furthermore, the Hougaard measures of skewness were lower than 0.25 for almost parameters, except two which were slightly higher than 0.25. The Fermi-Dirac, therefore, is the model close to the linearity.

The Gompertz parameterizations, otherwise, had high parameter-effect curvatures in contrast with the intrinsic-effect curvatures, except from data of Valencia-1 (Table 4). Moreover, numerous Hougaard measures of skewness were higher than 0.25 (Table 5).

In Loanda, therefore, the Fermi-Dirac was more appropriate because of the low IN and PE curvatures common to close-to-linear behavior, bias of Box lower than 1% for all parameters, high t values associated to the parameter estimates, and distribution of the errors close to the normality ($p < 0.05$).

Table 2. Critical value $(1/2\sqrt{F})$ and intrinsic curvature (IN) and parametric (PE) measures of the models L_1 and G_1 to the data set of each variety of sweet orange from Janete and Colorado Farms, located in the Loanda county, Paraná state.

Varieties	$(1/2\sqrt{F})$	Measure of curvature Curvatura	Model L_1	Model G_1
"Pêra"	0.2734	IN	0.1253	0.1626
		PE	0.2816	0.3308
"Valência-1"	0.2906	IN	0.1253	0.1626
		PE	0.2816	0.3308
"Valência-2"	0.2919	IN	0.1453	0.1021
		PE	0.3806	0.3232
"Valência-3"	0.2734	IN	0.115	0.098
		PE	0.3428	0.4741
"Folha Murcha"	0.2913	IN	0.1044	0.1405
		PE	0.3183	0.5914

Table 3. Bias of Box for the parameters and intrinsic curvature (IN) and parametric (PE) measures of logistic models to the data set of each variety of sweet orange from Janete and Colorado Farms, located in the Loanda county, Paraná state.

Varieties	Parameter	Model							
		L_1	L_2	L_3	L_4	L_5	L_6	Fermi	Germi
"Pêra"	A	0.029%	-0.015%	-0.015%	0.029%	-0.015%	0.029%	0.029%	0.029%
	B	0.593%	3.317%	3.317%	0.593%	0.568%	3.273%	0.007%	0.554%
	C	0.554%	0.554%	-0.01%	-0.01%	-0.01%	0.554%	0.150%	0.007%
	IN	0.1253	0.1253	0.1253	0.1253	0.1253	0.1253	0.1253	0.1253
	PE	0.2816	1.0513	1.0571	0.2772	0.2651	1.0196	0.1289	0.2722
"Valência-1"	A	0.024%	-0.012%	-0.012%	0.024%	-0.012%	0.024%	0.024%	0.024%
	B	0.252%	0.594%	0.594%	0.252%	0.224%	0.592%	0.015%	0.226%
	C	0.226%	0.226%	-0.001%	-0.001%	-0.001%	0.226%	0.114%	0.015%
	IN	0.0944	0.0944	0.0944	0.0944	0.0944	0.0944	0.0944	0.0944
	PE	0.2545	0.2991	0.2998	0.2535	0.2280	0.2823	0.1150	0.2315
"Valência-2"	A	0.052%	-0.033%	-0.033%	0.052%	-0.033%	0.052%	0.052%	0.052%
	B	0.604%	1.331%	1.331%	0.604%	0.488%	1.331%	0.010%	0.502%
	C	0.502%	0.502%	-0.003%	-0.003%	-0.003%	0.502%	0.279%	0.010%
	IN	0.1453	0.1453	0.1453	0.1453	0.1453	0.1453	0.1453	0.1453
	PE	0.3806	0.4435	0.4446	0.3789	0.3490	0.4197	0.1768	0.3628
"Valência-3"	A	0.055%	-0.038%	-0.038%	0.055%	-0.038%	0.055%	0.055%	0.055%
	B	0.516%	1.589%	1.589%	0.516%	0.465%	1.583%	0.054%	0.412%
	C	0.412%	0.412%	-0.005%	-0.005%	-0.005%	0.412%	0.263%	0.054%
	IN	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
	PE	0.3428	0.5806	0.5832	0.3398	0.3142	0.5502	0.1875	0.3308
"Folha Murcha"	A	0.058%	-0.023%	-0.023%	0.058%	-0.023%	0.058%	0.058%	0.058%
	B	0.348%	3.111%	3.111%	0.348%	0.264%	2.995%	0.056%	0.353%
	C	0.353%	0.353%	-0.002%	-0.002%	-0.002%	0.353%	0.092%	0.056%
	IN	0.1044	0.1044	0.1044	0.1044	0.1044	0.1044	0.1044	0.1044
	PE	0.3183	1.3349	1.3374	0.3165	0.2692	1.2347	0.1502	0.2955

Table 4. Bias of Box for the parameters and intrinsic curvature (IN) and parametric (PE) measures of the Gompertz model to the dataset of each variety of sweet orange, from Janete and Colorado Farms, located in the Loanda county, Paraná state.

Varieties	Parameters	Model		
		G_1	G_2	G_3
"Pêra"	A	0.030%	-0.607%	0.030%
	B	0.727%	1.411%	1.411%
	C	0.510%	-0.006%	0.510%
	IN	0.1626	0.1626	0.1626
	PE	0.3308	0.5805	0.5772
"Valência-1"	A	0.018%	-0.342%	0.018%
	B	0.210%	0.184%	0.184%
	C	0.124%	-0.001%	0.124%
	IN	0.0655	0.0655	0.0655
	PE	0.2191	0.1925	0.2077
"Valência-2"	A	0.038%	-0.223%	0.038%
	B	0.511%	0.434%	0.434%
	C	0.276%	-0.002%	0.276%
	IN	0.1021	0.1021	0.1021
	PE	0.3232	0.2872	0.3049
"Valência-3"	A	0.093%	-4.017%	0.093%
	B	0.713%	0.712%	0.712%
	C	0.355%	-0.003%	0.355%
	IN	0.098	0.098	0.098
	PE	0.4741	0.4142	0.4468
"Folha Murcha"	A	0.137%	-0.116%	0.137%
	B	0.582%	1.681%	1.681%
	C	0.524%	-0.002%	0.524%
	IN	0.1405	0.1405	0.1405
	PE	0.5914	0.7578	0.7481

Table 5. Hougaard asymmetry measures for the parameters of the Gompertz model to the dataset of each variety of sweet orange, from Janete and Colorado Farms, in the Loanda county, Paraná state.

Varieties	Parameter	Model		
		G_1	G_2	G_3
"Pêra"	A	0.0871	0.0504	0.0871
	B	0.3232	0.6658	0.6658
	C	0.3196	-0.3167	0.3196
"Valência-1"	A	0.0658	0.0389	0.0658
	B	0.0573	0.1856	0.1856
	C	0.1283	-0.1277	0.1283
"Valência-2"	A	0.1018	0.0667	0.1018
	B	0.0899	0.2889	0.2889
	C	0.1898	-0.1887	0.1898
"Valência-3"	A	0.2215	0.1719	0.2215
	B	0.1702	0.4194	0.4194
	C	0.1709	-0.1686	0.1709
"Folha Murcha"	A	0.2462	0.1570	0.2462
	B	0.3269	0.7046	0.7046
	C	0.2622	-0.2612	0.2622

The best model, therefore, fitted to these data sets was the Fermi-Dirac,

$$y_7(t) = \frac{A}{1 + \exp(\frac{t - B}{C})},$$

in which: the parameter estimates for every variety are showed in the Table 6, and the graphics are represented in the Figure 3.

Table 6. Values of estimated parameters of the Logistic model Fermi-Dirac, for the data set of each variety of sweet orange, from Janete and Colorado Farms, in the Loanda county, Paraná state.

Parameter	Varieties				
	"Pêra"	"Valência-1"	"Valência- 2"	"Valência-3"	"Folha Murcha"
A	0.9476	0.9526	0.8642	0.9588	0.4226
B	116.90	171.50	148.20	101.10	477.70
C	-55.33	-163.30	-151.70	-77.58	-151.20

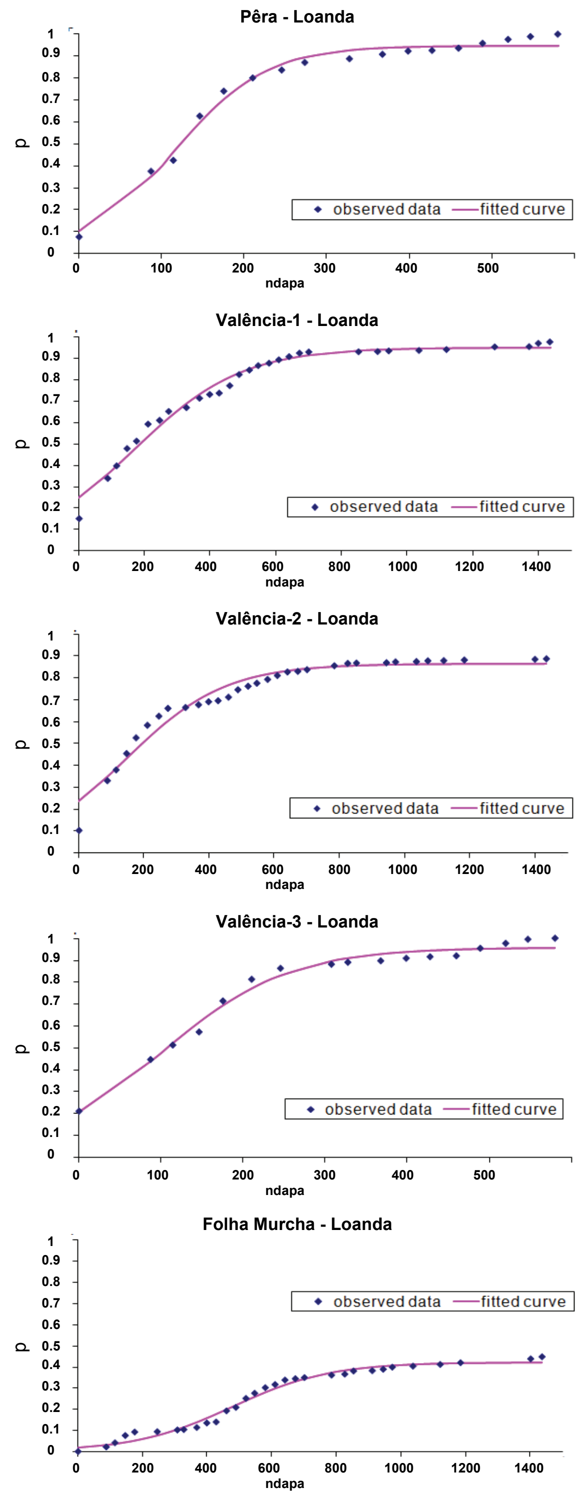

Figure 3. Fermi-Dirac model with the estimated parameters (solid line) and original data (of each variety of sweet orange, Janet and Colorado Farms, located in the Loanda county, Paraná state.

Nova Esperança

In Nova Esperança, the models L_1 and G_1 had the intrinsic-effects of curvature (IN) lower than the critical levels for almost data sets, except for data from the cv. "Folha Murcha". In contrast, the parameter-effect curvatures were higher than the critical value for data from the cv. "Valencia" and "Folha Murcha", but lower for data from cv. "Pera" and "Natal".

In Table 7, parameters from the Logistic model fit to data from the cv. "Folha Murcha" had parameter-effect curvatures high than the critical value for all parameterizations unlike for the cv. "Valencia" which had lower estimates in four of them, and the lowest values were found for the Fermi-Dirac parameterization. "Pera" and "Natal" had also parameter-effect curvatures lower than the critical. The bias of Box were lower than 1% (Table 7), and the measures of skewness were lower than 0.25, except or data from the cv. "Folha Murcha" (Table 8). Lower estimates of parameter-effect curvatures was obtained from the Fermi-Dirac model unlike the percentage of bias of Box and the Hougaard measures of skewness which were also lower in Fermi-Dirac, L_5 from all data sets, except those from the cv. "Folha Murcha". Reparameterizations of the Gompertz model have higher parameter-effect curvatures although the intrinsic curvatures were low for all data sets, except those from the "Pera" (Table 9). The Hougaard measures of skewness had values lower than 0.25, except those for data from the "Folha Murcha" (Table 10).

Table 7. Bias of Box for the parameters and intrinsic curvature (IN) and parametric (PE) measures of logistic models to the data set of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Varieties	Parameter	Model							
		L_1	L_2	L_3	L_4	L_5	L_6	Fermi	Germi
"Pêra"	A	0.006%	-0.004%	-0.004%	0.006%	-0.004%	0.006%	0.006%	0.006%
	B	0.043%	0.055%	0.055%	0.043%	0.035%	0.058%	0.014%	0.028%
	C	0.028%	0.028%	0.000%	0.000%	0.000%	0.028%	0.026%	0.014%
	IN	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.0370	0.037
	PE	0.1212	0.0993	0.0990	0.1208	0.1061	0.1173	0.0576	0.1122
"Valência"	A	0.038%	-0.027%	-0.027%	0.038%	-0.027%	0.038%	0.038%	0.038%
	B	0.217%	0.214%	0.214%	0.217%	0.163%	0.236%	0.126%	0.114%
	C	0.114%	0.114%	-0.001%	-0.001%	-0.001%	0.114%	0.138%	0.126%
	IN	0.0732	0.0732	0.0732	0.0732	0.0732	0.0732	0.0732	0.0732
	PE	0.3217	0.2597	0.2589	0.3209	0.2738	0.3156	0.1505	0.2941
"Folha Murcha 2"	A	1.075%	-0.774%	-0.774%	1.075%	-0.774%	1.075%	1.075%	1.075%
	B	4.117%	9.042%	9.042%	4.117%	1.740%	9.353%	2.580%	3.287%
	C	3.287%	3.287%	-0.013%	-0.013%	-0.013%	3.287%	3.429%	2.580%
	IN	0.3811	0.3811	0.3811	0.3811	0.3811	0.3811	0.3811	0.3811
	PE	1.4588	1.4128	1.4143	1.4556	1.2886	1.3816	0.8144	1,414
"Natal"	A	0.021%	-0.013%	-0.013%	0.021%	-0.013%	0.021%	0.021%	0.021%
	B	0.145%	0.290%	0.290%	0.145%	0.113%	0.296%	0.036%	0.122%
	C	0.122%	0.122%	-0.001%	-0.001%	-0.001%	0.122%	0.085%	0.036%
	IN	0.0718	0.0718	0.0718	0.0718	0.0718	0.0718	0.0718	0.0718
	PE	0.2151	0.1982	0.1988	0.2139	0.1890	0.2047	0.1010	0.1936

Table 8. Hougaard asymmetry measures for the parameters of logistic models to the data set of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Varieties	Parameter	Models							
		L_1	L_2	L_3	L_4	L_5	L_6	Fermi	Germi
"Pêra"	A	0.0465	-0.0199	-0.0199	0.0465	-0.0199	0.0465	0.0465	0.0465
	B	0.0227	0.1010	0.1010	0.0227	0.0267	0.0942	-0.0160	0.0542
	C	0.0542	0.0542	-0.0538	-0.0538	-0.0538	0.0542	-0.0852	-0.016
"Valência"	A	0.1450	-0.0817	-0.0817	0.1450	-0.0817	0.1450	0.1450	0.145
	B	0.0429	0.1991	0.1991	0.0429	0.0562	0.1791	-0.0111	0.1008
	C	0.1008	0.1008	-0.1001	-0.1001	-0.1001	0.1008	-0.2004	-0.0111
"Folha Murcha 2"	A	0.6696	-0.3408	-0.3408	0.6696	-0.3408	0.6696	0.6696	0.6696
	B	0.5363	1.4381	1.4381	0.5363	0.5006	1.4129	0.5513	0.6034
	C	0.6034	0.6034	-0.6003	-0.6003	-0.6003	0.6034	-0.9515	0.5513
"Natal"	A	0.0731	-0.0189	-0.0189	0.0731	-0.0189	0.0731	0.0731	0.0731
	B	0.0618	0.2412	0.2412	0.0618	0.0670	0.2304	-0.0130	0.1157
	C	0.1157	0.1157	-0.1144	-0.1144	-0.1144	0.1157	-0.1566	-0.013

Table 9. Bias of Box for the parameters and intrinsic curvature (IN) and parametric (PE) measures of the Gompertz model to the data set of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Varieties	Parameters	Models		
		G_1	G_2	G_3
"Pêra"	A	0.010%	0.462%	0.010%
	B	0.138%	0.038%	0.038%
	C	0.032%	0.000%	0.032%
	IN	0.0386	0.0386	0.0386
	PE	0.1675	0.1509	0.1649
"Valência"	A	0.046%	2.626%	0.046%
	B	0.646%	0.116%	0.116%
	C	0.091%	0.000%	0.091%
	IN	0.0617	0.0617	0.0617
	PE	0.3889	0.3473	0.3857
"Folha Murcha 2"	A	1.209%	-0.913%	1.209%
	B	4.489%	4.068%	4.068%
	C	2.243%	-0.007%	2.243%
	IN	0.2759	0.2759	0.2759
	PE	1.6714	1.4578	1.5982
"Natal"	A	0.032%	-0.249%	0.032%
	B	0.241%	0.145%	0.145%
	C	0.114%	-0.001%	0.114%
	IN	0.0665	0.0665	0.0665
	PE	0.2793	0.2493	0.2735

Table 10. Hougaard asymmetry measures for the parameters of the Gompertz model to the data set of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Varieties	Parameters	Models		
		G_1	G_2	G_3
"Pêra"	A	0.0697	0.0527	0.0697
	B	0.0161	0.0703	0.0703
	C	0.0566	-0.0562	0.0566
"Valência"	A	0.1784	0.1435	0.1784
	B	0.0261	0.1122	0.1122
	C	0.0835	-0.0829	0.0835
"Folha Murcha 2"	A	0.8698	0.6908	0.8698
	B	0.5132	1.0380	1.038
	C	0.4206	-0.4183	0.4206
"Natal"	A	0.1120	0.0797	0.112
	B	0.0429	0.1528	0.1528

Comparing the reparameterizations of the Logistic and Gompertz models, the L5 was the most adequate for fitting data from cv. "Pêra", "Valencia" and "Natal" because of its close-to-linear behavior. The biases of Box were always lower than 1%, and the measures of skewness were always lower than 0.1. They had also high values of t associated to the parameter estimates indicating goodness of fit and errors close to normality ($p < 0.05$). The model, therefore, with the best fit to these data was the:

$$\hat{y}_5(t) = \frac{1}{A + (\exp B)C^t},$$

in which: the parameter estimates are in the Table 11.

Table 11. Values of the parameters of the logistic model L5 to the data set of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Parameters	Varieties			
	"Pêra"	"Valência"	"Folha Murcha 2"	"Natal"
A	0,9958	1,0030	3,1766	1,1293
B	0,6768	0,6162	2,3905	1,0768
C	0,9948	0,9952	0,9960	0,9906

This L_5 model is represented in the Figure 4 where there are also representations of every variety of sweet orange.

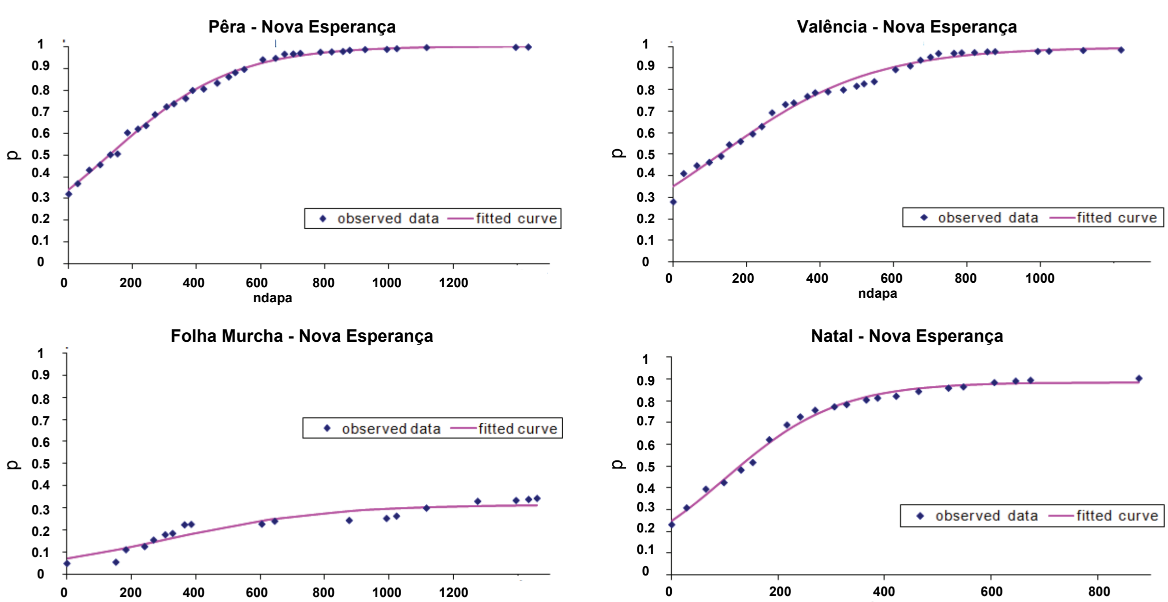

Figure 4. L5 model with the estimated parameters (continuous line) and with original data of each variety of sweet orange, from Laranjeira Farm, located in the Nova Esperança county, Paraná state.

Conclusion

The intrinsic-effects of Logistic and Gompertz parameterizations were nonsignificant for data sets from varieties, except for those data collect at Nova Esperança from the cv. "Folha Murcha". In Loanda, the parameter-effect curvature was nonsignificant only for the Fermi-Dirac. Most of the Hougaard measures of skewness were lower than 0.25, and the best responses were found for the Fermi-Dirac parameterization which was the best model fitted to these data. In Nova Esperança, the biases of Box were lower than 1%, the Hougaard measures of skewness were lower than 0.25, and most of them were obtained with the L5 which was the most adequate model to these data.

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