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Validation of a generic model for predicting garlic rust

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Abstract

Garlic rust (*Puccinia porri*) occurs in all producing regions. Currently, the control of fungal diseases is being done through the use of fungicides. Frequently, these products are applied without proper technical considerations, using unapproved or inefficient products for disease control, increasing production costs and environmental pollution. The objective of this work was to validate the generic disease model for predicting garlic rust. The work was carried out at the Experimental Station of Caçador – Epagri, during the agricultural years 2019, 2020 and 2021. In the three years, the cultivars Gigante (early garlic cultivar) and San Valentim (late garlic cultivar) were used. The rust occurred naturally in the field. Rust severity was evaluated weekly until disease progress stabilized. The "generic disease model" was used to predict garlic rust. The validation of this model was given from the graphic comparison between the observed values of rust severity in the field and simulated data by model. It was observed that in the year 2019, for both cultivars, the disease intensity was higher in relation to the seasons of 2020 and 2021. However, the generic model correctly simulated the beginning of the rust epidemic in the garlic crop in the three years studied, and may assist the producer in deciding the ideal time to start disease management.

Keywords – Control – Epidemiology – Garlic rust – *Puccinia porri*

Introduction

Brazilian garlic production in 2020 was just over 155 thousand tons, a growth of 15.92% compared to the 2019 season. The state of Santa Catarina is currently the third largest garlic producer in Brazil, with a production of 13.2 thousand ton in the 2020 season, second only to the states of Minas Gerais and Goiás, respectively (CONAB 2021). In Santa Catarina, garlic is grown mainly in the municipalities of Brunópolis, Caçador, Curitibanos, Fraiburgo, Frei Rogério, Lebon Régis and in the midwest regions of the state. The climate in this region is Cfb type, temperate, with mild temperatures in winter.

The garlic production is often limited by the occurrence of rust (*Puccinia porri* (Sowerby) G. Winter 1881 syn. *Puccinia allii* (DC.) F. Rudolphi), in all regions which, during the cultivation of susceptible plants, environmental conditions favor their progress. Regarding the life cycle of *Puccinia porri*, there is a divergence among authors regarding its ecio/autoecious nature, with some

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suggesting that all stages of its life cycle occur on a single host (Massola et al. 2016). However, Anikster et al. (2004) conducted an experiment where they inoculated leaves of *Allium sativum* (garlic) and *A. ampeloprasum* (wild leek) with basidiospores obtained from North American collections. On *A. sativum*, uredinia production was observed 9 to 13 days after inoculation, followed by telia formation 7 to 21 days later. No pycnia or aecia were observed. None of the North American collections caused infection on *A. ampeloprasum*. In contrast, inoculation with basidiospores of *P. porri* collected in the Middle East resulted in pycnia formation in 7 to 12 days on both *A. sativum* and *A. ampeloprasum*. If nectar from several of these pycnia were intermixed on the leaves, aecia appeared 3 to 4 days later and were well developed by 10 days.

The disease occurs in conditions of high relative humidity and low rainfall. Moderate temperatures favor infection, which is inhibited when values above 24 °C and below 10 °C are recorded (Massola et al. 2016). Mallmann et al. (2022) studying the garlic rust pathosystem, found that temperatures around 15 ºC and humidity above 12 hours are the ideal conditions for the disease to occur.

The measure commonly used to control garlic rust has been based on systematic fungicide applications according to a predetermined and often unnecessary application schedule due to the non-occurrence of conditions predisposing to the disease. Although incipient in Brazil (Reis 2004), warning or forecasting systems for diseases are in common use in other countries (Campbell & Madden 1990). Most of these predictors relate the presence of the pathogen to the optimal situation of climatic variables that predispose the plant to the disease, creating and developing models that allow issuing alerts for spraying (Pitblado 1992, Lacy 1994, Rogers & Stevenson 2006, Bounds & Hausbeck 2007).

This development has been aided by the advancements in computer science, bringing advantages and operational facilities for the construction of models that represent the complex agricultural pathosystems, in a more generic way.

In the garlic crop there is little information regarding the validation of disease prediction models, for this reason the objective of this work was to validate the generic disease model for the prediction of garlic rust.

Materials & Methods

The experiments were carried out at the Experimental Station of Caçador – Epagri – in the municipality of Caçador-SC geographic coordinates 26°49'17.2"S 50°59'09.7"W in the micro-region of Joaçaba, during the agricultural years 2019, 2020 and 2021. For three years, the Gigante (early) and San Valentim (late) cultivars were used, planted in nearby areas, from April 1st to 15th and July 1st to 15th, respectively. Each cultivar was planted in five beds measuring 4.0 m in length and 1.2 m in width, totaling 4.8 m2. Each bed consisted of five rows with approximately 35 plants in each row, spaced 0.30 m between rows and 0.10 m between plants. Fertilization was carried out according to the need of the soil. The occurrence of rust occurred naturally in the field, without the need for artificial inoculation. No fungicides were used to control the disease throughout the crop cycle.

From the garlic bulbing stage onwards, weekly assessments of rust severity began with the aid of a diagrammatic scale (Azevedo 1998), until the disease progresses stabilised. Severity data measured in the field were compared with simulated data for model validation. The “generic disease model” was used to predict garlic rust. The word “generic” refers to a parameterizable model, that is, used for different cultures and diseases, it being only necessary to calibrate it correctly for each pathosystem. For model development life cycle of the pathogen was taken as a basis, creating an easily parameterizable structure, seeking, in this way, to obtain the expected results. As the integration models developed (model of growth and disease progress), all processing takes place by exchanging data on the number of organs created and the available area of each one (healthy area) at that moment and by information on the area that the disease is using (infected area).

The model is a daily step model, and was fed with climate data observed by the INMET Meteorological Station, located close to the experimental area. This model was calibrated with information taken from the literature and/or from tests carried out at the experimental station of Epagri in Caçador-SC, referring to the garlic rust pathosystem, such as: incubation period, latency period, infection period, maximum production of spores, infection efficiency, initial inoculum, hours of leaf wetness, temperature, alloinfection, autoinfection, initial pustule size, among others (Table 1).

In the 2021 season, a spore collector was installed next to the experiment to measure the amount of rust spores present in the environment. From the combination of temperature, relative humidity (≥90%) and precipitation variables (input data), the model performs the simulation and provides the amount of spores present in the environment as output. The minimum (initial) value of spores entered in the model was 100 spores/m^3. The amount of 15,000 spores/m^3 is considered ideal to start the rust epidemic, at which point a favorable alert for the occurrence of the disease is issued. From this alert, it is suggested to start spraying with specific fungicides to control rust.

Rust severity data were submitted to the logistic model y=d/1+EXP(-b*(X-e)), where d is the largest asymptote, and is the X value at the inflection point, while b is the slope at the inflection point. The parameter b can be positive or negative and, consequently, y can increase or decrease as X increases.

Table 1 Parameters used in the garlic rust simulator.

Variable Name	Description	Unit	Example
Infection efficiency	Infection efficiency	Proportion	0.17
Environment favorability	Environment interference in the disease development	Proportion	1
Deposition frequency	Frequency of spore deposition	Proportion	0.05
Initial inoculum	Initial inoculum value	Unit	100
Size cloud field	Limit spores permanence in the field cloud	Unit	5
Size cloud plant	Limit spores permanence in the plant cloud	Unit	7
Size cloud organ	Limit spores permanence in the organ cloud	Unit	10
Maximum spores production	Maximum spores production	Unit/day	3,000
Maximum spores density	Maximum spores density in the cloud	Unit	15,000
Number of autoinfection spores	Number of autoinfection spores	Proportion	0.1
Cloud of aloinfection spores on the same plant	Cloud of aloinfection spores on the same plant	Proportion	0.04
Cloud of aloinfection spores in new plant	Cloud of aloinfection spores in new plant	Proportion	0.02
Favorable temperature for infection	Cardinal temperatures used to calculate temperature favorability in the infectious period (maximum, minimum and optimum)	Temperatures	30, 2 e 15
Favorable temperature in the latent period	Cardinal temperatures used to calculate temperature favorability in the latent period (maximum, minimum and optimum)	Temperatures	40, 0 e 27
Latent period	Latent period length	Days	6
Growth function in the latent period	Function used to calculate the lesion expansion in the latent period (visible lesion)	Function	Gompertz
Growth parameter in the latent period	Parameters of the function used to calculate the lesion expansion in the latent period (visible lesion)	Parameters	0.0161858; 1.563509; 0.441721

Table 1 Continued.

Variable Name	**Description**	**Unit**	**Example**
Infection period	Infectious period length	Days	20
Growth function in the infection period	Function used to calculate the lesion expansion in the infection period (visible lesion)	Function	Exponential
Wetting threshold	Hours of wetting (minimum) required to create new lesions	Hours	6
Maximum number of organs	Maximum number of organs per plant	Units	10
Maximum lifetime of an organ	Maximum lifetime of an organ per plant	Days	20

Results

The generic disease model was calibrated using several parameters involved in infection and severity of garlic rust (Table 1). The validation of this model was based on the adjustment of the values of these parameters and, later, on the graphic comparison between the observed values of rust severity in the field and the alerts issued by the model.

The Figs 1–6 show the results obtained in the field in different agricultural years, demonstrating that the simulator was correct in predicting the beginning of the epidemic for the different years in both cultivars. The importance of efficiently predicting the beginning of the epidemic is highlighted, in order to delay the first spraying as much as possible. The disease develops rapidly when there is free humidity and temperatures around 15 ºC and its spread occurs rapidly in the presence of wind and rain. In view of this, after the onset of the rust epidemic, the alert system will be less important in managing the disease, especially in rainy years with a predominance of the El Nino phenomenon, as occurred in the 2019 harvest (Figs 1, 2), with frequent alert issues that year.

In the agricultural years 2020 and 2021 (Figs 3–6), the model efficiently predicted the beginning of the rust epidemic, however, it sent more spaced alerts throughout the garlic crop season, when compared to the 2019 season (Figs 1, 2). The disease intensity in both cultivars was higher in the year 2019 (Figs 1, 2) compared to the 2020 (Figs 3, 4) and 2021 (Figs 5, 6) crops, possibly due to the highest amount of rainfall recorded that year, due to the El Nino phenomenon (Figs 7, 8, 9).

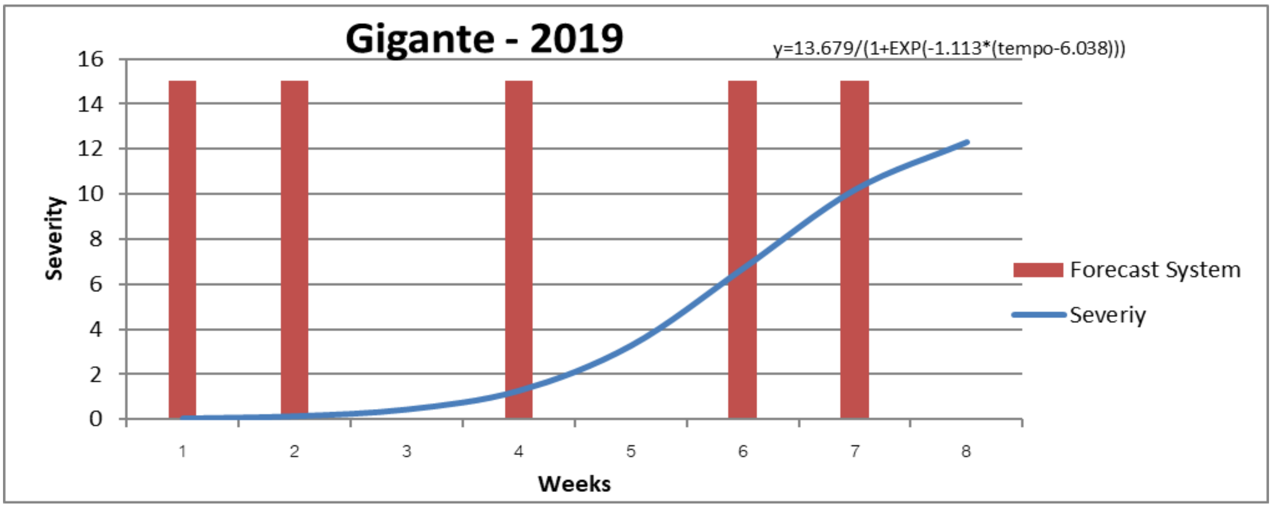

Fig. 1 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. Gigante in the 2019 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

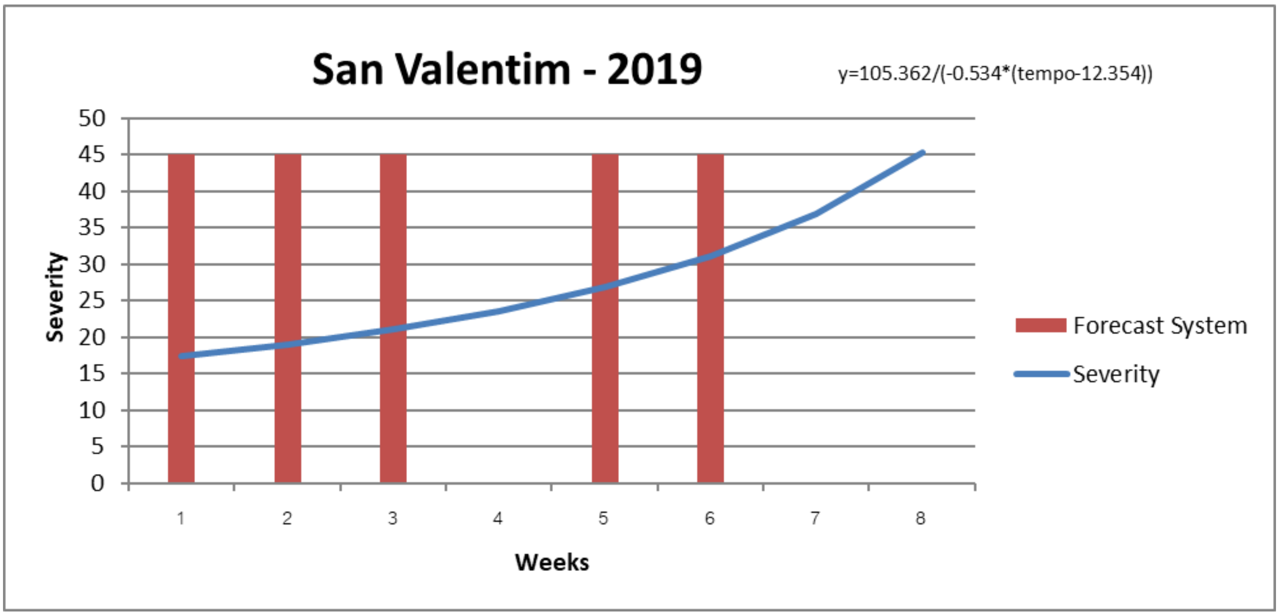

Fig. 2 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. San Valentim in the 2019 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

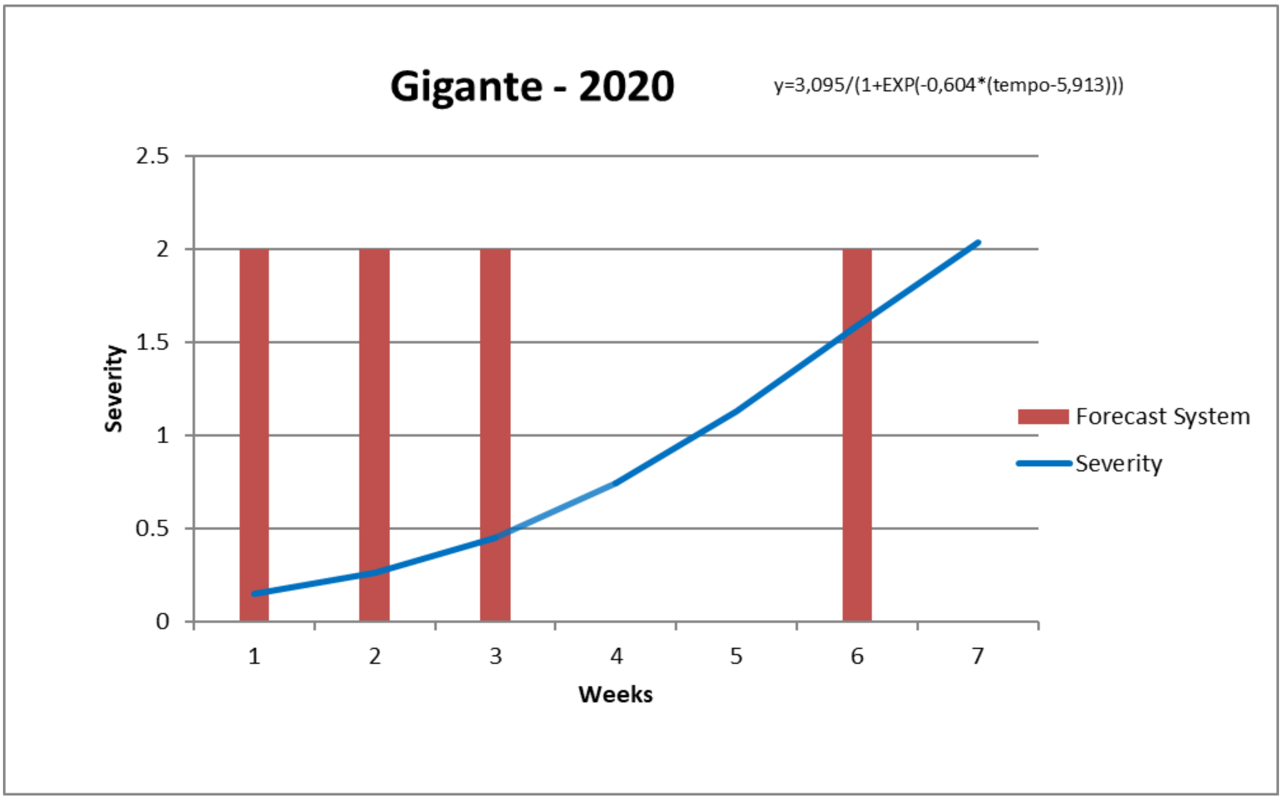

Fig. 3 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. Gigante in the 2020 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

Regarding the criteria for measuring the quality of the models shown in Table 2 (AIC, BIC and LokLik), model 5 was the most accurate for measuring the severity of garlic rust.

Analyzing the AIC (Akaike Information Criteria) criterion for measuring the quality of the models, we obtained -30.8 for model 5, -11.0 and -2.8 for models 3 and 2, respectively. The premise is that the smaller the value, the more adequate the model is in relation to the real values.

Regarding the Bayesian criterion of Schwarz (Bayesian Information Criteria-BIC), the model's adequacy increases as the obtained result decreases. The values found using the BIC criterion were -30.0; -11.2 and -2.5 for models 5, 3 and 2, respectively, reinforcing the finding that model 5 was more adequate to represent the severity of garlic rust.

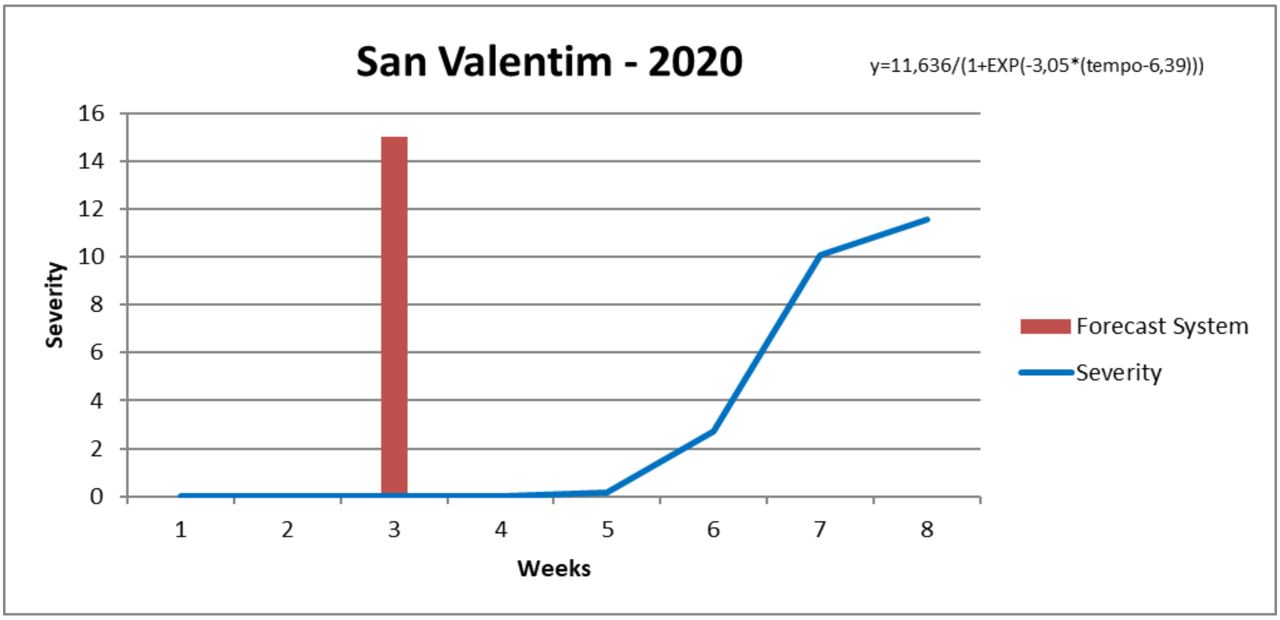

Fig. 4 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. San Valentim in the 2020 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

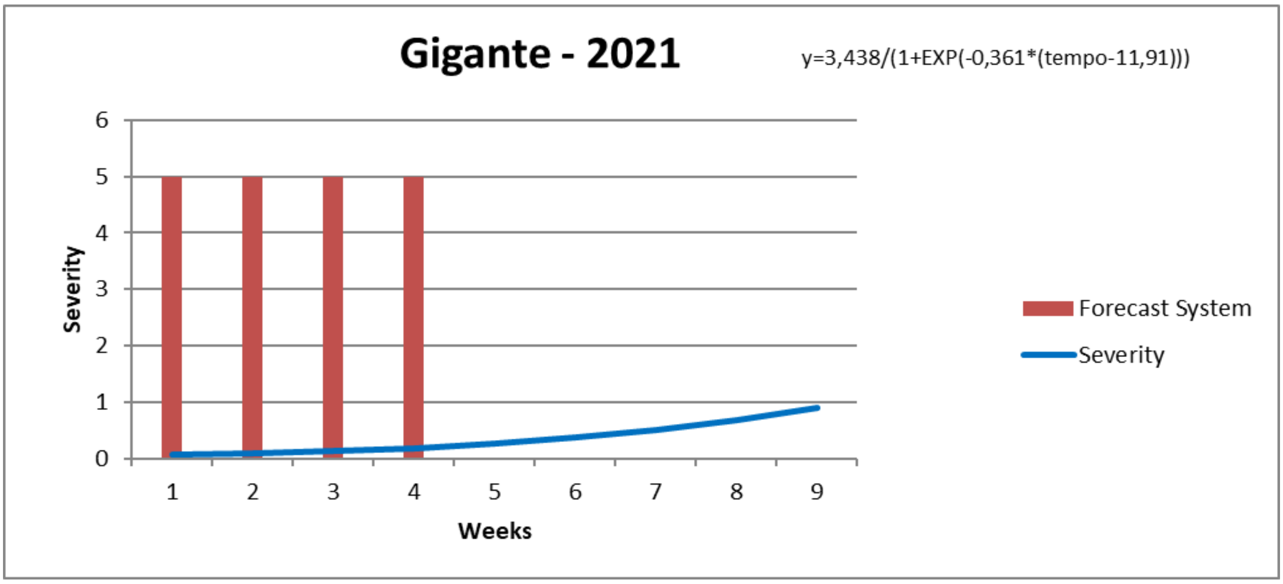

Fig. 5 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. Gigante in the 2021 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

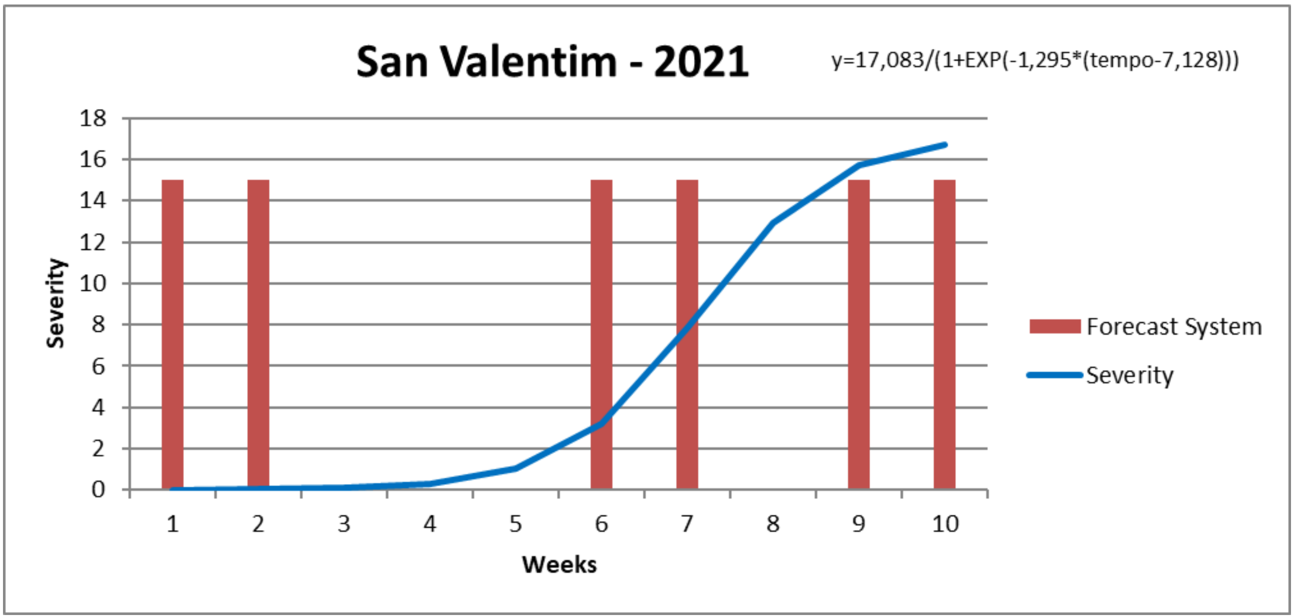

Fig. 6 – Comparing the severity of observed rust with the forcasted favorable conditions that trigger its occurrence for cv. San Valentim in the 2021 season.
*Red bars indicate only the occurrence of favorable conditions for rust infection predicted by the model.

On the other hand, the logarithmic value of a regression model (Lok.Lik.), the higher the value the better the fit of the model, also certified that model 5 presents the best fit, followed by models 3 and 2, respectively. Therefore, model 5 demonstrates that the severity of rust in the 2021 harvest using the Gigante cultivar had a less accentuated growth in relation to the other years and with less severity of the disease.

Table 2 Criteria values for measuring the quality of the models.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
b	1.113	0.534	0.604	3.050	0.361	1.295
	(0.113)	(0.049)	(0.104)	(1.104)	(0.067)	(0.255)
d	13.679	105.362	3.095	11.636	3.438	17.083
	(1.329)	(184.10)	(0.719)	(1.128)	(3.614)	(1.108)
e	6.038	12.354	5.913	6.390	11.910	7.128
	(0.214)	(3.966)	(0.842)	(0.185)	(4.371)	(0.194)
Num.Obs	7	8	7	8	9	10
AIC	3.1	-2.8	-11.0	27.0	-30.8	32.9
BIC	2.9	-2.5	-11.2	27.4	-30.0	34.1
Log.Lik.	2.429	5.420	9.477	-9.522	19.390	-12.450
isConv	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
finTol	0.000	0.000	0.000	0.000	0.000	0.000

*Model 1 = Weekly evaluations of garlic rust severity in the Gigante cultivar during the 2019 season
*Model 2 = Weekly evaluations of garlic rust severity in the San Valentim cultivar during the 2019 season
*Model 3 = Weekly evaluations of garlic rust severity in the Gigante cultivar during the 2020 season
*Model 4 = Weekly evaluations of garlic rust severity in the San Valentim cultivar during the 2020 season
*Model 5 = Weekly evaluations of garlic rust severity in the Gigante cultivar during the 2021 season
*Model 6 = Weekly evaluations of garlic rust severity in the San Valentim cultivar during the 2021 season

Discussion

Epidemic simulation models have been envisioned by many as a useful tool for farmers and extension agents, with a view to supporting them in decision-making regarding disease control, being able to project situations and estimate the system's response to the type management or available alternatives (Delponte 2004, Fernandes 2004).

Pavan & Fernandes (2009) developed a generic disease model. The model can be parameterized to cover several diseases that occur in a given crop. The model design aims at a detailed representation of disease progress. The model was designed to mimic a fungal disease cycle.

Mallmann (2009) calibrated and validated the "generic disease model" using observed data on the severity of wheat leaf rust collected in Passo Fundo – RS, during the years 2000 to 2007. According to the author, the generic model correctly simulated the progress of wheat rust, corroborating the results obtained in the present work, for the garlic rust pathosystem.

According to Fernandes et al. (2021) the "generic disease model" for predicting wheat blast became operational in Bangladesh and Brazil. The model adequately described the epidemic and non-epidemic years in both countries.

Other simulation models were tested and validated to issue phytosanitary alerts in different crops, with the aim of rationalizing the application of fungicides in crops, as is the case of tomatoes in the state of Santa Catarina. Becker et al. (2010) validated the models by MacHardy and Colpan40 for tomato late blight, with the possibility of 54.6% reductions in spraying required to control late blight compared to the conventional method.

Becker (2019a, b) also validated the TomCast model for black spot and septoria in tomato in Caçador-SC. After validating these forecast models at the integrated production pilot unit (Sispit), Ciram/Epagri made them available on the Agroconnect platform at no cost to the automatic grower, helping him decide when to apply the fungicide to control diseases.

In this context, the simulation models, in particular the generic model for garlic rust, fulfill their main function, that is, to simulate and predict the occurrence of the first rust pustules in the garlic crop (beginning of the epidemic), helping producers to take decision of the moment to start spraying, reducing product waste and increasing control efficiency.

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