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Analysis of Climatic Risk Favorability of Grapevine Fungal Disease Occurrence for Santa Teresa, Espírito Santo State, Brazil

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Abstract

The State of Espírito Santo, Brazil, has micro-regions with different climatic and soil conditions, which promote grapevine cultivation vine in several municipalities. However, the grape production process is strongly threatened by foliar fungal diseases, and its control increases the cost of production significantly. In turn, the use of models of prediction of disease occurrence allows the identification of regions with climatic risk potential for grapevine. Hence, the objective of this work was to analyze the agro-climatic favorability of climatic risk for occurrence of fungal diseases of downy mildew (*Plasmopara viticola*) and *Botrytis cinerea* on the grapevine for the municipality of Santa Teresa, in the state of Espírito Santo. Predictive models of favorability of downy mildew and *B. cinerea* were used. The number of sprayings was determined by the calendar system and by the rainfall system, according to the length of the cycle. Therefore, a series of meteorological data from 2007 to 2016 was used. The results showed that the frequency of days with low risk of mildew was 2%, medium risk 5%, high risk 93%. For *B. cinerea*, these values were 32%, 68%, and 0%, with low, medium and high risk, respectively. The number of required sprayings, according to the weather conditions, was lower than the number of sprayings recommended by the calendar system. The relationship between the risk of occurrence of the evaluated diseases showed a higher agro-meteorological favorability of occurrence of mildew in relation to *B. cinerea*.

Keywords: *Botrytis cinerea*, predictive models, mildew, sustainability, winegrowing

1. Introduction

The winemaking chain is potentially relevant due to its economic and social importance, generating labor and income in the country and the agro-industrial sector for the Country. The Brazilian winegrowing occupies an area of approximately 77,700 ha, with annual production varying between 1,300 and 1,400 thousand tons (Mello, 2015). In 2016, approximately 60% of the total production was commercialized for fresh consumption and 40% destined to the processing of wines and grape juice (Mello, 2015).

The State of Espírito Santo has in its microregions different conditions of climate and soil, which facilitates the production of the grapevine in several municipalities. Due to the pioneering spirit, tradition and dedication of the farmers, the municipality of Santa Teresa stand out as the largest producer of grapes and wine, with an expressive planted area (53 ha), knowledge and technology transfer for all the state (Incaper, 2016).

Grape crop is affected by several factors that depreciate its yield, where the occurrence of fungal diseases (Sonego et al., 2005) excels. According to Tonietto et al. (2012), downy mildew (*Plasmopara viticola*) and bunch rot (*Botrytis cinerea*) stand out among the major diseases that affect grapevines in the Espirito Santo region. For mildew, the most favorable moment for incidence is during the emission of new leaves, while the *B. cinerea* attacks the fruits, manifesting during the maturation of the berries.

The control of these diseases has caused significant negative impacts on winemaking production and to the environment since the main control measures are the systematic application of fungicides with no predefined calendar, based on the climatic conditions and the stage of development of the disease (Angelotti et al., 2012). Thus, these practices raise production costs and enhance the risk of contamination of the environment as a consequence (Bardin et al., 2010).

In order to better understand the risk of occurrence of diseases in a given locality and period, knowledge of the appropriate climatic conditions for the establishment and development of pathogens becomes indispensable. Regarding characterization of the spatial and year-on-year variability of the occurrence of diseases, it is convenient to use meteorological data applied to disease prediction models for historical series, in search of strategies for phytopathological management (Shimano & Sentelhas, 2013).

Different climate-based methods were developed to reduce the risk of applying unnecessary fungicides to control grapevine fungal diseases. Among them, the models described by Lalancette et al. (1988a) and Broome et al. (1995), for mildew and *B. cinerea*, respectively, stand out. Therefore, the adoption of methods to predict the occurrence and control of diseases caused by downy mildew and *B. cinerea* of the grapevine may promote a decrease in the risk of epidemics, a reduction in the number of sprayings, a higher profit and a lower risk of contamination of the environment (Angelotti et al., 2012).

Studies on this theme are still scarce in the literature, justifying the study of characterizing the risk of incidence of grapevine diseases in the State of Espírito Santo, particularly on diseases caused by mildew and *B. cinerea*. As a result, the objective of this work was to analyze the agrometeorological favorability of climatic risk of occurrence of fungal diseases of mildew and *B. cinerea* on grapevine for the municipality of Santa Teresa, in the state of Espírito Santo, Brazil.

2. Material and Methods

The municipality of Santa Teresa is located at latitude 19º56'08" S and longitude 40º36'01" W, 655 meters above sea level, in southeastern Brazil, in the state of Espírito Santo, Brazil (Figure 1).

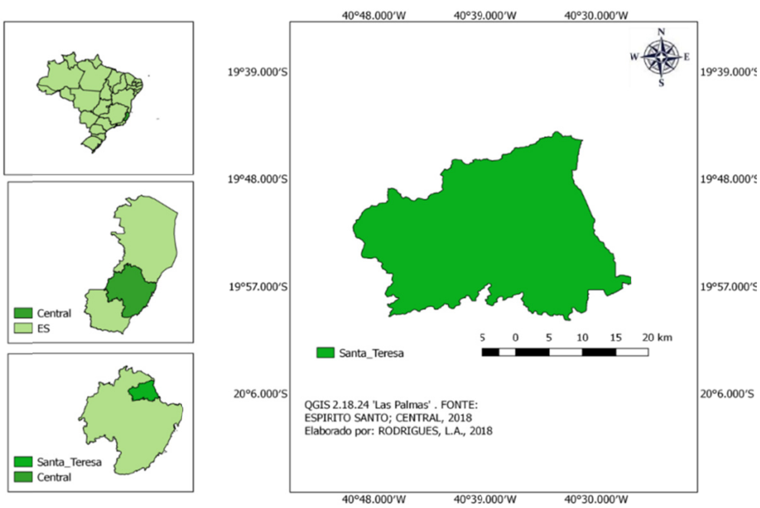

Figure 1. Geographic localization of the municipality of Santa Teresa, Espírito Santo, Brazil

The analyses of the agrometeorological favorability of mildew and *B. cinerea* occurrence were simulated through the already established models that use the temperature in the wet period and the leaf wetness duration (LWD) as input variables. The meteorological data used covers a period of 10 years (from 2007 to 2016) obtained through the automatic meteorological station of the National Institute of Meteorology located in Santa Teresa, state of Espírito Santo, Brazil and the mean of the climatic variables used can be seen in Table 1.

Table 1. Monthly means of average, maximum and minimum temperatures, relative air humidity (RH) and rainfall for the 2007-2016 period at INMET weather station in Santa Teresa, Espírito Santo, Brazil

Month	T Average	T Maximum	T Minimum	RH	Rainfall
	°C			%	mm
January	20.3	32.9	14.8	87.7	195.7
February	20.6	31.1	14.8	87.3	99.3
March	20.2	30.2	13.4	89.4	173.0
April	19.0	27.7	10.4	90.6	116.6
May	17.2	26.9	10.1	89.7	65.7
June	16.3	29.6	8.6	90.2	78.4
July	15.9	25.9	9.1	90.4	87.1
August	15.9	28.0	8.1	89.1	123.8
September	16.7	29.4	8.2	89.0	71.7
October	17.8	31.7	9.5	90.2	150.8
November	18.6	31.1	9.7	91.1	236.3
December	20.2	31.0	13.4	89.1	265.7
Total	-	-	-	-	1664.1
Means	18.2	29.6	10.8	89.5	-
Maximums	20.6	32.9	14.8	91.1	265.7
Minimums	15.9	25.9	8.1	87.3	65.7

Figure 2 shows the regular climatological water balance of the Santa Teresa region, for an available soil water capacity (CAD) of 100 mm. The largest water surplus in the soil occurs in the month of 174 mm, totaling 839 mm per year.

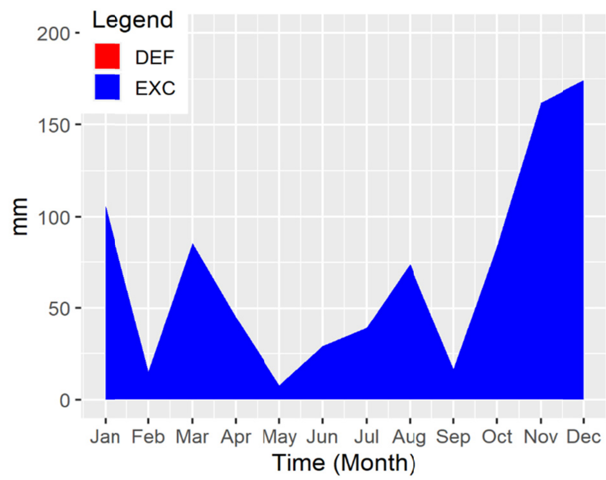

Figure 2. Regular climatological water balance record of Santa Teresa, Espírito Santo, Brazil, for the 2007-2016 period considering a 100 mm CAD

The periods of analysis were set according to the cycle of the diseases, as well as the incidence period. Therefore, for mildew, the first months after regrowth (September to December) were analyzed due to the presence of new leaves, a propitious moment. Concerning *B. cinerea*, the last two months of the cycle (January to February) were analyzed as this fungus attacks the fruits and they display when the berries mature.

The model described in Lalancette et al. (1987), Lalancette et al. (1988a) and Lalancette et al. (1988b) were selected. For mildew, this model is represented in Equation 1.

$$EI = (-0.061 + 0.018T - 0.0005T^2) \times (1 + e^{(-0.24LWD + 0.07LWD \times T^2)})^{-5} \quad (1)$$

Where, EI = infection efficiency; T = temperature over the wetting period, in °C, and LWD = leaf wetness duration of the day, in hours.

The model described by Broome et al. (1995) for *B. cinerea* was selected. This model identifies periods of infection in grape berries according to leaf wetness duration and in average temperature over wetness events. This model is represented by Equation 2.

$$II = In\left(\frac{Y}{1-Y}\right) = 2.6479 - 0.3749LWD + 0.0616LWD \times T - 0.0015LWD \times T^2 \quad (2)$$

Where, II = infection index; LWD = leaf wetness duration, in hours; T = temperature over the wetness period, in °C; *In*[Y/(1 – Y)]= disease incidence logit; and Y = infected fruit proportion.

The LWD was estimated from the number of hours in which the humidity presented NRH ≥ 90. The threshold adopted is considered a common value in the literature (Sentelhas et al., 2004). The temperature over the wetness period was computed when the number of hours of relative humidity reached values ≥ 90.

For the potential risk of occurrence of fungal diseases in grapevines, the days with high, medium and low infection risk were analyzed. For mildew, infection efficiency (IF) was characterized by zero condition when the percentage is equal to zero (0%) and the highest infection efficiency corresponding to a value of one hundred percent (100%). Also, for mildew, in the frequency analyzes, it was characterized by infection efficiency (IE) values as follows: IE less than 3.5% corresponds to a low risk of infection; IE between 3.5 and 50% corresponds to the average risk of infection; and IE greater than 50% corresponds to the high risk of infection. For *B. cinerea*, the following risk classes were considered: Infection index less than 0 corresponds to no risk of infection; between 0.0 and 0.50, low risk; between 0.50 and 1.00, medium risk; and when the index is greater than 1.0, it corresponds to a high risk of infection.

The climatic risk (CR) of occurrence of fungal diseases in the grapevine, defined as the ratio between the number of sprayings required due to the occurrence of rainfall (NSrain) and the maximum number of possible sprays based on the calendar, considering that a spray is carried out every seven days (NScalendar) as a function of cycle length: pruning-harvest, expressed in percentage was estimated according to García (2005) and Bardin et al. (2010).

$$CR = \left(\frac{NPrain}{NPcalendar}\right) \times 100 \quad (3)$$

Where, CR = climatic risk; NPrain = number of required sprayings due to the rainfall occurrence; NP calendar = maximum number of possible sprays based on the calendar, considering that a spray is carried out every seven days.

Daily rainfall values for 10-year meteorological data series (2007-2016) were used to calculate the CR. The number of sprays required to control fungal diseases in the vine was determined according to Pedro Júnior et al. (1999), using the rainfall system for a recommendation of the application of fungicides. The applications are made after the occurrence of periods that total 20 mm of rain, respecting the lack of seven days of the commercial product.

Regarding data analyses of the annual and average values of CR, this variable was classified into four classes according to the following intervals, proposed by Shimano and Sentelhas, (2013): Low < 20% (L); Moderate, between 21 and 40% (Mo); High, between 41 and 60% (H); and Very High > 60% (VH). All calculations, statistical analysis, and graph confection were elaborated using Excel electronic spreadsheet and open source program R (R Core Team, 2016).

3. Results and Discussion

The favorable prevalence of mildew was characterized by the low average frequencies of the occurrence of days with high, medium and low infection risk between 2007 and 2016, for Santa Teresa, state of Espírito Santo, as shown in Figure 3. It was observed that frequency of days with low risk was 2%, medium risk 5%, and high risk 93%, evidencing that the Santa Teresa region presents highly favorable climatic conditions for the occurrence of mildew, therefore, requiring more efficient control measures. These high-risk results were superior to those found by Alves et al. (2015), in the region of Santana do Livramento, state of Rio Grande do Sul, which verified frequency of days with low risk of 23%, medium risk, 45%, and high risk, 32% for mildew of the vine. According to Angelotti et al. (2017), the area that favors the occurrence of grape mildew in Brazil is around 90%, with 1% less favorable area and 5% unfavorable area.

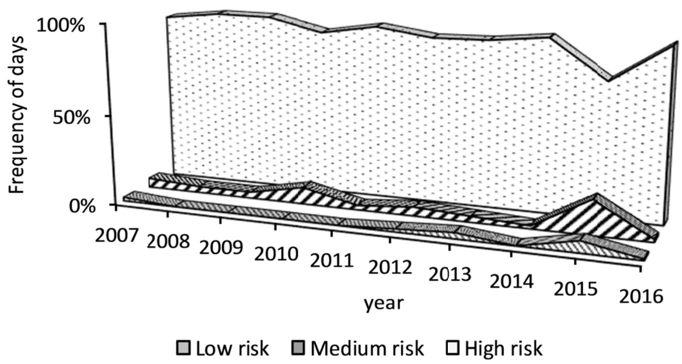

Figure 3. Occurrence frequency with days of low, average and high risk of mildew infection in Santa Teresa, Espírito Santo, calculated from 2007 to 2016 at the early months of the crop cycle

These results were confirmed by the meteorological variables, in which it was observed that the rise in the temperature results in a reduction in the favorability of the incidence of mildew of the vine (Figure 4). According to Gessler et al. (2011), the mildew epidemic can be favored by optimal temperatures between 18 and 20 °C (zoospores) and 11 and 13 °C (oospores) under saturation humidity, because under such environmental conditions, the oomycete germinative structures respond with maximum viability. For Angelotti et al. (2012) and Gava et al. (2014) the ideal temperatures for normal mildew growth range from 18 °C to 25 °C. According to Caffi et al. (2016), the combination of temperatures between 20 and 25 °C and wetness of the leaves are optimal conditions for the development of the disease of the grapevine downy mildew. Angelotti et al. (2017), when studying climate change scenarios and the occurrence of mildew in Brazilian vines, confirmed these results, in which they found the highest levels of infection occurring at 26 °C and the lowest at 31.8 °C.

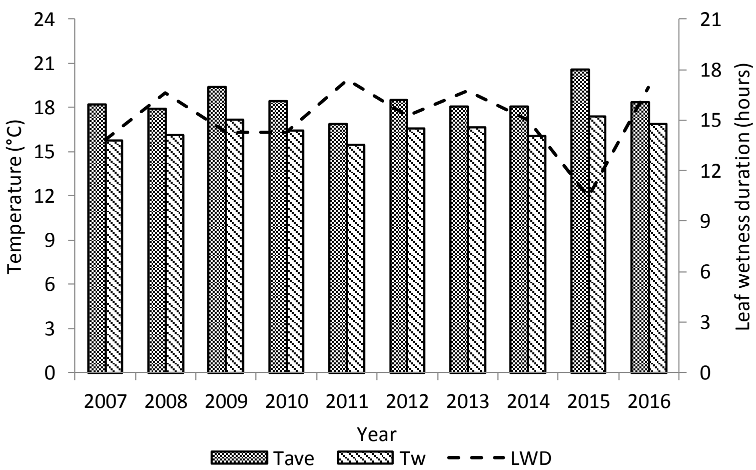

Figure 4. Average temperature (Tave), the temperature in the wet period (Tw) and leaf wetness duration (LWD) observed in Santa Teresa, Espírito Santo, between September and December, in the period from 2007 to 2016

Also, it can be seen in Figure 4 that the LWD values ranged from 10.5 to 17.4 hours. It was observed that the lower values of LWD correspond to higher frequencies of days of low and medium risk of infection of mildew. In contrast, higher values of LWD correspond to higher frequencies of days of high risk of infection of the disease, Figure 3.

In relation to the intensity of the frequency of days of *B. cinerea* occurrence for Santa Teresa, Espírito Santo in 2007 and 2016, values of 32% and 68% were observed, with low and medium risk, respectively (Figure 5). Alves et al. (2015), found frequency values of days with low 15%, medium 78% and high risk 7% for the occurrence of *B. cinerea* in the municipality of Santana do Livramento, Rio Grande do Sul, Brazil. Monteiro et al. (2015) revealed very different situations in three grape producing regions in Brazil, and the frequency of days with high risk for gray rot was 26% in Bento Gonçalves (Rio Grande do Sul), 12% in Jales (São Paulo), 7% in

Petrolina (Pernambuco), with high, high and low year-on-year variability, respectively. The results of this work showed that the Santa Teresa region presents less susceptibility to Botrytis than the other regions in Brazil that were analyzed.

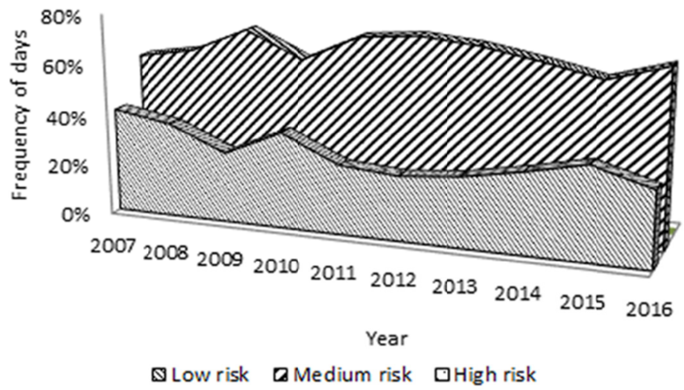

Figure 5. Frequency of occurrence of days with low, medium and high risk of *B. cinerea* infection in Santa Teresa, Espírito Santo, calculated over the period from 2007 to 2016 in the maturation months of the crop

Regarding *B. cinerea* infection, both in leaves and in berries, temperature plays a crucial role, with larger infections observed in great temperature ranges in optimal moderate temperatures, depending on the isolate and the region in the world (Elad et al., 2007). The mean temperature values ranged between 17.8 and 21.7 °C, as it is shown in Figure 6.

For LWD, values higher than 11.7 hours were found. According to De Bem (2014), average temperatures between 11.6 and 18.7 °C combined with high relative humidity and rainfall during the maturation-harvest period allow the development of Botrytis rot in the grapevine. Previous studies have shown that for this fungus, ideal growth is between 15 and 23 °C (Hed et al., 2009).

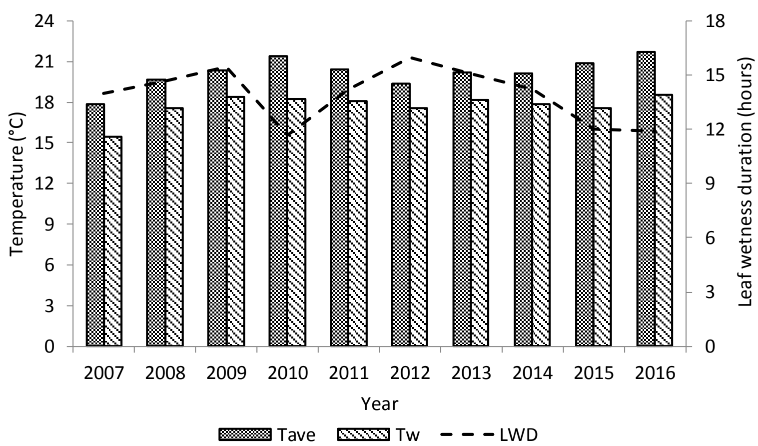

Figure 6. Average temperature (Tave), temperature in the wetting period (Tw) and leaf wetness duration (LWD) observed in Santa Teresa, Espírito Santo, between January and February, from 2007 to 2016

The average number of sprayingss based on the rainfall system, the number of sprayings based on the calendar and the average climatic risk of occurrence of mildew and *B. cinerea* for grapevine plants in Santa Teresa are shown in Table 2. It was observed that the average medium climatic risk was 37.6 and 42.0% for mildew and *B. cinerea*, respectively. However, the years with more extended wetness periods (LWD) for mildew (Figure 4) and *B. cinerea* (Figure 6), resulted in a higher climatic risk and, consequently, an NSrainfall higher than the years in which the duration of the wetting period (LWD) was shorter.

The climatic risk for the occurrence of the diseases caused by mildew and *B. cinerea* shown in this study also allows observing that in all the years analyzed, the number of required sprayings, according to the meteorological conditions, was smaller than the number of sprayings recommended by the calendar system. This demonstrates that streamlining the control of fungal diseases is necessary to reduce the risks of contamination of the environment, of the producers and the final consumer.

Table 2. Average values of number of sprayings due to rainfall (NSrainfal), number of sprayings based on the calendar (NScalendar) and average climatic risk of occurrence of diseases (CR) of mildew and *B. Cinerea* for grapevine in Santa Teresa, Espírito Santo, from 2007 to 2016

	Year	NSrain	NScalendar	CR (%)
Mildew	2007	6	15	35.3
	2008	8	15	45.9
	2009	5	15	28.7
	2010	6	15	41.2
	2011	10	15	50.2
	2012	6	15	34.4
	2013	8	15	46.3
	2014	7	15	40.2
	2015	3	15	19.3
	2016	6	15	34.4
	Mean	**6.5**	**15**	**37.6**
B. Cinerea	2008	4	9	46.7
	2009	4	9	47.5
	2010	2	9	23.7
	2011	4	9	47.5
	2012	5	9	58.3
	2013	4	9	47.5
	2014	3	9	35.6
	2015	3	9	35.6
	2016	3	9	35.6
	Mean	**3.6**	**9**	**42.0**

These results corroborate with those obtained by Shimano and Sentelhas (2013) when determining the climatic risk of occurrence of fungal diseases in different producing regions of the South and Southeast of Brazil, using the same model of spraying prediction based on the occurrence of rainfall. The authors demonstrated that the occurrence risk of these diseases varies according to the climate and that the monitoring of the meteorological conditions can help to the rational recommendation of sprayings for the control of fungal diseases in the *Vitis labrusca* grapevine.

Figure 7 shows the year-on-year variation in climatic risk of occurrence of mildew and *B. cinerea* for grapevine in Santa Teresa, Espírito Santo, Brazil. A gradual increase in the CR of *B. Cinerea* was found in comparison to the mildew, with a substantial increase also in the year-on-year variability. While the mildew CR remains classified as low, moderate and high, for *B. cinerea*, RC ranges from moderate to high.

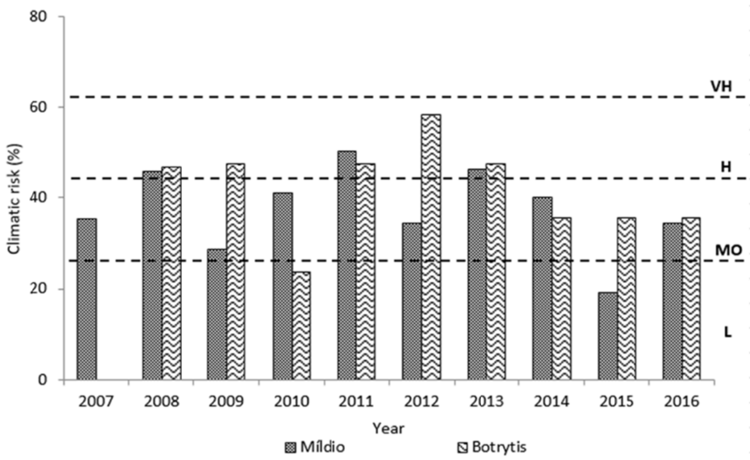

Figure 7. Year-on-year variation of the average climatic risk for the occurrence of mildew and *B. Cinerea* for grapevine in Santa Teresa, Espírito Santo from 2007 to 2016

Besides, it can be observed in Figure 7 a direct relationship between CR and total annual rainfall (Figure 8). In general, the rainy years have the highest CR values. Although the models used in this study have not yet been validated for the climatic conditions of the Santa Teresa, Espírito Santo region, these results guide the characterization of the risk of incidence of mildew and *B. cinerea* of the grapevine in the region. The authors Ricce et al. (2013) emphasize that the model of Lalancette et al. (1988b) was efficient in determining the potential severity of mildew in the state of Paraná and in generating maps that can be used for planning purposes. As observed by the authors Köycü et al. (2018), the prediction of inoculation and infection, adapted to the grapevine, may help at the time of application of fungicide to protect flowers from B. *cinerea* infections.

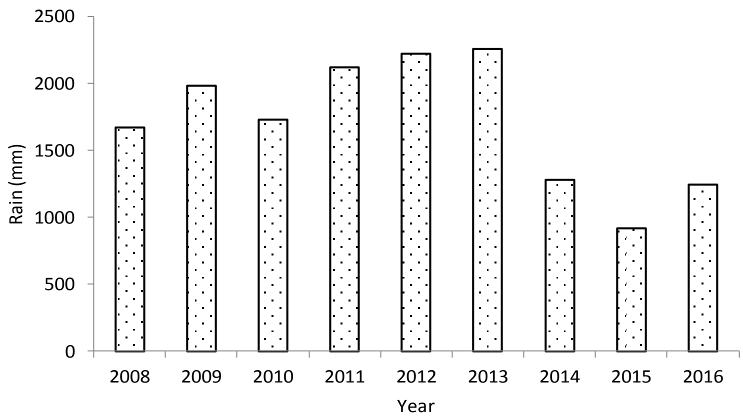

Figure 8. Year-on-year variation of the total annual rainfall for Santa Teresa, Espírito Santo, from 2008 to 2016

In relation to the two diseases evaluated in the study, a higher agrometeorological favorability of occurrence of mildew was observed in relation to *B. Cinerea*; however, the climatic risk of *B. cinerea* was higher in relation to mildew. Therefore, both need to be controlled in order to avoid damages and reduction in the productivity and quality of the grape.

It should be observed that the use of fungicides at the correct times allows a greater efficiency in the control of the disease since control in the diseases of the grapevine is made basically through the application of synthetic fungicides (Shimano & Sentelhas, 2013). Consequently, the overuse of these fungicides often causes problems related to pathogen resistance, phytotoxicity and environmental pollution (Peruch et al., 2007), which are undesirable for sustainable agriculture.

4. Conclusion

The favorability analyses of mildew and *B. cinerea* occurrence showed a frequency of days with a high risk of 93% and medium risk 68%, respectively, for the region of Santa Teresa, Espírito Santo, where the occurrence of mildew is more favorable.

The results of the analyses of the days with a low, medium and high risk of infection are primarily associated with regard to the LWD values. Lower values of LWD correspond to higher frequencies of days of low and medium risk of infection of diseases, higher values of LWD correspond to higher frequencies of days of the high risk of infection of diseases.

Higher occurrences of climatic risks of mildew and *B. cinerea* were found for grape growing in years with the most prolonged wetness periods.

The rainier years showed higher values of climatic risk. Also, for mildew, it remains in the majority of evaluated years classified as moderate and high, whereas for *B. cinerea,* it oscillates between the high and very high classes.

The number of sprays used in the calendar system was continuously greater than the necessary for the control of mildew and *B. Cinerea*.

References

Alves, M. E. B., Cavalcanti, F. R., & Monteiro, J. E. B. (2015). *Análise da favorabilidade de ocorrência de doenças fúngicas da videira no município de Santana do Livramento-RS*. Embrapa Informática Agropecuária-Artigo em anais de congresso (ALICE). Congresso brasileiro de agrometeorologia, 19, 2015, Lavras. Agrometeorologia no século 21: O desafio do uso sustentável dos biomas brasileiros. *Anais....* Lavras: UFLA.

Angelotti, F., Gava, C. A. T., Batista, D. D. C., Fernandes, J. M. C., & Pavan, W. (2012). *Sistema de Alerta e Previsão para Doenças da Videira*. Petrolina: EMBRAPA/MAPA.

Angelotti, F., Hamada, E., Magalhães, E. E., Ghini, R., Garrido, L. D. R., Júnior, P., & José, M. (2017). Climate change and the occurrence of downy mildew in Brazilian grapevines. *Pesquisa Agropecuária Brasileira, 52*(6), 426-434. https://doi.org/10.1590/s0100-204x2017000600006

Bardin, L., Pedro Júnior, M. J., & Moraes, J. F. L. D. (2010). Risco climático de ocorrência de doenças fúngicas na videira 'Niágara Rosada' na região do polo turístico do circuito das frutas do Estado de São Paulo. *Bragantia, 69*(4), 1019-1026. https://doi.org/10.1590/S0006-87052010000400030

Broome, J. C., English, J. T., Marois, J. J., Latorre, B. A., & Aviles, J. C. (1995). Development of an infection model for Botrytis bunch rot of grapes based on wetness duration and temperature. *Phytopathology, 85*(1), 97-102. https://doi.org/10.1094/Phyto-85-97

Caffi, T., Legler, S. E., González-Domínguez, E., & Rossi, V. (2016). Effect of temperature and wetness duration on infection by *Plasmopara viticola* and on post-inoculation efficacy of copper. *European Journal of Plant Pathology, 144*(4), 737-750. https://doi.org/10.1007/s10658-015-0802-9

De Bem, B. P. (2014). *Intensidade de míldio da videira em folha e podridão cinzenta em cacho em variedades viníferas sob diferentes sistemas de sustentação* (Dissertação Universidade do Estado de Santa Catarina, Brasil).

Elad, Y., Williamson, B., Tudzynski, P., & Delen, N. (2007). *Botrytis* spp. and diseases they cause in agricultural systems—An introduction. In Y. Elad et al. (Eds.), *Botrytis: Biology, Pathology and control* (p. 412). Dodrecht: Springer. https://doi.org/10.1007/978-1-4020-2626-3_1

García, B. I. L. (2005). *Risco climático de ocorrência da requeima da batata na região dos Andes, Venezuela* (Tese, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Brazil).

Gessler, C., Pertot, I., & Perazzolli, M. (2011). *Plasmopara viticola*: A review of knowledge on downy mildew of grapevine and effective disease management. *Phytopathologia Mediterranea, 50*(1), 3-44.

Hed, B., Ngugi, H. K., & Travis, J. W. (2009). Relationship between cluster compactness and bunch rot in Vignoles grapes. *Plant Disease, 93*(11), 1195-1201. https://doi.org/10.1094/PDIS-93-11-1195

INCAPER (Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural). (2016). *Fruticultura: Polos de fruticultura*. Retrieved from https://incaper.es.gov.br/fruticultura-uva

Köycü, N. D., Özer, C., Solak, E., & Delen, N. (2018). Infection of Botrytis cinerea in Different Fungicide Application Programs in Semillon Grape. *Journal of Tekirdag Agricultural Faculty, 15*(3), 61-67.

Lalancette, N., Ellis, M. A., & Madden, L. V. (1987). Estimating infection efficiency of *Plasmopara viticola* on grape. *Plant Disease, 71*, 981-983. https://doi.org/10.1094/PD-71-0981

Lalancette, N., Ellis, M. A., & Madden, L. V. (1988a). Development of an infection efficiency model for *Plasmopara viticola* on American grape based on temperature and duration of leaf wetness. *Phytopathology, 78*(6), 794-800. https://doi.org/10.1094/Phyto-78-794

Lalancette, N., Madden, L. V., & Ellis, M. A. (1988b). A quantitative model for describing the sporulation of *Plasmopara viticola* on grape leaves. *Phytopathology, 78*(10), 1316-1321. https://doi.org/10.1094/Phyto-78-1316

Mello, L. M. R. (2015). *O Brasil no Contexto do Mercado Vitivinícola Mundial: Panorama 2014* (p. 192). Bento Gonçalves: Embrapa Uva e Vinho.

Monteiro, J. E. B. A., Conceição, M. A. F., Cavalcanti, F. R., & Segundo, F. A. (2015). *Caracterização do risco de ocorrência de mildio da videira em três regiões produtoras*. Congresso brasileiro de agrometeorologia, 19, Lavras. Agrometeorologia no século 21: O desafio do uso sustentável dos biomas brasileiros. *Anais...* Lavras: UFLA.

Pedro Júnior, M. J., Pezzopane, J. R. M., & Martins, F. P. (1999). Uso da precipitação pluvial para previsão de épocas de pulverização visando controle de doenças fúngicas na videira 'Niagara Rosada'. *Revista Brasileira de Agrometeorologia, 7*, 107-111.

Peruch, L. A. M., de Medeiros, A. M., Della Bruna, E., & Stadinik, M. (2007). Biomassa cítrica, extrato de algas, calda bordalesa e fosfitos no controle do míldio da videira, cv. Niágara Branca. *Revista de Ciências Agroveterinárias, 6*(2), 143-148.

R Core Team. (2016). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from https://www.R-project.org

Ricce, W. S., Caramori, P. H., & Roberto, S. R. (2013). Potencial climático para a produção de uvas em sistema de dupla poda anual no Estado do Paraná. *Bragantia, 72*(4), 408-415. https://doi.org/10.1590/brag.2013.042

Sentelhas, P. C. (2004). *Duração do período de molhamento foliar: Aspectos operacionais da sua medida, variabilidade espacial em diferentes culturas e em sua estimativa a partir do modelo de Penman-Monteith* (p. 182, Tese Livre-Docência, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo, Brazil).

Shimano, I. S. H., & Sentelhas, P. C. (2013). Risco climático para ocorrência de doenças fúngicas da videira no Sul e Sudeste do Brasil. *Revista Ciência Agronômica, 44*(3), 527-537. https://doi.org/10.1590/S1806-6690 2013000300015

Tonietto, J., Mandelli, F., Zanus, M. C., Guerra, C. C., & Pereira, G. E. (2012). O clima vitícola das regiões produtoras de uvas para vinhos finos do Brasil. *Clima, zonificación y tipicidad del vino en regiones vitivinícolas iberoamericanas* (pp. 111-145). Madrid: CYTED.