Prediction of *Botrytis cinerea* Risk in Vineyards Based on Weather Indicators

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Abstract

Botrytis cinerea causes grey mould, a major disease occurring in vineyards worldwide, resulting in loss of grape production and wine quality. Predictive models of favorability of *Botrytis cinerea* were used. Therefore, a series of meteorological data from 2010 to 2019 was used. The results showed that the frequency of years with low risk of *Botrytis cinerea* was 10%, medium risk 10%, high risk 80%. The disease can drastically reduce both yield and wine quality (Ribereau Gayon *et al*., 1980). The harvest years 2010, 2011, 2012, 2013 and 2014, favored the manifestation of an attack degree of 62.9% (2012) and 34.2% (2013). Positive correlations were observed in the case of Broome index and Bacchus index with the duration of sunlight (r2 = 0.935), respectively (r2 = 0.944) and the sum of the hours of moisture on the leaves (r2 = 0.833, r2 = 0.848). Based on the results a model for prediction of *Botrytis cinerea* risk will be developed.

Keywords: climatic indicators, grey mould, *Vitis vinifera*

Introduction

Weather conditions such as temperature, moisture and rainfall have a major impact on the grapevine growing, when the plants are exposed to various climatic parameters extremes. The major weather contrasts generated by daily temperatures surpassing the threshold where grapevine is significantly affected (>35°C), high sunlight intensity (which generates burn scars on berries skin), higher relative humidity (80-100%) induce a high susceptibility of grapes for *Botrytis cinerea*.

The infection filaments can get into the plant tissues, either by penetrating the cuticle or by opened wounds caused by other pathogens, such as powdery mildew, generating small spots of soft tissue on infected berries surface, which grow quickly and always getting into the pulp. On tight bunches, in rainy and high wetness conditions berries split and on their surface grow a gray colour mould, powdery, represented by fungus spores, and in drought conditions and dry air can shrivel the berries. The incidence of sun burns on Chardonnay is high and is correlated with *Botrytis cinerea* infection severity (Haselgrove 2000, Steel, 2008; Hector, 2008). Although, heavy rainfalls at veraison growth stage can lead to berry splits, supporting *Botrytis cinerea* development and crop losses.

Materials and methods

A database on agri-environmental factors related to Valea Călugărească viticultural center was created for a period of 10 years (2010-2019). Based on this, for each harvest year, five climatic indicators were calculated, namely: heliothermal, edaphoclimatic, hydrothermal, for drought, standardized precipitation and Bacchus (Kim *et al*., 2007) and Broome model (Broome *et al.,* 1995).

The Bacchus risk value was calculated as follows: $f(x) = 1/[(84.37-(7.238T) + (0.156T^2)]$, where x

= the Bacchus risk value for a given wet hour and T = mean temperature. This equation represents a correction to the model published by Kim *et al*. (2007). The Broome risk value was calculated as follows: $f(x) = -2.647866 - 0.374927W + 0.061601Tw - 0.001511Tw^2$; where x = Broome risk for a given wet period, W = duration of surface wetness (h) and Tw = mean temperature during the period of surface wetness. The modified Broome risk value was calculated as follows: $f(x) = 0.00616T - 0.00015T^2$, where x = Broome risk value for a given wet hour, and T = mean temperature.

Both models took into account the two main periods (windows) of infection corresponding to two growth stages: 'Inflorescences clearly visible' (BBCH 53) and 30% of 'berries full sized' (BBCH73); during this period the model calculates the infection through conidia developed on inflorescences and young bunches. The second infection window appears between 'majority of berries full sized' and 'berries ripe for harvest' (BBCH 89). The *Botrytis cinerea* severity was ranked according to 7 levels (0%, 5%, 10%, 25%, 50% and 100%).

Results and discussions

The grape growing weather specific for 2010-2019 season, essential for *Botryris cinerea* occurance is characterised by average temperatures of 19.6°C, with a maximum of 24.1°C (BBCH81) and an air relative humidity of 60%. Rainfall displays poor resources (45mm) (Tab. 1). When optimal development conditions are ensured, e.g. temperature between (15-15-23°C, the evolution of fungus is favourable.

The environmental indexes with synthetic characters: hidro-thermal index (Ih), helio-thermal

Table 1. Monthly average temperature, relative air humidity, rainfall and rainfall standardizat index for 2010-2019 period

Month	T average (%)	RH (%)	Rainfall	ISP
April	13.0	64.2	64.7	0.24
May	17.9	69.6	97.7	0.16
June	21.9	70.0	81.1	-0.01
July	23.7	66.4	71.9	-0.02
August	24.1	60.0	45.9	-0.07
September	19.1	61.7	40.7	-0.08
Mean	19.6	65.3	67.0	0.04
Maximum	24.1	70.0	97.7	0.24
Minimum	13.0	60.0	40.7	-0.08

Table 2. Synthetic indices for 2010 – 2019

Year	Ih	IH	Sunshine (hours)	Total rainfall (mm)	Mean T of leaf wetness period (°C)	Leaf wetness (hours)	*Botrytis* occurance (hours)
2010	1.94	2.78	449.6	398.6	22.9	281.6	299.4
2011	2.48	2.96	564.7	384.8	23.3	285.3	309.6
2012	2.37	3.46	139.9	501.7	20.9	52	57.8
2013	1.48	2.91	117.8	306	20	66	109.8
2014	2.48	2.25	329.4	515.6	20	121.3	182.8
2015	1.45	3.46	338.7	357.9	20.2	109.5	188.4
2016	2.31	3.47	406.5	443.4	21.4	155.3	183.4
2017	1.84	1.94	259.4	411.3	20.9	205.5	208.5
2018	1.69	2.39	443.3	264.6	19.9	273.9	273.9
2019	2.47	2.47	372.8	436.4	17.8	229.5	253.2

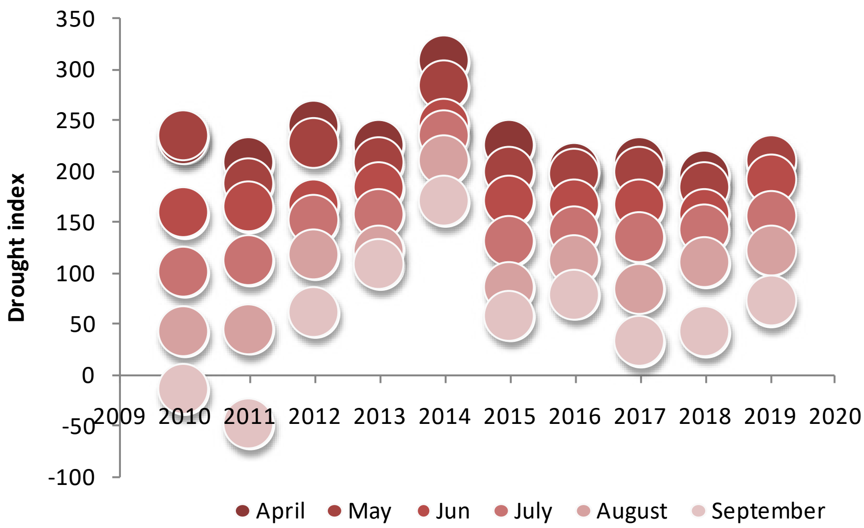

Figure 1. Soil moisture expressed by drought index in the period of 2010-2019

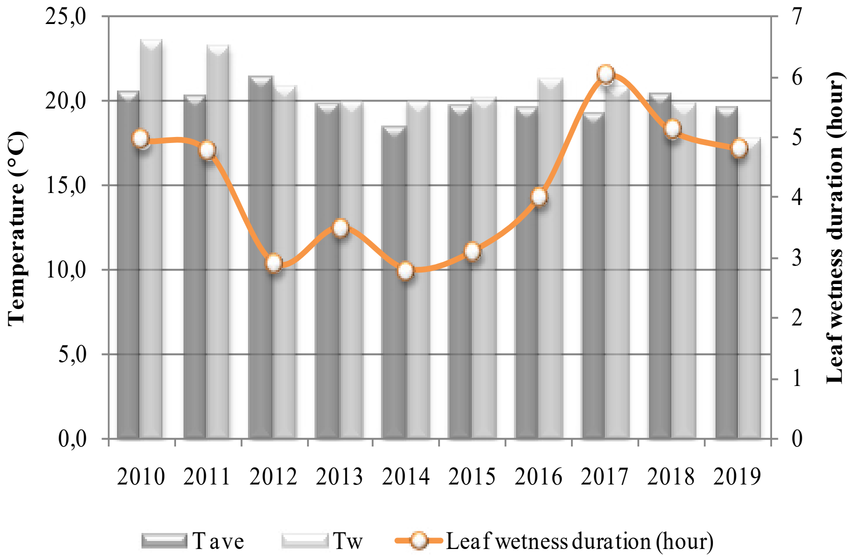

Figure 2. The temperature in the wet period (Tw), average temperature (Tave) and leaf wetness duration (hour) in the period of 2010-2019

index (IH), edafo-climatic index (Iec), drought index (IS) and rainfall standardised index (ISP), sunshine duration, highlights the great degree of favourability concerning the growth of grapevine. The hidro thermal index displays in 90% of years of period of reference the favorability for obtaining of high quality white wines and 10% of years for white table wines.

The rainfall measured over the flowering stage (BBCH 61) shows values from +14 to 30.7 mm, compared to deficit values (-21.1mm) measured over the veraison growth stage (BBCH 81). The frequency of hours with favourable conditions of *Botrytis cinerea* development were recorded in 2011 (309.6 hours), 2010 (299.4 hours), 2018 (273.9 hours) and 2019 (253.2 hours). In the seasons of 2012 (57.8 hours) and 2013 (109.8 hours), there were no *Botrytis cinerea* symptoms conditions recorded (Tab. 2).

Sunshine period over 'Inflorescences clearly visible' growth stage (BBCH 53) was short: 117.8 hours compared to 338.7 hours over the 'berries full sized' growth stage (BBCH 79). Favourable conditions for *Botrytis cinerea* were recorded in

Table 3. Acumulated Bacchus and Broome index and frequency of *Botrytis cinerea* appearance for the period 2010-2019

Year	Accumulated Bacchus index	Accumulated Broome index	Frequency of appearance *Botrytis cinerea* (F%)	Degree of atack (%)
2010	3.26	3.12	188.2	62.9
2011	3.41	3.62	196.1	51.9
2012	1.18	1.16	69.2	42.4
2013	1.17	1.15	59.4	34.2
2014	2.94	2.74	144.3	35.6
2015	2.37	2.18	115.1	24.9
2016	2.49	2.41	127.6	18.0
2017	2.19	2.10	110.6	24.6
2018	3.20	3.37	179.8	31.6
2019	2.71	2.06	108.1	32.6
Median	2.60	2.30	121.4	35.9
25%	1.94	1.84	98.4	20.3
75%	3.22	3.18	181.9	65.9

Table 4. All Pairwise Multiple Comparison Procedures (Tukey test):

Comparison	Diff. of Ranks	q	P	P<0,050
F (%) vs Accumulated Broome index	254.000	6.871	<0.001	yes
F (%) vs Accumulated Bachus index	238.000	6.438	<0.001	yes
F (%) vs Degree of attack	104.000	2.813	0.192	no
Degree of attack vs Accumulated Broome index	150.000	4.058	0.021	yes
Degree of attack vs Accumulated Bacchus index	134.000	3.625	0.051	no

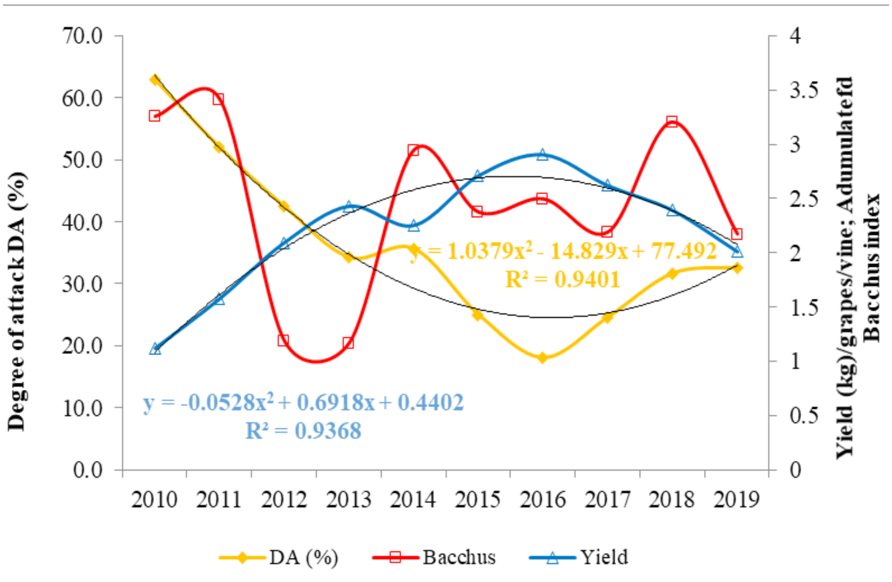

Figure 3. The degree atack (DA%), Bacchus index and yield (kg/vine) in the period of 2010-2019

Table 5. Correlations of accumulated Broome index with climatic parameters

Weather Parameters	Accumulated Broome index	
	Equation	Regression coefficient
Sun Shine (duration) (SS)	0,454 + (0,00566 * SS)	0.935**
Total Leaf Wetness (hours)	0,975 + (0,00801 * SUM LWD)	0.833*
Day degrees (GDD)	8,855 - (0,00346 * GDD)	0.449
Air temperature during leaf wetness	-2,667 + (0,244 * T LWD)	0.445
Actual temperature	5,951 - (0,00197 * Tutila)	0.353
Drought index (IS)	3,481 - (0,00709 * IS)	0.296
Helio – thermal index (IH)	3,568 - (0,419 * IH)	0.271
Standardised Rainfall index (ISP),	2,445 - (1,477 * ISP)	0.228
Rainfall	3,291 - (0,00224 * Rainfall)	0.210
Relative Humidity (RH)	4,103 - (0,0262 * RH)	0.100
Helio – thermal index (Ih)	1,596 + (0,387 * Ih)	0.193
Edafo - Climatic index(Iec)	3,172 - (0,0514 * Iec)	0.147
Mean Air Temperature	4,295 - (0,0955 * Tave)	0.09

Table 6. Correlations of accumulated Bacchus index with climatic parameters

Weather Parameters	Accumulated Bacchus index	
	Equation	Regression coefficient
Sun Shine (duration) (SS)	0,638 + (0,00542 * SS)	0.944**
Total Leaf Wetness (hours)	1,125 + (0,00774 * SUM LWD)	0.848*
Day degrees (GDD)	8,994 - (0,00348 * GDD)	0.529
Air temperature during leaf wetness	-0,419 + (0,141 * TLWD)	0.270
Actual temperature	6,394 - (0,00216 * Tutila)	0.408
Drought index (IS)	3,226 - (0,00477 * IS)	0.210
Helio – thermal index (IH)	3,866 - (0,489 * IH)	0.334
Standardised Rainfall index (ISP),	2,540 - (1,306 * ISP)	0.213
Rainfall	2,915 - (0,00105 * Rainfall)	0.104
Relative Humidity (RH)	2,177 + (0,00483 * RH)	0.019
Helio – thermal index (Ih)	1,447 + (0,510 * Ih)	0.268
Edafo - Climatic index(Iec)	3,419 - (0,0609 * Iec)	0.184
Mean Air Temperature	6,798 - (0,216 * Tave)	0.210

2010 (281.6 hours), 2011 (285.3 hours) and 2018 (273.9 hours) sustained by optimal temperatures, respectively: 22.9°C, 23.3°C and 19.9°C. Soil moisture monitoring displays values from high levels of 244 mm (2014), 168 mm (2013), 162 mm (2012), 160 mm (2019) to low as 112 mm (2011), 126 mm (2010), (Fig. 1).

The high air humidity plays a major role in gray mould development, influencing positively both conidia germination and mycelium development. There is a direct correlation between rainfall and frequency of leaf wetness days, as following:

Rainfall = 455,677 - (0,320 * LW)

During 2010-2019 leaf wetness varied between 2,8 hours (2014) and 6 hours (2017), (Fig. 2).

The harvest years 2010, 2011, 2014 si 2018 have displayed specifically favourable weather conditions for *Botrytis cinerea* development, which determined a more severe level of gray mould infection 62.9% (2010), 51.9% (2011), 35.6% (2014) and 32.6% (2019). In 2015-2017 weather conditions were less favourable for *Botrytis cinerea* development, displaying lower severity infections: 24.9%., 18.0% and 24.6%repectively (Tab. 3.).

Differences between mean values are high, showing a statistically significant difference (P = <0.001), in the instance of correlations of *Botrytis cinerea* frequency (F%) and accumulated Bacchus index and Broome index, as well as between Broome index and infection severity (Tab. 4).

The environmental weather conditions specific for 2010-2019 and the degree of infection with *Botrytis cinerea*, influenced in a different way the yield of grapevine plants. The *Botrytis cinerea* severity of 62.9% determined a crop loss of 37%, or 1.114 kg/plant (2010), as in 2016 the yield/plant was 2.909 kg/plant (3%) (Fig. 3).

The modelling equations display distinct correlations for the weather parameters such as sunshine, total leaf wetness for both models: in accumulated Broome index the regression coefficient presenting values between 0.935 and 0.833 (Tab. 5) and in accumulated Bacchus index the regression coefficients are 0.944 and 0.848 (Tab. 6). For estimating the Broome index and Bachus index the following equation can be used:

- Broome index = 0,765 + (0,00582 * Sun shine) - (0,178 * Ih), (R=0.939);
- Bacchus index = -2,552 + (0,00575 * SS) + (0,0517 * RH) - (0,146 * Ih), (R=0.964).

Conclusion

In the present research work, a strong link between some climatic indicators and the severity of diseases with *Botrytis* was observed. The degree of attack of *Botrytis cinerea* registered values of 62.9% which determined crop losses of 37%, respectively 1.114 kg/vine (2010) while in 2016 the production obtained was 2.909 kg/vine (3%).

Higher occurences of climatic risk of *Botrytis cinerea* were found in years with the most prelonged wetness period. In case of Broome and Bacchus indicators positive correlations with sunshine duration (r^2=0.935 si r^2=0.944) and total leaf wetness (r^2=0.833 and r^2=0.848) were observed. These indicators could be used as early tools in the scheduling the treatment applications against *Botrytis cinerea*.

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