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Temporal dynamics of *Plasmopara viticola* as function of bud load increase in 'Sauvignon Blanc'

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Abstract – The objective of this work was to evaluate the effect of increasing bud load per plant on epidemiological variables of downy mildew on 'Sauvignon Blanc'. The study was carried out in a commercial vineyard in a high-altitude region of the municipality of São Joaquim, in the state of Santa Catarina, Brazil, during the 2016/2017 and 2017/2018 vintages. The treatments consisted of four bud loads: 15, 30, 50, and 75 per vine. The maximum incidence, maximum severity, beginning of symptom appearance, time to reach maximum disease incidence and severity, area under the incidence and severity disease progress curve were determined. Increasing bud load over 50 per vine results in higher incidence and severity of downy mildew (*Plasmopara viticola*) in 'Sauvignon Blanc' leaves but does not influence the time to reach maximum disease incidence and severity. Increasing bud load over 50 per vine results in an increase in the area under the disease incidence and severity progress curve for downy mildew in 'Sauvignon Blanc' leaves. To adopt over 50 buds per vine treatment, it is necessary additional disease control measures, with an emphasis on integrated management to control downy mildew.

Index terms: *Vitis vinifera*, integrated disease management, vine diseases, winter pruning.

Dinâmica temporal de *Plasmopara viticola* em função do aumento da carga de gemas em 'Sauvignon Blanc'

Resumo – O objetivo deste trabalho foi avaliar o efeito do aumento de carga de gemas por planta nas variáveis epidemiológicas de míldio em 'Sauvignon Blanc'. O estudo foi realizado em um vinhedo comercial em uma região de altitude do munícipio de São Joaquim, no estado de Santa Catarina, Brasil, durante as safras de 2016/2017 e 2017/2018. Os tratamentos consistiram em quatro cargas de gemas: 15, 30, 50 e 75 por videira. Incidência máxima, severidade máxima, início da aparição dos sintomas, tempo para alcançar a máxima incidência e severidade da doença, área abaixo da curva de progresso da incidência e abaixo da curva de progresso da severidade da doença foram determinados. O aumento da carga de gemas acima de 50 gemas por videira resulta em aumento da incidência e severidade de míldio (*Plasmopara viticola*) nas folhas de 'Sauvignon Blanc', mas não influencia o tempo para atingir a máxima incidência e severidade da doença. O aumento da carga de gemas acima de 50 por videira resulta em aumento da área abaixo da curva de progresso de incidência e severidade da doença para o míldio nas folhas de 'Sauvignon Blanc'. Para adotar o tratamento de mais de 50 gemas por videira, é necessário utilizar medidas adicionais de controle de doenças, com ênfase no manejo integrado para controle de míldio da videira.

Termos para indexação: *Vitis vinifera*, manejo integrado de doenças, doenças da videira, poda invernal.

Introduction

The vineyards of the state of Santa Catarina, Brazil, are located in a high-altitude region, between 900 and 1,400 m above sea level, which provides adequate conditions, such as higher availability of solar radiation and lower night temperatures during maturation, influencing positively wine quality and, consequently, resulting in better characteristics of color and aroma (Marcon Filho et al., 2015; Malinovski et al., 2016). However, despite these desirable characteristics, this region has high water availability and precipitation rates (over 1,200 mm per year) (Bem et al., 2017; Bitencourt et al., 2021), high levels of soil organic matter (Mafra et al., 2011), and extensive use of vigorous rootstocks (Marcon Filho et al., 2021), resulting in high vineyard vigor, lower bud fruitfulness, and, thus, reduced productive potential (Brighenti et al., 2014; Würz et al., 2018).

To increase vineyard yield and improve its vegetative balance (Würz et al., 2020a), it is indicated to increase bud load per vine (*Vitis vinifera* L.) during winter pruning, which is the branch removal at the end of the dormancy period (Gangjee, 2012). The pruning may affect the number of branches, productive and qualitative potential of the vine, and vine management (Qiu et al., 2019; Teker & Altindisli, 2021), so it is important to establish the optimal ratio of specific bud load for each viticultural region, considering its cultivation system and technology level, in order to optimize production (Popović et al., 2020).

According to Dobrei et al. (2016), pruning is a well-studied technological step that can be optimized for each variety, according to the production purpose, environmental conditions, and vineyard management. The high-altitude region of Santa Catarina, though, lacks studies that indicate the most appropriate vine canopy management (Macedo et al., 2015).

As a consequence of adopting a pruning system with a higher bud load, the vegetative canopy becomes denser, directly affecting the occurrence of fungal diseases (Würz et al., 2017, 2020b), such as downy mildew, which reduces the plant photosynthetic capacity, impairing vegetative development and fruit production during the following year. Downy mildew has global importance, including the Southern region of Brazil, with the *Plasmopara viticola* oomycete as its causal agent (Gessler et al., 2011). Therefore, according to the bud load to be adopted, preventive control measures should be carried out (Wurz et al., 2021), relating the management of winter pruning and its effects on vegetative canopy with the occurrence of downy mildew.

The objective of this work was to evaluate the effect of the increase in bud load per plant on epidemiological variables of downy mildew in Sauvignon Blanc cultivar leaves in the high-altitude region of the state of Santa Catarina, Brazil.

Materials and Methods

The present work was carried out during the 2016/2017 and 2017/2018 vintages, in a commercial vineyard, located in the municipality of São Joaquim, in the state of Santa Catarina, Brazil (28°24'88"S, 49°96'88"W, at 1,230 m of altitude). 'Sauvignon Blanc' grapevines plants grafted on Paulsen 1103 rootstock were used for the present study, and the experimental design was randomized complete blocks, with four blocks and ten plants per replicate.

Established in 2004, the vineyard has vines spaced at 3.0x1.5 m, in rows arranged in the north-south direction, trained in vertical shoot position, pruned in a double spur cordon, at 1.2 m in height, and covered with an anti-hail protection net.

Soils in the region are considered Cambissolo Húmico, Neossolo Litólico, and Nitossolo Háplico (Santos et al., 2018), which correspond respectively to Humic Cambisol, Litholic Neosol and Haplic Nitosol, developed from rhyodacite and basalt rocks. The climate of the region is classified according Koppen-Geiger as cold and humid with cold nights, Heliothermal Index of 1,714, average annual rainfall of 1,621 mm and average annual relative humidity of 80% (Tonietto & Carbonneau, 2004).

The treatments consisted of four levels of bud load: 15, 30, 50, and 75 per vine. After pruning, 8, 15, and 25 spurs with two buds each were left for the 15, 30, and 50 buds per vine treatments; and for the 75 buds per vine treatment, 30 spurs were left with two buds, two canes, and eight buds each, this treatment was pruned in the mixed pruning system, characterized by the presence of spurs and canes. Pruning was carried out on September 1, 2016, and August 31, 2017.

To obtain better experimental control, the Fruit Production team of Agroveterinary Sciences Center of Universidade do Estado de Santa Catarina carried out the vine management, which consisted of pruning, thinning, training, leaf removing, and harvesting, in accordance with the standards of the company that provided the vineyards for the experiment. During the vegetative cycle, the following fungicides (a.i./c.p.) to prevent downy mildew and other fungal diseases were used: mancozeb/Dithane NT (dithiocarbamate, 800 mL a.i. kg^{-1}, 350 g c.p. ha^{-1}); fenamidone/Censor SC (imidazole, 500 mL a.i. L^{-1}, 30 mL c.p. ha^{-1}); methyl thiophanate/Cercobin 700WP (benzimidazole, 700 g a.i. kg^{-1}, 70 g c.p. ha^{-1}); chlorothalonil/ Bravonil 720 (tetrachloroisophthalonitrile, 123 g a.i. kg^{-1}, 150 g c.p. ha^{-1}); and fosetyl Al/Aliette (phosphonate, 450 g a.i. kg^{-1}, 250 g c.p. ha^{-1}).

The downy mildew incidence and severity were evaluated at the onset of the first symptoms, at 15-day intervals, under conditions of natural infection. The incidence was calculated by the percentage of leaves with, at least, one lesion in relation to the total number of leaves evaluated. The diagrammatic scale by Buffara et al. (2014) was used to assess the severity, with five median shoots of ten randomly marked plants and 30 leaves of each marked shoot evaluated.

With the data obtained from downy mildew, progression curves of incidence and severity were constructed, and the epidemic was compared in relation to: the beginning of symptom appearance (BSA), in days; time to reach maximum disease incidence and severity (TRMDI and TRMDS), in days; maximum disease incidence (Imax), in percentage; and maximum disease severity (Smax), in percentage; area under the disease incidence (AUDIPC) and severity (AUDSPC) progress curve. To calculate the area under the disease progression curve (AUDPC), the following formula was used:

$$AUDPC = \Sigma ((Yi+Yi+1)/2)(ti+1–ti),$$

where Y is the disease intensity, both incidence and severity; t is the time; and i is the number of evaluations in time (Campbell & Madden, 1990).

The meteorological data were obtained from Centro de Informações de Recursos Ambientais e de Hidrometeorologia de Santa Catarina (CIRAM), a meteorological station located near the vineyard. The daily data of precipitation, in millimeters, and mean temperature, in Celsius degrees, were registered during the vine vegetative growth period: the months of August 2016 to April 2017 and August 2017 to April 2018.

The average disease incidence data were transformed by arc sine of the square root to normalize the statistical distribution. Averages were submitted to analysis of variance (ANOVA) and the detection of significant differences between treatments was obtained through the Tukey's test, at 5% probability.

Results and Discussion

Climatic conditions favorable to development of downy mildew occurred in both evaluated vintages (Figure 1). In the period of intense vegetative growth, during the 2016/2017 vintage, the average temperature was 17.3°C, whereas in 2017/2018, during the same period, the average temperature was 16.1°C. The precipitation from December to April 2016/2017 was 532.7 mm, while in 2017/2018, it was 519.8 mm. The average relative humidity in the period was 81.2% and 79.4% in 2016/2017 and 2017/2018, respectively.

According to Bem et al. (2020), all the factors that contribute to increasing the moisture in the soil, air, and plant favor the development of downy mildew. Therefore, although downy mildew occurs more severely in regions with favorable climatic conditions for its development, with temperatures ranging from 17 to 22ºC, epidemics may occur outside the range, when the relative humidity is high and the leaves are wet due to fog and/or dew (Agrios, 2005). During the present study, there were favorable climatic conditions for the development of the disease, especially in 2017/2018, during the months of December and January.

The effects of bud load on epidemiological variables of downy mildew in 'Sauvignon Blanc' vines are described in Table 1. Bud load per vine affected the epidemiological variables during both evaluated vintages. The load of 75 buds per vine showed a lower value when the symptoms began to appear (BSA) than the other treatments, while the symptoms took longer to manifest for the load of 15 buds per vine. The time to reach maximum disease incidence (TRMDI) and time to reach maximum disease severity (TRMDS) variables were not affected by the different bud load treatments.

In the 2016/2017 vintage, the maximum incidence of downy mildew in 'Sauvignon Blanc' leaves was lower for the load of 15 buds per vine, which was 69.6%, while the loads of 30, 50, and 75 buds per vine resulted in an incidence percentage of 96.0, 99.3 and 99.0%, respectively, and did not differ from each other. The highest values for downy mildew severity in 2016/2017 were 12.0 and 13.8% for the loads of 50 and 75 buds per vine, respectively, and the lowest disease severity value was observed in the load of 15 buds per vine, with 4.4%.

For the 2017/2018 vintage, the behavior observed for the incidence and severity variables were similar to 2016/2017 vintages. The lowest incidence of downy mildew was observed in the load of 15 buds per vine, with 90.5%, while the loads of 30, 50, and 75 buds per vine showed values of 98.6, 99.3 and 100.0%, respectively. For downy mildew severity variable, the load of 75 buds per vine showed the highest value, 16.75%, while the loads of 15 and 30 buds per vine showed values of 4.3 and 5.5%, respectively (Table 1).

The results of the variables AUDIPC and AUDSPC were similar in 2016/2017 and 2017/2018 vintages. The highest AUDSPC values were observed in the load of 75 buds per vine, with 336.3 and 252.0 in 2016/2017 and 2017/2018, respectively, and the lowest value was observed in the load of 15 buds per vine, with values of 121.9 and 60.4 in 2016/2017 and 2017/2018, respectively. For the AUDIPC, in both seasons, the

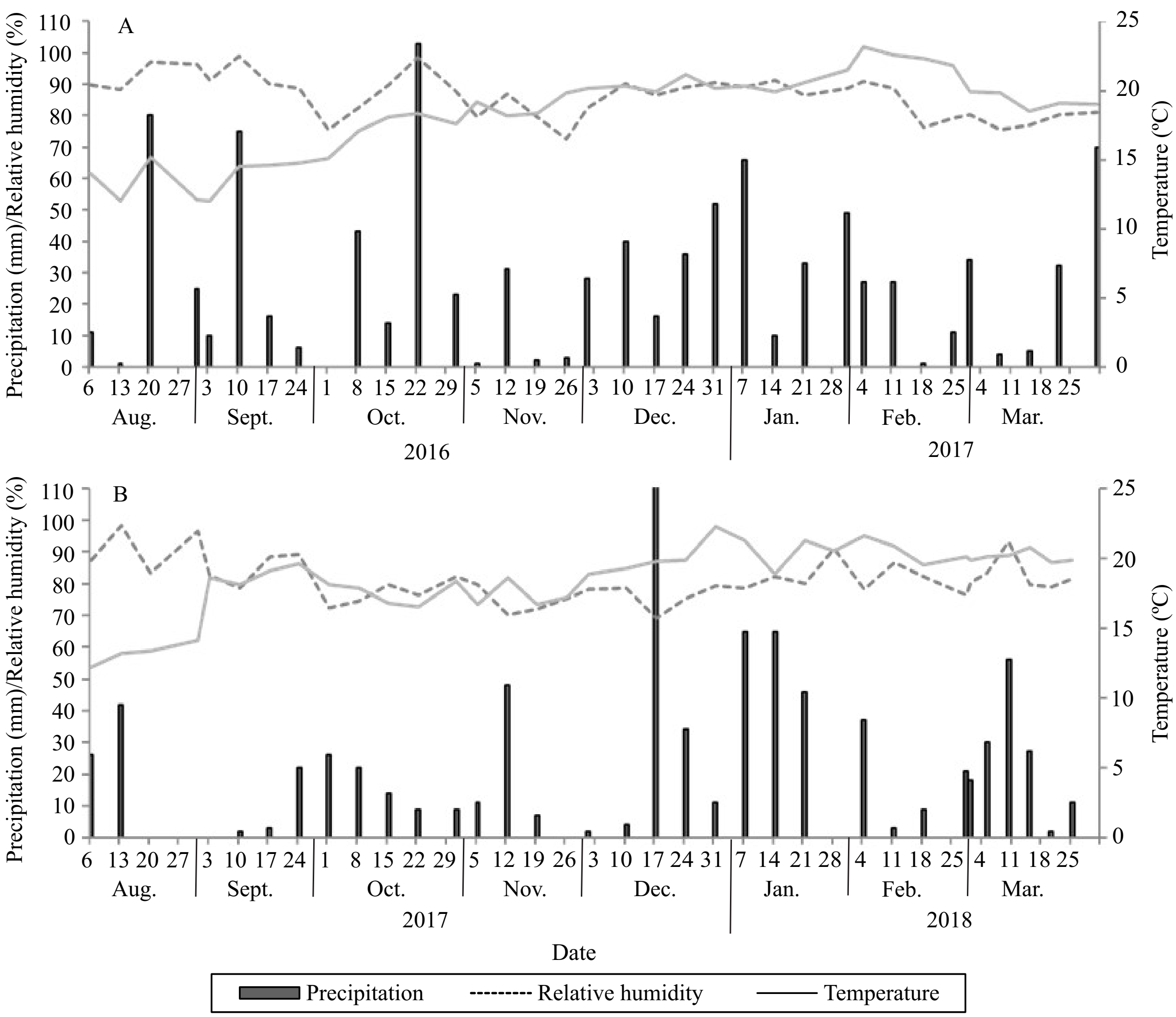

Figure 1. Accumulated precipitation, relative humidity, and mean air temperature in the municipality of São Joaquim, in the state of Santa Catarina, Brazil, during the 2016/2017 (A) and 2017/2018 (B) vintages. Source: Epagri (2020).

highest values were observed in the load of 75 buds per vine, with 4,038.6 and 4,305.7, in 2016/2017 and 2017/2018, respectively, and the lowest values were observed in the load of 15 buds per vine, 2,117.9 and 2,586.6, for 2016/2017 and 2017/2018, respectively (Table 1).

Therefore, the increase in bud load results in an increase in the number of shoots, which allows the vegetative canopy to become denser, resulting in a more favorable microclimate for the occurrence of fungal diseases, since solar radiation penetration into the canopy is lower and, consequently, the leaves take longer to get dried (O'Daniel, 2012; Wurz et al., 2021).

These data corroborate to those observed by Bem et al. (2016) while evaluating epidemiological variables of downy mildew in different training systems. They observed that the lowest incidence and severity of disease, the lowest values of AUDIPC and AUDSPC in training systems with reduced vegetative density, which provides a less favorable microclimate for the development of downy mildew. A previous work carried out by Wurz et al. (2021) also verified similar data evaluating the increase in bud load of 'Cabernet Franc' in the epidemiology of downy mildew.

The effects of bud load in the area under the incidence of downy mildew progress curve of 'Sauvignon Blanc', during the 2016/2017 vintage, are described in Figure 2. The first evaluation took place on December 1, 2016, and the last evaluation, on February 23, 2017. The period between the first evaluation and January 12, 2017, showed similar behavior among the different bud loads, presenting low increase in AUDIPC. However, from January 1, 2017, an exponential increase was observed for the loads of 50 and 75 buds per vine, while the loads of 15 and 30 buds per vine showed a less accentuated increase in AUDIPC in relation to the other bud loads. An increase in this variable was observed until the moment of harvest, however, it is noteworthy that the loads of 15 and 30 buds showed lower values of AUDIPC compared to the loads of 50 and 75 buds per vine.

Regarding the evaluations of the 2017/2018 vintage, the first evaluation took place on November 30, 2017, and the last one, on February 8, 2018. After 14 days from the first evaluation, a more expressive increase in AUDIPC was observed for the load of 75 buds per vine, while the other treatments did not show a significant increase in AUDIPC until the evaluations on January

Table 1. Effect of bud loads on 'Sauvignon Blanc' (*Vitis vinifera*), grown in a high-altitude region of Santa Catarina state, Brazil, during 2016/2017 and 2017/2018 vintages[(1)].

Variable[(2)]	Bud load (buds per vine)				Coefficient of variation (%)
	15	30	50	75	
			2016/2017 vintage		
BSA (days)	37.0a	27.5ab	24.7ab	16.7b	26.8
TRMDI (days)	93.0[ns]	93.0	82.5	82.5	9.7
TRMDS (days)	93.0[ns]	93.0	93.0	93.0	0.0
Imax (%)	69.6b	96.0a	99.3a	99.0a	5.3
Smax (%)	4.4c	7.9b	12.0a	13.8a	12.6
AUDIPC	2,117.9c	3,229.6b	3,723.0ab	4,038.6a	9.3
AUDSPC	121.9d	182.0c	257.2b	336.3a	13.8
			2017/2018 vintage		
BSA (days)	35.0a	24.0b	14.0c	14.0c	19.5
TRMDI (days)	60.0[ns]	62.0	52.0	52.0	9.7
TRMDS (days)	70.0[ns]	70.0	70.0	70.0	0.0
Imax (%)	90.5a	98.6b	99.3b	100.0b	2.1
Smax (%)	4.3c	5.5c	11.7b	16.7a	15.7
AUDIPC	2,586.6c	2,714.9c	3,469.5b	4,305.7a	12.6
AUDSPC	60.4d	126.6c	188.7b	252.0a	11.8

[(1)]Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 5% probability. [(2)] BSA, beginning of symptom appearance; TRMDI, time to reach maximum disease incidence; TRMDS, time to reach maximum disease severity; Imax, maximum incidence; Smax, maximum severity; AUDIPC, area under the disease incidence progress curve; AUDSPC, area under the disease severity progress curve. [ns]Not significant.

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7, 2018. From then on, there was a significant increase in the variable in the load of 50 buds, which together with the load of 75 buds showed the highest values of AUDIPC until the last evaluation. As of January 20, 2018, there was an exponential increase in AUDIPC values for loads of 15 and 30 buds, however, the values observed throughout the evaluations were lower than those observed for the loads of 50 and 75 buds.

The effect of bud load on AUDSPC in 2016/2017 and 2017/2018 vintages is described in Figure 3. In both evaluated vintages, a similar behavior was observed in the different bud loads. In general, after 42 days from the first evaluation, the AUDSPC values were similar for the different bud loads in both vintages. After this period, an exponential increase in AUDSPC was observed for loads of 50 and 75 buds, presenting the highest AUDSPC values in the last evaluation, while the load of 15 buds per vine showed the lowest increase in AUDSPC during the entire evaluation period.

The significant increase in the disease progress in January and February can be explained by the higher air temperature and volume of rainfall recorded in these periods (Figure 1), favoring the disease epidemic, mainly in the loads of 50 and 75 buds. In addition to downy mildew, studies by Wurz et al. (2017, 2019), evaluating the effect of bud loads, verified an increase in the intensity of anthracnose in shoots and leaves of 'Cabernet Franc'.

There were significant differences between the bud loads in relation to the area under disease incidence and severity progress curve (AUDIPC and AUDSPC), indicating that the increase in bud load resulted in a greater susceptibility to downy mildew.

The increases in AUDIPC and AUDSPC observed in Figures 2 and 3 coincide with periods of high average air temperature and precipitation rates. The interaction

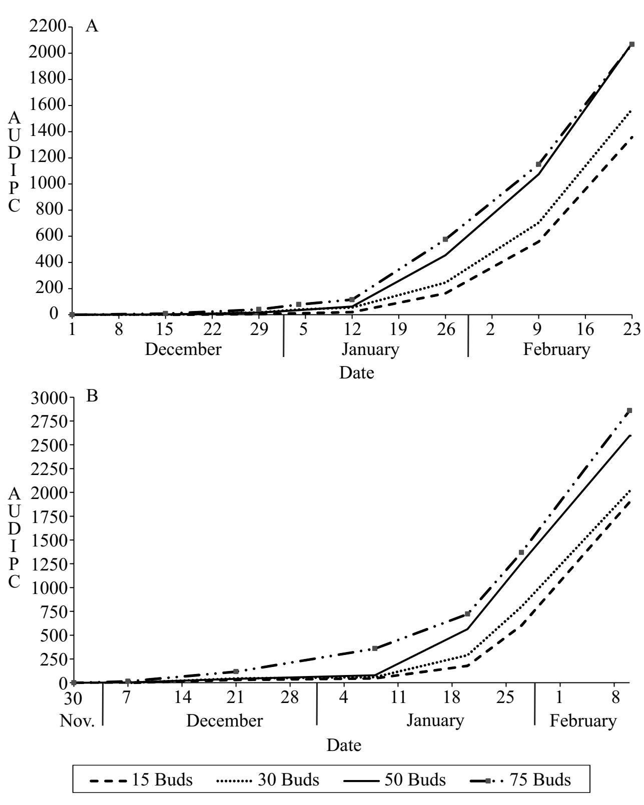

Figure 2. Effect of bud load (buds per vine) on the area under downy mildew (*Plasmopara viticola*) incidence progress curve of 'Sauvignon Blanc' (*Vitis vinifera*), grown a in high-altitude region of Santa Catarina state, Brazil, during 2016/2017 (A) and 2017/2018 (B) vintages.

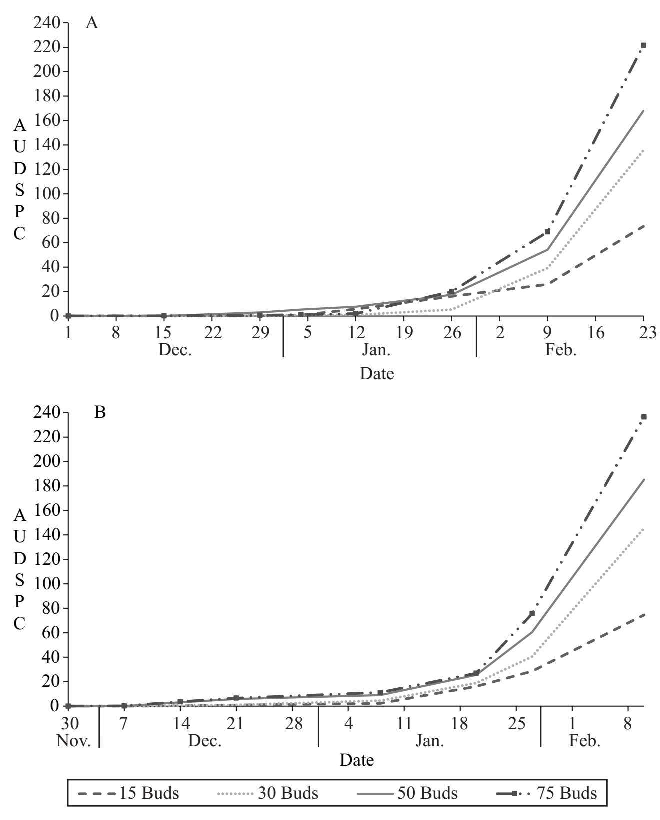

Figure 3. Effect of bud load (buds per vine) on the area under downy mildew (*Plasmopara viticola*) severity progress curve of 'Sauvignon Blanc' (*Vitis vinifera*), grown in a high-altitude region of Santa Catarina state, Brazil, during 2016/2017 (A) and 2017/2018 (B) vintages.

between higher values of average temperatures with higher rainfall provided a more favorable environment for the development of downy mildew in 2016/2017 vintage, leading to higher values of disease severity compared to the 2017/2018 vintage. Infection rarely occurs if the air humidity is under 75%; however, it will be more severe if the leaf is wet for over 3 hours (Bem et al., 2020).

A pruning system with a low bud load (< 50 buds per vine) reduces the leaf area and the number of leaves, which results in a less dense canopy (Greven et al., 2014). On the other hand, high bud loads treatments are a strategy to increase yield and improve vine balance (Wurz et al., 2021). According to Smart (1990), a denser canopy without adequate management leads to less air circulation, which impairs adequate penetration of fungicides, causing a greater occurrence of fungal diseases.

Downy mildew control usually requires excessive use of fungicides, especially in regions with a temperate rainy climate, to prevent epidemics and obtain quality grapes; however, an economically and environmentally sustainable viticulture demands the rational use of fungicides (Bem et al., 2020). Therefore, it is essential to adopt techniques for managing the vegetative canopy to reduce the occurrence of downy mildew in vines pruned with high bud loads.

Conclusions

1. Increasing bud load over 50 per vine results in higher incidence and severity of downy mildew (*Plasmopara viticola*) in 'Sauvignon Blanc' (*Vitis vinifera*) leaves but does not influence the time to reach maximum disease incidence and severity.

2. Increasing bud load over 50 per vine results in an increase in the area under the disease incidence and severity progress curve for downy mildew in 'Sauvignon Blanc' leaves.

3. To adopt over 50 buds per vine, it is necessary additional disease control measures, with an emphasis on integrated management to control downy mildew.

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