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SHORT COMMUNICATION

Assessing the relationship between cordon strangulation, dieback, and fungal trunk disease symptom expression in grapevine

Patrick O'Brien[1], Roberta De Bei[1] and Cassandra Collins[1,2]*

[1] The University of Adelaide, School of Agriculture, Food and Wine, Waite Research Institute, PMB 1 Glen Osmond, 5064 South Australia, Australia
[2] ARC Industrial Transformation Training Centre for Innovative Wine Production, Waite Research Institute, PMB 1 Glen Osmond, 5064 South Australia, Australia

ABSTRACT

Grapevine cordons wrapped tightly around the cordon wire during establishment may be susceptible to an early occurrence of decay and dieback symptoms. A loss of productivity is often observed in older permanent cordons that have been constricted in this fashion but is not unique to them. Other factors of decline, such as fungal trunk disease infection, also play a significant role in perennial wood decline. This study aimed to quantify the impact of different contributors to cordon decline, including cordon strangulation and incidence of *Eutypa lata* infection and to investigate their relationship to each other. A survey was conducted over two seasons at ten vineyard sites to visually assess and capture images for algorithmic analysis of vines displaying varying degrees of cordon strangulation, cordon dieback, and characteristic foliar symptoms of *Eutypa* dieback. Rather than finding evidence of cordon strangulation being a driving force behind cordon decline, there was actually a trend of lower severity of dieback observed, with cordons displaying the greatest degree of strangulation. There was also a trend for increased foliar symptoms in relation to an increase in the degree of strangulation, but it is difficult to assign causality in this regard, as the occurrence of foliar symptoms may be influenced by a multitude of factors, including climatic conditions. Further research quantifying the extent to which xylem morphology and functionality are compromised by constrictive pressure in severely strangled cordons could provide further insight into this condition and the effect it could have on vine health and defence response.

KEYWORDS: cordon, *Eutypa*, disease resistance, trunk disease, water status

*correspondence:
cassandra.collins@adelaide.edu.au

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INTRODUCTION

Wrapping canes tightly around the cordon wire during the establishment of permanent cordon arms is a method used by many grape growers to reduce costs, provide additional canopy stability, and aid in mechanisation (Caravia *et al*., 2015a; O'Brien *et al*., 2021). While not observed in all wine regions, it is an extremely common practice in heavily mechanised areas such as Australia, where permanent cordon training methods are prevalent. It may reduce the risk of cordon rolling, especially in the seasons immediately following establishment, thereby helping to avoid fruit overexposure and the accompanying risk of sunburn damage (Chorti *et al*., 2010). It may also aid in the establishment of cordon architecture by mitigating disruption to the selection and establishment of permanent spur positions. One key drawback of this method, however, is that wrapped cordons may become tightly constricted over time, with the cordon wire often becoming visibly embedded within the wood of the cordon, potentially disrupting the flow of water and nutrients through vascular conduits (Caravia *et al*., 2015b). In the context of climate change, any disruption to vine water movement is an issue of growing concern, as it is likely that such a condition may be exacerbated by increasingly common water and heat stress events (Keller, 2010; Schultz, 2000). Strangulation of the cordon as a result of tight wrapping is a condition that visibly worsens over time as the cordon grows and thickens, with arms fashioned in this manner often displaying signs of decay and dieback after as little as 15–20 years. These declining cordons may also be suffering from the negative effects of fungal trunk disease infection caused by a range of phytopathogenic species (Fontaine *et al*., 2016; Mondello *et al*., 2018; van Niekerk *et al*., 2011), among the most economically impactful for growers in Australia being *Eutypa* dieback, caused by *Eutypa lata* (Siebert, 2001; Sosnowski *et al*., 2013) and Botryosphaeria dieback, caused by a range of Botryosphaeriaceous species (Bénard-Gellon *et al*., 2015). Grapevine trunk diseases (GTDs) are not a problem that is unique to Australia however, with winegrowing regions all over the world subject to their damaging effects (Bois *et al*., 2017). While cordons may die back themselves over time without the presence of any such infections, possibly in part or in whole, as a consequence of severe strangulation, there may be a complex relationship between such dieback and the susceptibility of the vine to infection and symptom expression. This symptom expression may include visible dieback of the cordon itself, as well as, in the case of *E. lata*, foliar symptoms occurring as a result of translocated toxins released by the advancing fungus (Tey-Rulh *et al*., 1991). The colonisation of woody tissue by one or more fungal pathogens typically leads to the occlusion of cordon xylem and phloem elements and, eventually, decay and dieback (Rolshausen *et al*., 2010). Vines may, however, be infected by fungal pathogens without displaying any symptoms, and the results of several studies have indicated that vines may be more likely to express non-foliar symptoms if their health is already compromised by stress (Claverie *et al*., 2020; Edwards *et al*., 2007a; Edwards *et al*., 2007b; Ferreira *et al*., 1999; Fischer and Kassemeyer, 2012; Songy *et al*., 2019). In a trial on potted vines, those subjected to a combination of extreme heat or cold plus low or high soil moisture displayed more severe foliar symptoms of *Eutypa* dieback than those in moderate conditions; however, severe symptoms were not produced with either factor alone (Sosnowski *et al*., 2011a). This conflicts with the results of a subsequent water-deficit trial, where the extent of colonisation of *E. lata* and *Diplodia seriata* (Botryosphaeria dieback) didn't increase under water stress, with the progress of *E. lata* showing a reduction in water-stressed vines (Sosnowski *et al*., 2021). Previous research has investigated the relationship between certain cultural practices and GTDs. Numerous studies have indicated that the incidence and severity of GTDs may be influenced by pruning practices (Henderson *et al*., 2020; Sosnowski and Mundy, 2019; Travadon *et al*., 2016). The pruning technique has also been reported to impact the area and depth of wood necrosis in the absence of GTDs (Faúndez-López *et al*., 2021). Training methods involving minimal pruning reportedly show less esca disease effect than methods involving regular manual pruning (Lecomte *et al*., 2021), and surgically removing necrotic wood has been successful in the recovery of esca-diseased grapevines (Cholet *et al*., 2021). If stressed vines are more likely to express symptoms of *E. lata* and other fungal trunk diseases (Songy *et al*., 2019), then it is possible that the use of training methods which avoid strangulation of the cordon may help to limit the onset of symptoms by avoiding a reduction in vine defence response. There is currently limited research in this area, and the exact nature of the relationship between these factors of decline (cordon strangulation, dieback, and incidence of GTDs and their symptom expression, including *Eutypa* dieback foliar symptom expression) remains unclear. This research aimed to investigate the nature of the relationship between these factors by assessing their incidence in commercial vineyards displaying varying degrees of cordon decline.

MATERIALS AND METHODS

1. Vineyard site selection and trial design

Ten vineyard sites across the Barossa Valley and the Adelaide Hills wine regions in South Australia were selected for this study. These sites displayed varying degrees of cordon strangulation and were selected based on their age, use of a permanent cordon training system, and willingness of vineyard managers to participate in the trial. Site selection took place in the spring of 2020, and each site was surveyed and imaged twice, once in the spring of 2020 and again in the spring of 2021. At each site, 10 rows were randomly selected, and depending on the block, 20 or 21 consecutive vines were selected from each of these rows for a total of 200 or 210 vines surveyed in each vineyard. However, some vines were missing from selected panels and were removed from the trial resulting in fewer vines assessed at these sites. Additionally, three rows of vines were removed from the trial when Site A was partially reworked during the winter of 2020. Site information is displayed in Table 1.

TABLE 1. Site details of vineyards selected for assessment.

Site	Variety	Region	Block Size (ha)	Year Planted	# Vines Assessed	Cordon Length (m)	Rootstock	Irrigation Applied (ML/ha)	Soil Type
A	Shiraz	Barossa Valley	3.1	2007	146	2.0	Own Roots	0.88	Red-brown earth over ironstone
B	Shiraz	Barossa Valley	1.4	2003	183	1.8	Own Roots	0.4	Sand over ironstone
C	Shiraz	Barossa Valley	3.7	1988*	191	2.0	Riesling	0.2	Red-brown earth over ironstone
D	Shiraz	Barossa Valley	2.1	2000**	207	1.8	Merlot	1.2	Sandy loam over red clay
E	Shiraz	Barossa Valley	1.8	1998	200	2.5	Own Roots	1.2	Sandy loam over red clay
F	Shiraz	Barossa Valley	2.0	1998	209	1.8	Own Roots	0.5	Sand over clay
G	Chardonnay	Adelaide Hills	0.9	2001	200	1.5	Own Roots	0.74	Sandy loam over red clay
H	Shiraz	Barossa Valley	2.2	1997	209	1.5	Own Roots	0.7	Loamy sand over granite
I	Shiraz	Barossa Valley	3.0	1998	204	1.5	Own Roots	0.7	Loamy sand over granite
J	Cabernet-Sauvignon	Barossa Valley	2.9	1998	206	1.4	Own Roots	0.7	Loamy sand over granite

*grafted 2003, **grafted 2004.

The climatic conditions for the sites were sourced from the nearest Australian Bureau of Meteorology (http://www.bom.gov.au/, accessed on 11 May 2022) weather stations: Nuriootpa PIRSA (station number 23,373), Woodside Wicks Estate (station number 23,920), and Mount Barker (station number 23,733). Mean average temperature and rainfall were calculated for surveyed years (2020 and 2021) as well as the year preceding the survey (2019). Accumulated degree days (base 0) were calculated for the spring of each survey year (1 October–30 November) using monthly averages.

2. Visual Assessments

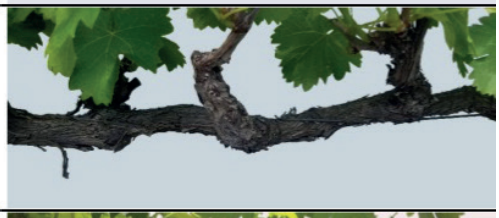
All sites were surveyed in the spring of two consecutive growing seasons (2020 and 2021) when symptomless developing shoots were 50–100 cm long (late October to early December). Each living vine was visually assessed as follows: (i) Cordon dieback was assessed on a 0–100 % scale as a proportion of the entire cordon length, which had died back and where the canopy was no longer present (i.e., no remaining foliage = 100 % dieback). This assessment did not take into account the cause of dieback but a rather quantified loss of productive cordon indiscriminately. (ii) The presence of *Eutypa* dieback foliar symptoms was assessed on a 0–100 % scale as a proportion of the canopy present which displayed characteristic *Eutypa* dieback foliar symptoms (stunted shoots with chlorotic and yellow leaves, often cupped and with tattered margins) (Carter, 1991) (Figure 1).

This assessment did not include areas of the cordon where foliage was not present and, in the case of vines displaying dieback, was expressed as a percentage of all remaining foliage displaying symptoms. (iii) Vines were assessed for degree of cordon strangulation only once during the second survey (as the degree of strangulation remained relatively constant between the two seasons). The degree of cordon strangulation was assessed on a 0–4 scale according to the criteria presented in Table 2.



FIGURE 1. Typical *Eutypa* dieback foliar symptoms (stunted shoots with chlorotic and yellow leaves, often cupped and with tattered margins).

TABLE 2. Visual scale for degree of cordon strangulation caused by tight wrapping. Arrows indicate areas where more severe strangulation is apparent.

0	no strangulation	Cordon positioned entirely on top of wire or otherwise lacking significant wire contact. Minimal to no pressure applied from wire to cordon.	
1	minimal strangulation	Cordon wrapped loosely around wire with much of cordon directly in contact with wire. Minimal pressure applied from wire to cordon and though cordon slightly coiled, minimal to no embedding of wire in wood of cordon.	
2	moderate strangulation	Cordon wrapped moderately tightly around wire with almost all of cordon in direct contact with wire. Moderate pressure applied from wire to cordon, with wire slightly embedded within cordon wood in some areas. Cordon coiled in shape and wire also potentially slightly coiled as a result of contact with cordon.	
3	severe strangulation	Cordon wrapped tightly around wire with almost all of cordon in direct contact with wire. Large amount of pressure applied from wire to cordon and in many areas wire visibly embedded deeply in cordon wood. Cordon coiled in shape and wire likely coiled as well in line with shape of cordon.	
4	very severe strangulation	Cordon wrapped extremely tightly around wire with almost all of cordon in direct contact with wire. Large amount of pressure applied from wire to cordon and in many areas wire no longer visible as so deeply embedded in cordon wood. Cordon tightly coiled in shape with creases visible in cordon wood.	

3. Canopy Assessment with VitiCanopy

Images were taken with the front camera of an iPhone (Apple, Cupertino, CA) at the time of visual assessment for the purpose of measuring canopy architecture using the VitiCanopy App (De Bei *et al.*, 2016). One upwards-facing image was taken from about 80 cm below the cordon of each vine and used for the determination of the plant area index (PAI).

4. Statistical Analysis

Principal component analysis (PCA) was used to identify the dominant patterns in spectral data using The Unscrambler X Version 10.2 (CAMO Software, Oslo, Norway). The Hotelling T^2 test was computed on PCA scores, and spectral outliers were removed (defined as any samples falling outside the associated critical limit of a *p*-value of 5 %). Additional PCA and ANOVA were performed using XLSTAT Version 2021.2.2 (Addinsoft SARL, Paris, France). Means were assessed across all sites and were separated using Fisher's LSD test at a significance level of $p \leq 0.05$ for all data. Arithmetic means within each site were used to calculate site averages.

RESULTS AND DISCUSSION

The spring of 2020 was warmer than the spring of 2021, with 1061-degree days compared to 913-degree days in the Barossa Valley, and 986 compared to 876 in the Adelaide Hills (Figure 2).

The first two principal components (PCs) in the PCA in Figure 3 explain 70 % of the variation in the dataset. PC1 separates dieback from PAI, degree of strangulation, and cordon age. There was a strong correlation observed between the degree of strangulation and cordon age. Sites with younger cordons, such as A, B, and C, are separated from older sites, including G and J. PC2, which explains over 30 % of the variability in the data set, mostly separates site E from the other sites and in particular from sites B, D, and J, and is related to higher foliar symptoms for site E in both seasons, particularly 2021.

Both the percentage of cordon displaying dieback and the percentage of foliage displaying signs of characteristic symptoms of *Eutypa* dieback increased at all sites between assessed seasons (Table 3). The percentage of cordon with visible dieback symptoms increased from an average of

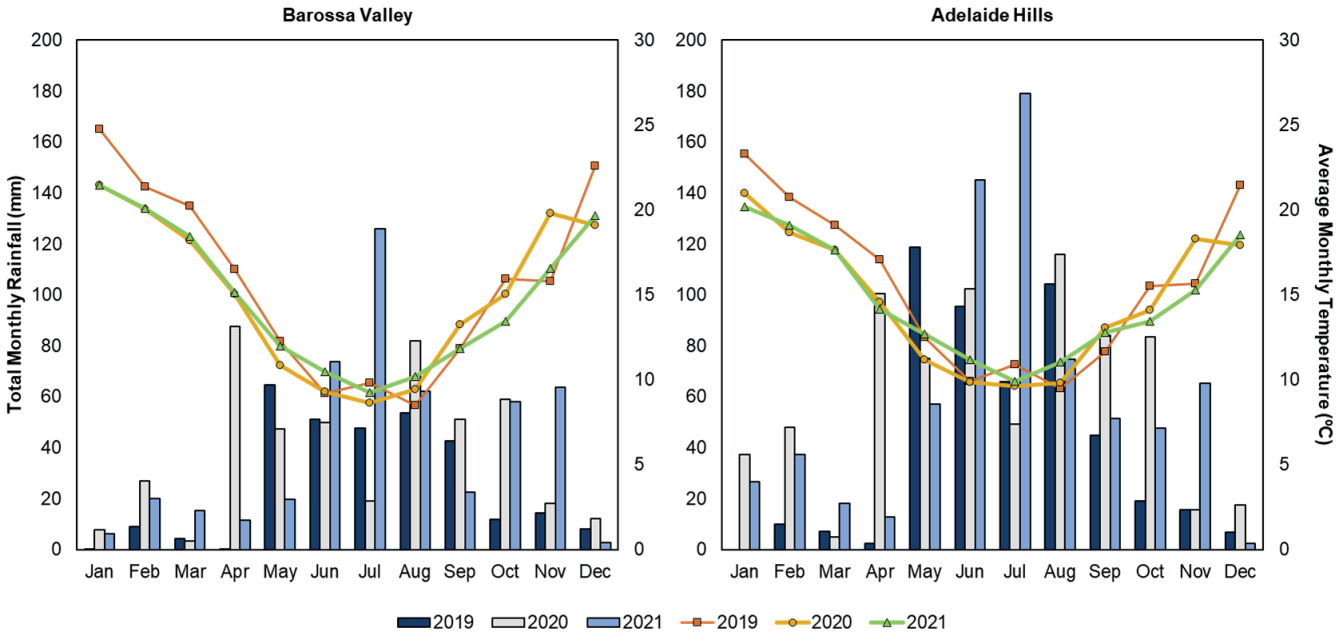


FIGURE 2. Average monthly temperature and rainfall calculated for 2019, 2020, and 2021.

Climatic data were sourced from the nearest Australian Bureau of Meteorology (http://www.bom.gov.au/) weather stations.

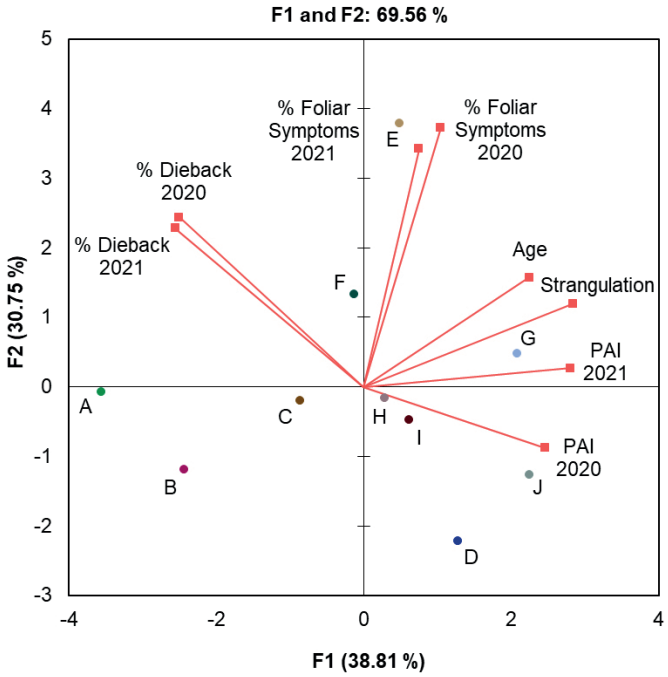


FIGURE 3. Principal component analysis biplot of % cordon dieback, % foliage displaying symptoms characteristic of *Eutypa* dieback, plant area index (PAI), degree of cordon strangulation, and cordon age observed across the 10 surveyed vineyard sites (A–J).

12.7 % across all sites in 2020 to an average of 18.8 %. Cordon dieback is an irreversible condition that cannot be rectified in the absence of major reworking and as such, the increase in dieback observed between assessed seasons at all sites is in line with what one would expect from such a survey. It was decided to conduct the survey across ten vineyard sites to capture as wide a range of degrees of strangulation as possible under different vineyard conditions. Some sites had a greater within-site variability of observed strangulation degrees. Others, such as sites E and G, were comprised almost entirely of very severely strangled vines. Assessed vines were selected to be representative of the sites, and these differences came down to the directions given to the practitioners who were responsible for the cordon training. Considering each site individually, it was apparent that not every site provided the same response to strangulation

according to their own growing conditions. However, several sites which were highly variable in their range of observed strangulation degrees displayed surprising trends where the most severely strangled cordons displayed less dieback than their less strangled counterparts. When comparing the means of data collected at all sites, a trend was observed where cordons suffering from the greatest degree of strangulation displayed the least amount of dieback (Figure 4). Vines with the most cordon strangulation (4) showed significantly less dieback than those that displayed little (1) or no (0) signs of strangulation in both 2020 and 2021. In 2020, very severely strangled (4) cordons actually showed significantly less dieback than all other degrees of strangulation, up to and including vines which were severely strangled (3). This is surprising given that dieback is a condition which is normally associated with advanced cordon age, and a correlation was observed between the degree of strangulation and cordon age (Figure 3). This correlation is logical when one considers how the condition of cordon arms wrapped tightly around the cordon wire typically worsens over time. Arms positioned in this fashion may not display any signs of constriction during the seasons immediately following establishment. However, with normal growth, the pressure applied by the wire onto the cordon and the extent to which it may become embedded within the cordon wood can become progressively worse over each passing year. One might also suspect that cordons displaying very severe strangulation could be more susceptible to dieback, given the possibility that the normal functionality of their vascular conduits could be compromised by constrictive pressure. Any decrease in the number or diameter of xylem conduits would likely reduce the capacity of the cordon for water and nutrient transport, as xylem conductivity is determined by vessel structure, size, and efficiency (Schultz and Matthews, 1993; Tyree and Ewers, 1991). It is also very common to observe dieback in tightly wrapped arms in older vineyards, both in the presence and (apparent) absence of grapevine trunk diseases. One possible explanation for the negative correlation observed between strangulation and dieback in this trial is that three of the sites with the youngest cordons (A, B, and C) had a high occurrence of dieback but did not have a very high average degree of strangulation, pulling the results towards a negative correlation between the degree of strangulation and dieback. Site B, in particular, had by far the lowest average degree of strangulation (1.60) and among the highest rates of dieback for both 2020 and 2021 (16.2 % and 20.3 %, respectively) (Table 3). While the exact causes of the dieback at this site were not investigated outside of the factors assessed in the survey, it is likely that *Eutypa* dieback was a significant contributing factor, as the presence of foliar symptoms in both seasons of assessment confirmed its presence. Additionally, some sites, such as D and G, had very high average degrees of strangulation (3.87 and 3.96) and relatively low incidence of dieback (6.9 % and 6.0 % in 2020).

PAI decreased at all sites between seasons, with an average observed decrease of 0.90 or 42 %. Very severely strangled cordons generated surprisingly high PAI values. Because of the nature by which strangulation may constrict the vasculature of the cordon and interrupt water flow, one would not expect that strangulation would favour growth, especially in the most distal areas of the cordon. In both 2020

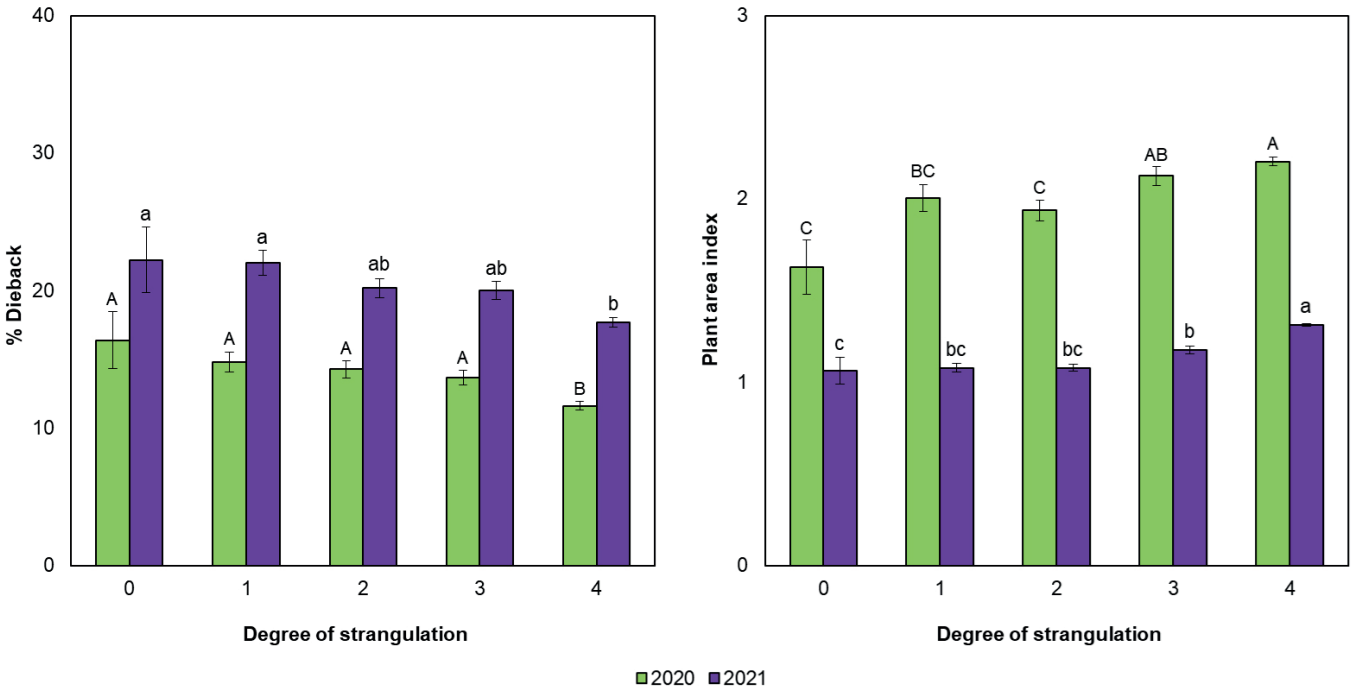


FIGURE 4. Effect of cordon strangulation on cordon dieback and plant area index, PAI.

Means of data across sites were separated by ANOVA using Fisher's LSD test at a significance level of $p \leq 0.05$. Bars indicate the standard error. Uppercase letters indicate significant differences between degrees of strangulation in 2020. Lowercase letters indicate significant differences between degrees of strangulation in 2021.

and 2021, vines displaying the least amount of strangulation (0, 1, 2) had a significantly lower PAI than those displaying the greatest average degree of strangulation (4) (Figure 4). While the assessment of cordon dieback in this trial was based on visual observation and is, therefore, to some extent subjective, measurement of PAI was undertaken with the use of the VitiCanopy app. This app uses upward-facing digital images of canopies captured by a smartphone to implement image analysis algorithms automatically, calculating canopy architecture parameters and thereby providing an objective measurement of PAI. In the results of this trial, high cordon dieback correlated with low PAI, helping to eliminate the possibility of human error during the visual assessments used for the determination of dieback severity. This negative correlation between dieback and PAI is expected given that PAI describes the total one-sided area of plant tissue per unit ground surface area (De Bei *et al*., 2016), and more dieback equates to the less remaining productive cordon. The positive correlation between the degree of strangulation and PAI is difficult to explain; however, one would typically imagine that vines of advanced age and displaying severe strangulation would be more prone to increased canopy porosity (light penetration through the canopy) and reduced PAI.

The percentage of foliage displaying signs of characteristic symptoms of *Eutypa* dieback increased at all sites between assessed seasons. In both 2020 and 2021, a trend of an increase in visible *Eutypa* dieback foliar symptoms was observed with an increase in the degree of strangulation (Figure 5). While the presence of characteristic foliar symptoms of *Eutypa* dieback indicates the presence of the pathogen *Eutypa lata*, the absence of such symptoms does not necessarily mean that a vine is free of infection from *Eutypa lata* or other fungal wood pathogens, as vines may be infected by such pathogens without displaying any symptoms (Sosnowski *et al*., 2011b). One possible explanation for the increased presence of foliar symptoms observed with an increase in the degree of cordon strangulation is that the effects of strangulation could negatively impact the vines' ability to counter the advance of fungal disease infection. In this case, it is possible that cordons which are already under increased stress from the constrictive effects of tight wrapping may be more likely to express symptoms of infection than those which are trained in a less constrictive manner. It is difficult to assign causality here; however, as many factors may be involved in the propensity of infected vines to express visual symptoms (Claverie *et al*., 2020; Fischer and Ashnaei, 2019; Songy *et al*., 2019). It has been reported that foliar symptoms of *Eutypa* dieback are influenced by climatic factors, including winter rainfall and spring temperature. Sosnowski *et al*. (2007) stated that increased symptom expression might be related to increased rainfall during the winter of the year prior to the growing season of interest. Our results differ from this in that winter rainfall (June–July) in the Barossa valley, where most of the sites of this trial were located, was 98.8 mm in 2019 and 69.1 mm in 2020 (Figure 2). While in the Adelaide hills, the winter rainfall for 2019 and 2020 was 161.4 mm and 151.8 mm, respectively.

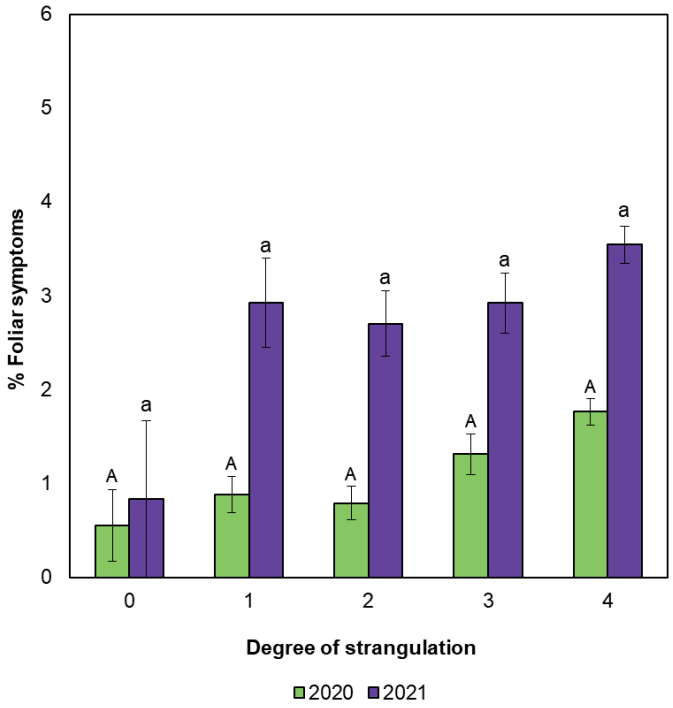


FIGURE 5. Effect of cordon strangulation on the incidence of foliage displaying characteristic foliar symptoms of *Eutypa* dieback.

Means of data across sites were separated by ANOVA using Fisher's LSD test at a significance level of $p \leq 0.05$. Bars indicate the standard error. Uppercase letters indicate significant differences between degrees of strangulation in 2020. Lowercase letters indicate significant differences between degrees of strangulation in 2021.

The percentage of foliage displaying foliar symptoms in this trial increased from an average of 1.46 % in 2020 to an average of 3.24 % in 2021 (Figure 5). The same 2007 study suggested that decreased disease incidence may be related to increased spring temperature. Our results agree with this, as spring degree days (base 0) were higher in both the Barossa valley and the Adelaide hills in 2020 (1061 and 986) than in 2021 (913 and 876). While it is interesting that in this trial foliar symptoms seemed to increase in relation to the degree of strangulation, it is curious that this effect was observed in the absence of increased cordon dieback. This could be related to poor pruning practices, as the number and size of pruning cuts may influence the susceptibility of the cordon to fungal trunk disease infection (Henderson *et al*., 2020), as well as pruning during wet conditions when spore inoculum is prevalent (Carter, 1957). Additionally, poor pruning decisions may lead to an associated loss of spur positions in the absence of infection (Castaldi, 2016), resulting in a redistribution of reserves and, therefore, a bigger canopy in areas of the cordon that remain productive.

The argument that increased stress owing to tight wrapping could reduce vine defence response and result in more symptoms of wood disease is, to some extent, based on the idea that this stress is linked to an increased prevalence of dieback. Other stress-imposing conditions, including water deficit, have been demonstrated as potentially having such an impact on vine defence response (Songy *et al*., 2019). In this trial, this did not seem to be the case as there was actually a trend for less dieback observed in cordons displaying the greatest degree of strangulation, an unexpected result that may be at least in part related to pruning practices. Vigour would have also likely played a role in the vine's response to strangulation. Whether tightly wrapping cordons around the cordon wire could influence the susceptibility of vines to fungal trunk disease infection or the likelihood of infected vines expressing symptoms is not immediately clear. Moreover, unclear is the question of whether such an effect could be observed in advance of or absence of visual cordon dieback, a possibility if strangulation was impeding the regular functionality of vascular conduits without being so severe as to cause perennial wood dieback. Further research quantifying the extent to which xylem morphology and functionality are compromised by constrictive pressure in severely strangled cordons could provide further insight into this condition and the effect it could have on vine health and defence response. Micro-CT could be a valuable tool in this regard as it has recently been used to model grapevine graft unions (Milien *et al*., 2012), the spatial distribution of xylem network connections in cane internodes (Wason *et al*., 2021), and defective wood suffering from symptoms of black rot, necrosis, and decay (Vaz *et al*., 2020). Examining esca-diseased Cabernet Sauvignon, Ouadi *et al*. (2021) reported sap flow measurements were significantly lower in infected plants several weeks before changes in the expression of stress and defence genes were observed, as well as the appearance of any foliar symptoms. While the restriction of vascular tissue reduces the capacity for sap flow, it may not lead to increased progression of *Eutypa* dieback as one might expect. Conversely, a study on the effect of water stress on *E. lata* colonisation found that smaller xylem vessel areas and narrower cane diameter were correlated with less colonisation of *E. lata* in water-stressed vines (Oswald, 2017). Increased xylem vessel diameter has also been reported to be correlated with greater susceptibility to *Phaeomoniella chlamydospora* due to less efficient vessel compartmentalisation (Pouzoulet *et al*., 2017). These results highlight the complexity of the relationship between these different factors of cordon decline and the challenge presented in elucidating their interactions with one another in regard to their impact on vine health. While a negative trend between the degree of strangulation and dieback was observed in this survey, it was not a strong trend. Dieback is a common problem in many older vineyards displaying signs of severe strangulation, and it is logical that such a constriction may be having a negative impact on health and productivity. If vineyard management decisions such as the selection of cordon training method could reduce the likelihood of early cordon decline, then a quantitative analysis of different

TABLE 3. Individual site details for average measurements of degree of strangulation, % of died back cordon, % of canopy displaying typical *Eutypa* dieback foliar symptoms, and plant area index (PAI) (mean ± std).

Site	Degree of Strangulation	% Dieback 2020	% Dieback 2021	% Foliar Symptoms 2020	% Foliar Symptoms 2021	PAI 2020	PAI 2021
A	2.42 ± 0.95	16.3 ± 7.5	23.5 ± 10.5	1.01 ± 2.69	3.53 ± 6.25	1.14 ± 0.18	0.63 + 0.11
B	1.60 ± 0.84	16.2 ± 9.1	20.3 ± 9.8	0.31 ± 1.53	1.82 ± 4.67	1.46 ± 0.30	1.10 ± 0.21
C	3.55 ± 0.69	15.9 ± 10.7	21.1 ± 12.0	0.99 ± 3.02	2.01 ± 4.88	1.40 ± 0.26	1.30 ± 0.27
D	3.87 ± 0.42	6.9 ± 7.3	13.1 ± 9.1	0.44 ± 2.62	1.48 ± 4.06	1.99 ± 0.33	1.45 ± 0.27
E	3.99 ± 0.08	19.1 ± 11.8	23.7 ± 13.5	3.95 ± 6.49	6.56 ± 9.19	1.91 ± 0.45	1.33 ± 0.28
F	3.29 ± 0.85	17.5 ± 10.7	21.6 ± 12.1	2.46 ± 6.01	2.86 ± 5.65	1.52 ± 0.30	1.40 ± 0.27
G	3.96 ± 0.19	6.0 ± 7.0	12.9 ± 9.7	2.81 ± 5.80	5.41 ± 7.10	2.00 ± 0.29	1.29 ± 0.29
H	2.74 ± 1.12	11.6 ± 8.8	22.1 ± 12.6	0.64 ± 1.82	3.67 ± 6.15	3.11 ± 0.52	1.17 ± 0.22
I	3.02 ± 1.10	11.8 ± 8.7	17.7 ± 11.2	1.25 ± 2.94	2.92 ± 6.04	2.96 ± 0.70	1.12 ± 0.26
J	3.73 ± 0.53	8.1 ± 9.3	14.8 ± 12.3	0.88 ± 3.23	2.43 ± 5.80	3.36 ± 0.67	1.37 ± 0.29

cordon establishment techniques could provide valuable understanding in regard to this decision-making. A limitation of this study was the absence of additional physiological measurements to attest to the disruptive effect the observed strangulation had on vine function. Future projects could include additional variables, such as water conductivity, as part of the investigation to improve the scope of the research.

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