Australian Government

Grape and Wine Research and Development Corporation

Tools for managing fruit composition of Pinot Noir in cool climates



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

Project Number: UT05/01

Principal Investigator: **Mark Robertson**

Research Organisation: **Tasmanian Institute of Agricultural Research**

Date: **26th June 2009**

Australian Grape and Wine Research and Development Corporation

Project Number: UT05/01

Project Title:

Title: Tools for managing fruit composition of Pinot Noir in cool climates
Original title: Fruit quality and yield in Vitis Vinifera cv. Pinot Noir

Report Date: June 26, 2009.

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Acknowledgements
This report presents preliminary outcomes of the PhD project of Mr Mark Robertson, prior to thesis submission for examination. Mr Robertson received an Australian Postgraduate Award from the University of Tasmania, with further support from the GWRDC. S.J Wilson was the first-named PhD supervisor, with co-supervision provided by Dr Joanna Jones of the School of Agricultural Science, University of Tasmania (UTAS). Our vineyard co-operators provided feedback and access to commercial vines in Tasmania and, with much appreciation, we thank:
Adrian Hallam for Meadowbank Wines, near Cambridge and Glenora,
Matt Barwick for Clarence House Vineyard, near Rokeby,
Fred Peacock for Bream Creek Vineyard, near Bream Creek.

Disclaimer: The reader is referred to the publication, in due course, of the PhD thesis of Mr Mark Robertson. This thesis is likely to be available electronically through the library of the University of Tasmania. This GWRDC final report may be of assistance to you but the authors and their employer do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaim all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

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1.0 Executive Summary

This report presents preliminary outcomes of the PhD project of Mr Mark Robertson, supervised by Drs Steve Wilson and Joanna Jones at the Tasmanian Institute of Agricultural Research, University of Tasmania.

Three experiments were implemented in an attempt to further understanding about the use of different mechanisms for altering the fruit composition of Pinot Noir in cool climates.

The first experiment focused on the implications of leaf removal for yield and fruit composition. Over three seasons there was no influence of defoliation on anthocyanin concentration, titratable acidity, Brix°or pH. In 2007, there was a significant reduction in bunch number for the 100% defoliation treatment, however yield was not effected in any of the other treatments or years. There was a significant correlation between mean berry mass and anthocyanin concentration, with smaller berries having a significantly higher anthocyanin concentration. The decrease in anthocyanin concentration with increasing berry number suggests that colour development may be related more to internal shading within the bunch than to internal shading within the canopy. There was also a significant relationship between mean berry mass and titratable acidity (TA), with smaller berries having lowers TA values.

Due to the relationship between bunch size and anthocyanin accumulation in the previous experiment, the second experiment aimed to look at the direct effect of shading on the fruit, without altering the canopy. When bunches were shaded, anthocyanin concentration increased with increasing light accumulation. Anthocyanin concentration did not appear to be affected by mean temperature in this study. However the temperatures exhibited in this study were not considered extreme, with the highest mean temperature not exceeding 22˚C. It remains to be seen if a decrease in anthocyanin concentration would occur when mean maximum temperature was used.

Furthering the relationship between bunch size and colour development, the final experiment was planned in an attempt to alter bunch architecture. Gibberellic Acid when applied at concentrations of 300ppm and above, appeared to significantly influence bunch architecture, with resulting lower bunch densities. These lower bunch densities were associated with higher anthocyanin concentrations at harvest.

2.0 Project Aims and Performance Targets

The three main objectives of the study were to:

- Clarify the factors influencing the relationship between yield and fruit quality of Pinot Noir
- Establish the effect of fruiting zone leaf removal in Pinot Noir on yield and wine quality in both the current and subsequent seasons
- Further develop the understanding of light and temperature effects on fruit quality in Pinot Noir

The planned project outputs were agreed on as follows:

Year	Output	Performance Target	Status
2005-2006	• Preliminary advice on bunch size/quality relationships • Literature Review	• Presentation at ICCS (NZ) Feb 2006 • Draft completed Sept 2005	A (achieved) A
2006-2007	• Clarification of the effects of leaf plucking on fruit colour in the current season	• A paper to be completed by Dec 2006	D (delayed)
2007-2008	• Clarification of the effects of leaf plucking into the second season • Establish links between light exposure of and in bunches on colour and other quality factors	• Thesis completed Jan 2008 • Final report to GWRDC • Paper completed by Nov 2007	N (not completed) A D

3.0 Implications of leaf removal for yield and fruit composition

Background:

Fruit zone leaf removal is routinely carried out in vertically trained cool climate vineyards primarily to increase airflow and light penetration within the fruiting zone (Smith et al, 1998). The practice has been associated with a decrease in disease incidence and improved fruit and wine composition and quality. It has been shown to allow greater penetration of fungicide and light into the canopy, thus reducing disease incidence in the fruit (Hunter and Visser 1990a). The improved exposure of fruit to direct light increases its temperature (Smart and Sinclair 1976) which aids in malic acid decomposition and improves the sugar:acid ration of the resulting must (Ruffner et al 1975, cited in Petrie et al 2003). Dokoozlian and Kliewer (1996) also reported that in cool climates improved exposure can also result in an improvement in berry colour. Leaf removal is routinely carried out by hand in many vineyards and significantly adds to the cost of production. The aim of this trial was to measure the effect of ongoing defoliation on Pinot Noir fruit composition and key yield parameters in current and subsequent seasons.

Methods:

The trial was carried out Meadowbank Vineyard, Cambridge, Tasmania. Vertically shoot positioned Pinot Noir vines of three clones (MV6, D5V12 and 8104) between 6 and 8 years of age were subject to four fruiting zone defoliation treatments, applied to vines following pea size but prior to bunch closure (approximately late January). The treatments were 0%, 40%, 70% and 100% defoliation within the fruiting zone (*Plate 1*).

Veraison was scored (1=no berries coloured to 4= all berries coloured) at mid veraison for individual bunches in 2007. At harvest, anthocyanin concentration, titratable acidity, Brix°and pH were measured and bunch number, bunch size and berry number and size were recorded.


Treatment 1: Control

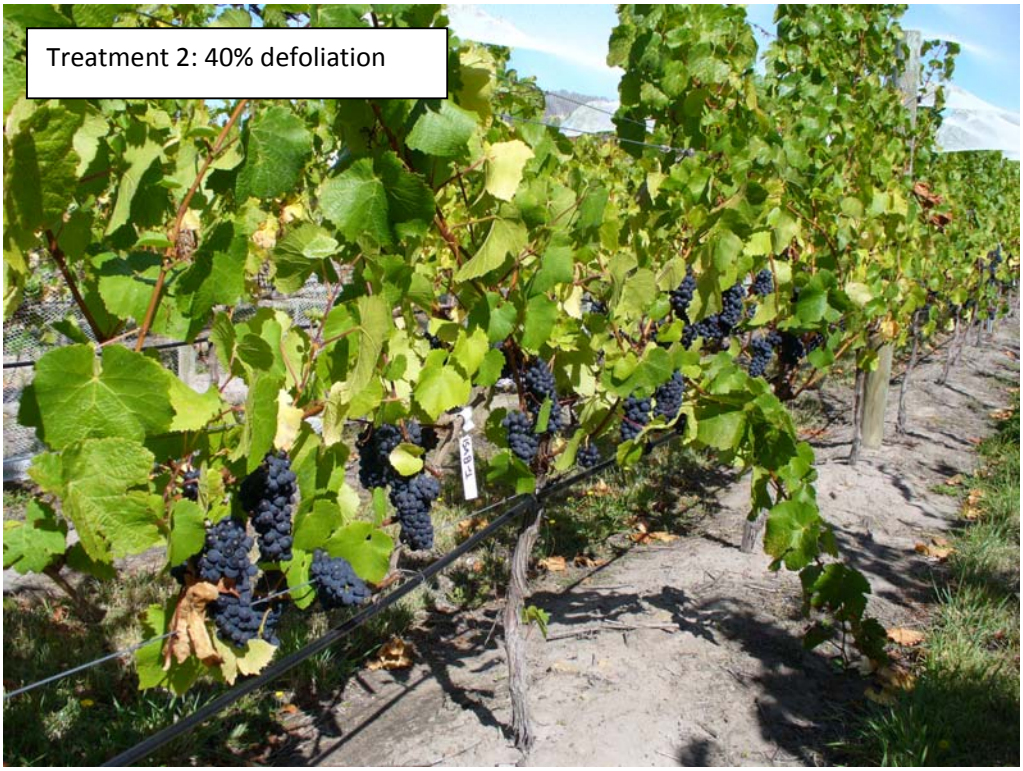

Treatment 2: 40% defoliation





Plate 1: Defoliation levels of the fruiting zone ranging from 0% in the control to 100% defoliation of the fruiting zone.

Results and Discussion:

Over three seasons there was no influence of defoliation on anthocyanin concentration, titratable acidity, Brix°or pH. Studying Sauvignon blanc, Petrie et al (2003) found soluble solids, titratable acidity, sugar per berry and bunch weight were all significantly reduced by leaf removal when all leaves in the bottom 30cm of the canopy were removed, but pH was not affected. The decrease in titratable acidity shown by Petrie et al (2003) was said to reflect greater fruit exposure resulting in a higher fruit temperature (Smart and Sinclair 1976) and, in turn a faster rate of malic acid metabolism (Lakso and Kliewer 1975).

Based on mean berry colour class there was a significant delay in progression through veraison for the 100% defoliation treatment in 2007. Other treatments were not significantly affected by defoliation (*Table 1*). However by harvest, there was no significant difference in anthocyanin content.

Table 1: The effect of defoliation on progression through veraison

Treatment	Veraison Score
0%	2.891
40%	2.876
70%	2.664
100%	2.165
LSD (P=0.05)	0.464

In other studies, defoliation has been reported to increase Pinot Noir fruit anthocyanin concentration (Iland 1988). The results of the present study support the findings of Price et al (1995) who reported that exposure had no influence on the concentration of anthocyanins in the skin of Pinot Noir.

There was a significant year effect on yield and bunch number, with 2006, the second year having a lower bunch number in all treatments and the control. As the control vines also displayed decreased bunch numbers of a similar magnitude, the decreased bunch numbers over the treatment vines was thought not to be due to defoliation. The

decrease in bunch number with increased defoliation in the first year (2005) is thought to be a statistical anomaly, as the defoliation treatments were imposed after bunch number was established. It is possible that human error was involved in counting bunch numbers, with bunches being more visible in the higher defoliation treatments. In 2007, there was a significant reduction in bunch number for the 100% defoliation treatment (*Figure 1*). Treatments resulted in no significant effects on berry or bunch size.

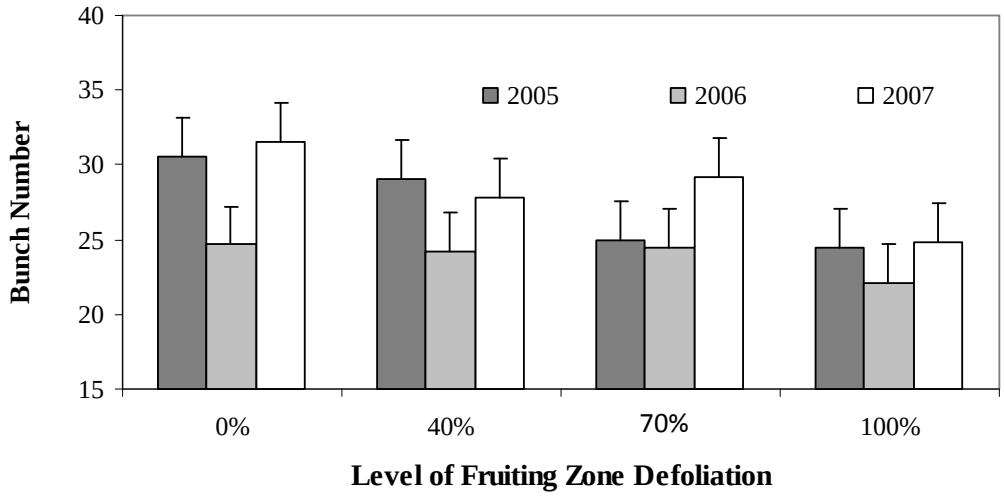


Figure 1: Illustrating a significant differences in bunch number, LSD=6.51 (P=0.05)

There was a significant correlation between mean berry mass and anthocyanin concentration, with smaller berries having a significantly higher anthocyanin concentration (Figure 2). This trend can be explained by the concept of surface area to volume ratio, whereby the ratio decreases with berry size. It is generally assumed that anthocyanins which accumulate in the exocarp will become less diluted from the solvent as berry size diminishes.

The decrease in anthocyanin concentration with increasing berry number suggests that (in this experiment) colour development may be related more to internal shading within the bunch than to internal shading within the canopy. Rojas-Lara and Morrison (1989) reported that anthocyanin accumulation in the fruit was affected more by cluster shading than by leaf shading. Haselgrove *et al* (2000) reported that anthocyanin metabolism

responds to changes in both light and temperature conditions. Responding to the findings of Dokoozlian (1990) who found that Pinot Noir berries showed maximum colour accumulation at low light intensities, of less than 18% ambient photosynthetic photon flux density, Haselgrove (2000) suggested that if light conditions within a canopy are such that the bunches receive sufficient light of moderate intensity, then light is not necessarily a limiting factor for anthocyanin synthesis. Overall, these reports appear to support the results obtained in the present trial and indicate that internal shading in the canopy is not a major determinant of fruit colour.

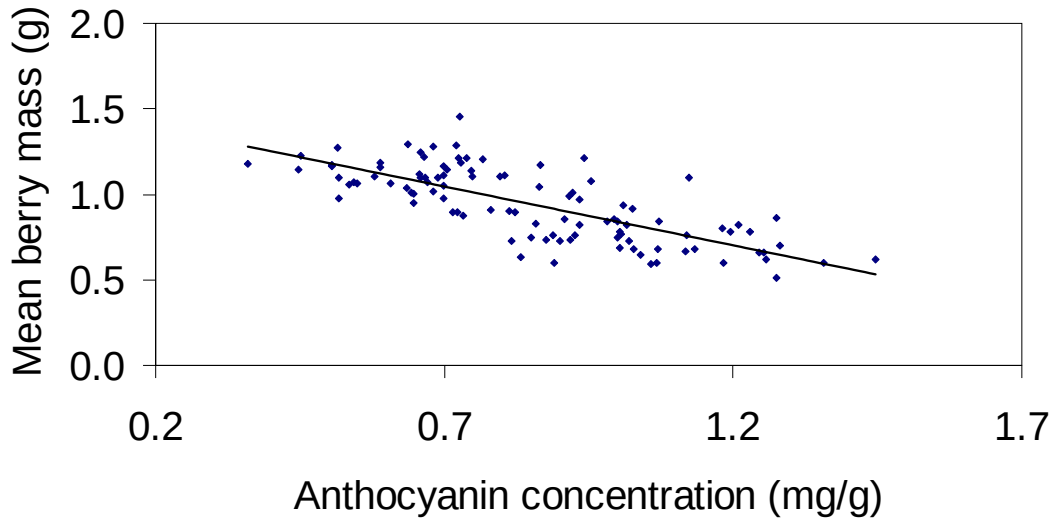


Figure 2: The relationship between mean berry mass and berry anthocyanin concentration (P=0.05, R^2 = 0.64)

There was also a significant relationship between mean berry mass and titratable acidity (TA), with smaller berries having lowers TA values (Fig 3).

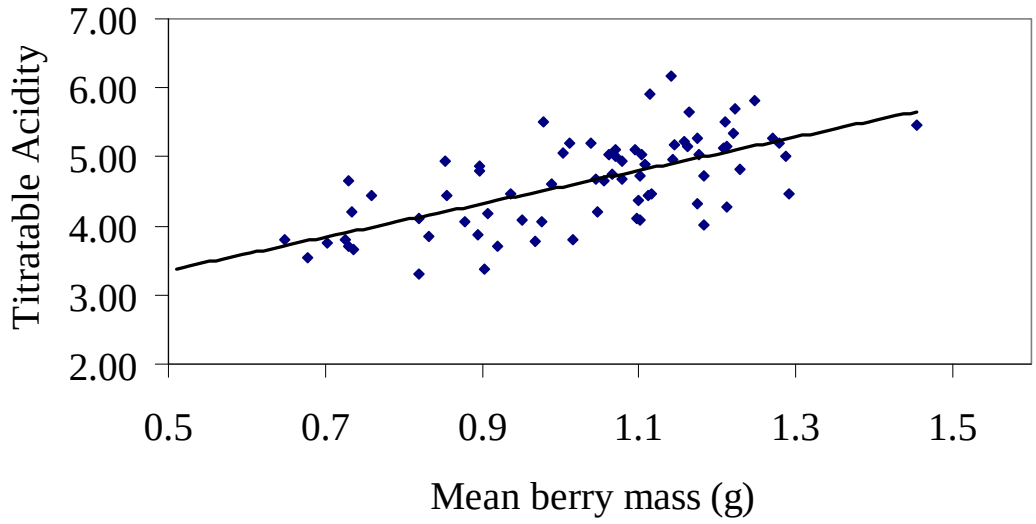


Figure 3: The relationship between mean berry mass and berry titratable acidity (P=0.05,R^2 0.42)

Overall this study found defoliation in the fruiting zone to have very little influence on yield components and fruit composition of Pinot noir. Only the total leaf defoliation in the fruiting zone treatment in the third year resulted in a decrease in bunch number. Howell et al (1994) found very similar results to the present study when working with Pinot noir grapevines, where leaf removal at berry pea-size had no significant impact on yield, fruitfulness, cluster number or weight, berries per cluster or fruit composition. The results presented here relating to the relationship between berry size and both anthocyanin concentration and titratable acidity adds credence to the importance of bunch size in terms of berry number for colour accumulation.

4.0 Implication of shading on fruit composition

Background

Grape composition can be affected by sunlight in many ways. Sunlight provides light energy for photosynthesis and other light-stimulated metabolic processes and provides heat, both by direct solar radiation on plant surfaces and by heating the surrounding air. Heat from sunlight can influence reaction rates of metabolic processes and can also cause stress, either by direct temperature stress or by dehydration. Solar heating of grape berries may increase cellular respiration and water loss, and both heat and light may affect the accumulation of anthocyanins and other phenolic compounds (Crippen and Morrison 1986).

Greater fruit exposure results in a higher fruit temperature (Smart and Sinclair 1976). Previous literature reports that altering vine microclimate to improve berry exposure increases radiation interception by the berries and in cooler climates should also provide a more favourable berry temperature for anthocyanin synthesis (Pirie 1977). A more open canopy does improve fruit composition in that it produces lower juice pH, and potassium and increased colour in berries and wine (Iland 1984, cited in Iland 1988).

Due to the results found in the leaf plucking experiment presented in the previous chapter, the following trial was established to focus on the direct effect of light rather than the indirect effect created by leaf plucking.

Methods

The trial was carried out Meadowbank Vineyard, Cambridge, Tasmania on vertically shoot positioned Pinot noir vines of clone D5V12. Treatments included a glasshouse treatment (plastic chambers were made from polypropylene and were 90mm tall and 68mm in diameter as seen in plate 1), a 50% shade cloth (as seen in plate 2), 70% shade cloth, 90% shade cloth, dark (an opaque cardboard box similar to that used by Downey et al, (2004), and as seen in plate 3) and an untreated control. Treatments were imposed at the first sign of veraison in 2007, and remained in place until harvest.



Plate 1: The glasshouse treatment where bunches were enclosed in a plastic chamber made from polypropylene.



Plate 2: The 50% shade cloth treatment where bunches were enclosed in a bag made of 50% shade cloth.



Plate 3: The dark treatment where bunches were enclosed in an opaque cardboard box.

Thermocouples inserted into a smaller polystyrene ball (1cm diameter) and light sensors (Silonex, SLD-70BG2 planar photodiode) were attached using string to the sides of the bunches, to sit within the bunch, under the treatment cover. The light sensors were calibrated against a quantum sensor (International Light, 700, Research Radiometre) under clear sky conditions (PAR data are thus reported as $W/cm^2/nm$). Sensors were connected to a Datataker DT500 S3 logger, and measurements were collected every twenty minutes (see Plate 4).



Plate 4: Trial design whereby temperature and light sensors were connected to a data logger.

Results and Discussion:

The light environment surrounding the bunches was significantly effected by the treatments imposed. The glasshouse treatment had significantly higher total accumulated light than all other treatments and the untreated control (Table 1).

The diurnal pattern in temperature over the ripening period is illustrated in Figure 1, with the minimum temperature within the untreated bunches being 4°C and the maximum 34°C. The pattern for light interception is shown in Figure 2.

Table 1: Total accumulated light (sum of total light received W/cm^2/nm) for the treatments imposed as compared with ambient conditions.

Treatment	Total accumulated light
Ambient	4.91004
Glasshouse	0.700952
Untreated	0.469416
50% shade cloth	0.233732
70% shade cloth	0.134204
90% shade cloth	0.101914
Cardboard box	0.001702

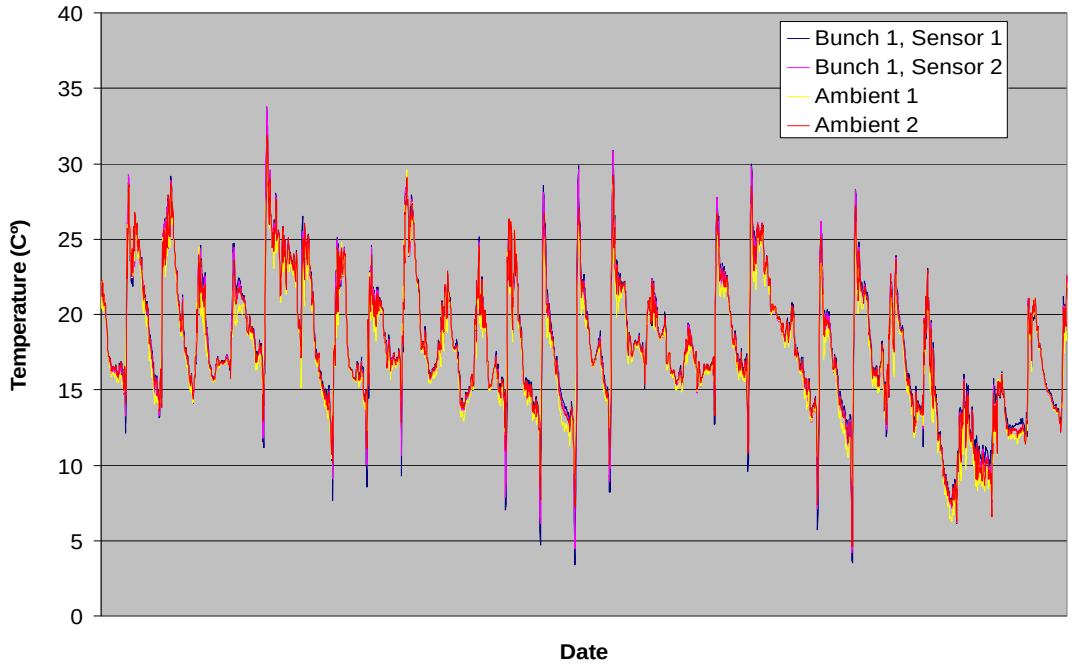


Figure 1: Temperature within the bunches of the untreated control during the ripening phase

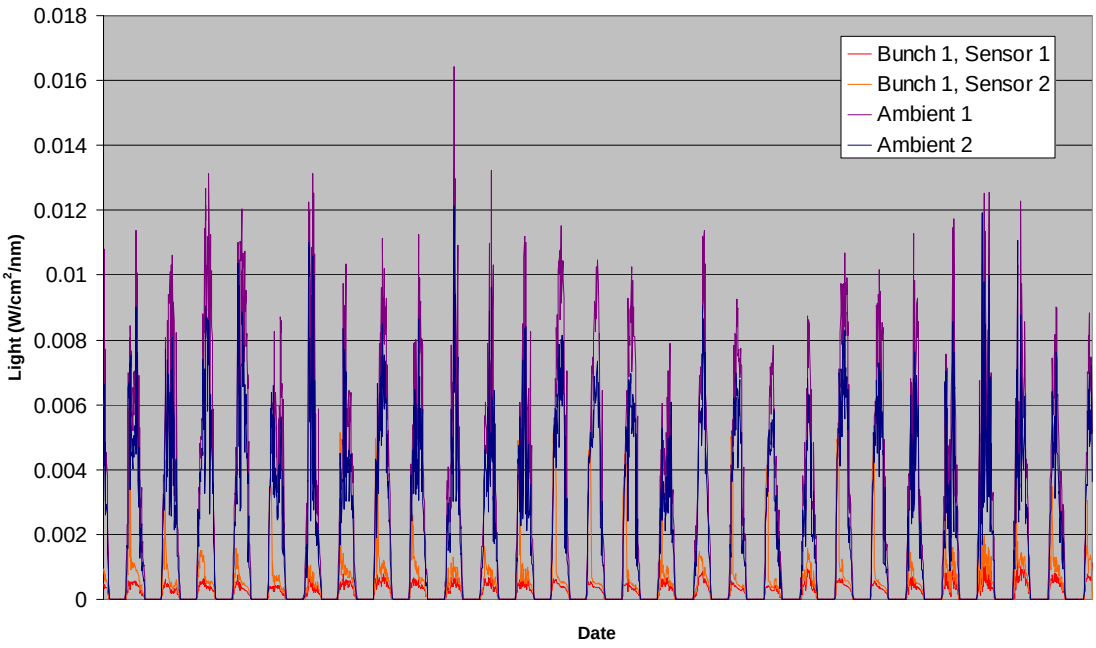


Figure 2: Light variation within the bunches of the untreated control during the ripening phase

A significant relationship was seen between anthocyanin concentration and light accumulation as seen in Figure 3, anthocyanin concentration increased with increasing light accumulation. This finding agrees with previous research as presented in a review by Smart (1985) who reported that fruits well exposed to sunlight generally exhibit higher concentrations of sugars, anthocyanins and total phenolics compared to fruits ripened in dense canopy shade.

Haselgrove et al (2000) showed that anthocyanin metabolism responds to changes in both light and temperature conditions. When bunches were heavily shaded light appeared to be a limiting factor in the accumulation of anthocyanins during the early stages of ripening.

Studies by Pirie (1977) suggest that the optimum temperature range for activity of enzymes involved in anthocyanin biosynthesis is between 17 and 26˚C. Very high temperatures experienced by exposed bunches may inhibit anthocyanin synthesis. In trials where temperature exceeded 35˚C, Haslegrove et al (2000) reported that anthocyanin synthesis may have been inhibited.

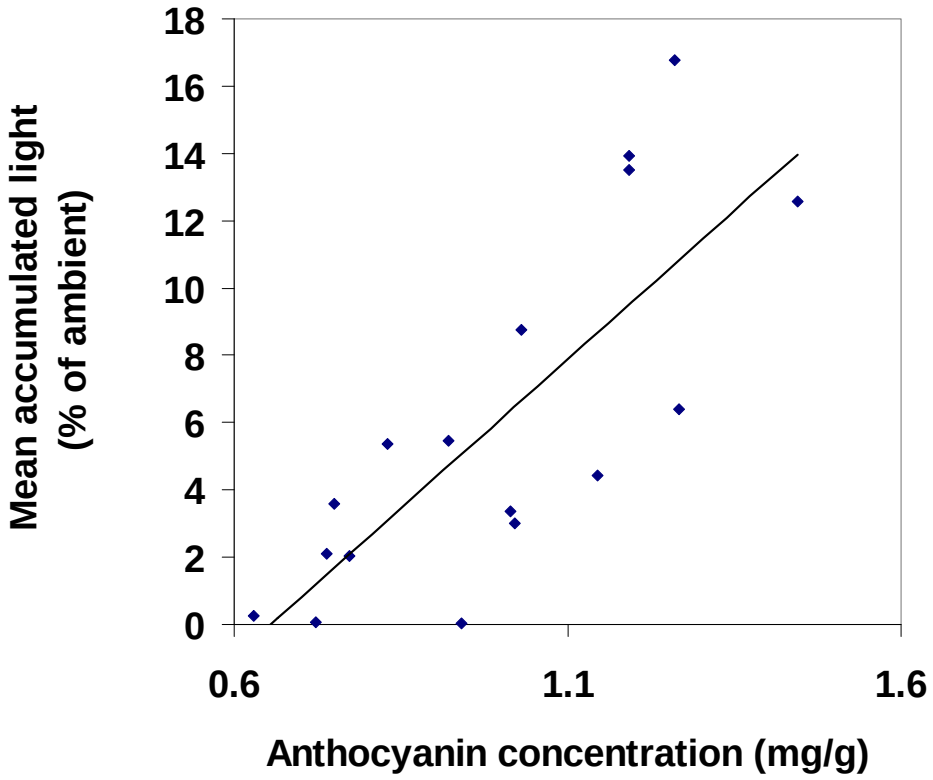


Figure 3: The relationship between anthocyanin concentration and light (R^2=0.61)

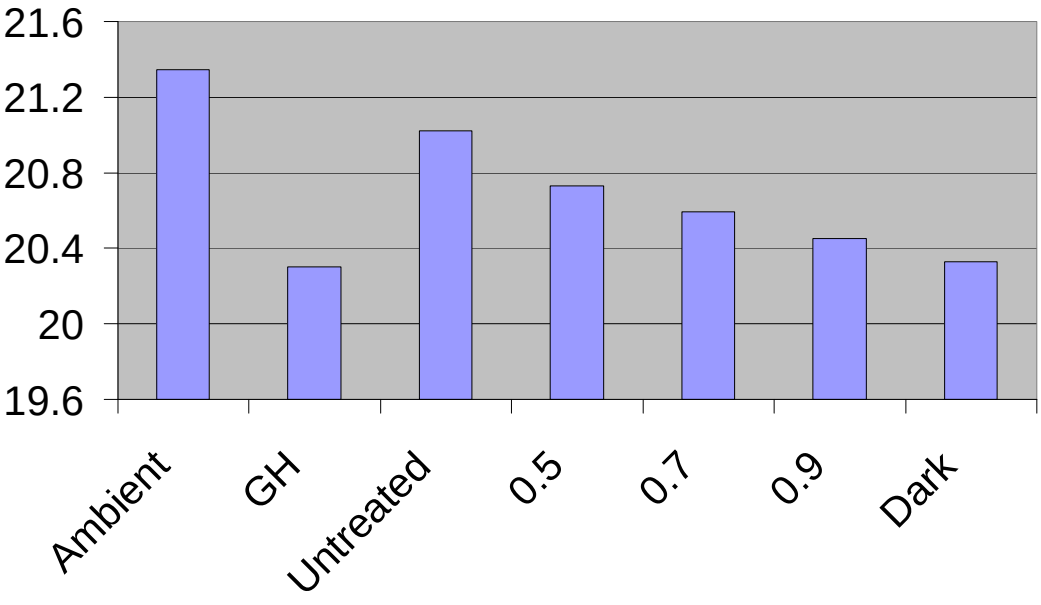


Figure 4: Mean temperature (˚C) experienced under the different treatments

Despite the different temperatures experienced by bunches exposed to the different shading treatments (as seen in Figure 4), anthocyanin concentration did not appear to be affected by mean temperature in this study, as seen in Figure 5, which is contrary to the findings of Haselgrove et al (2000). However the temperatures exhibited in this study were not considered extreme, with the highest mean temperature not exceeding 22˚C. It remains to be seen if a decrease in anthocyanin concentration would occur when mean maximum temperature was used. Temperatures experienced by bunch 1, in Figure 1 exceed 35˚C, suggesting it may be possible for high temperatures to influence colour development even in cool climate regions such as Tasmania.

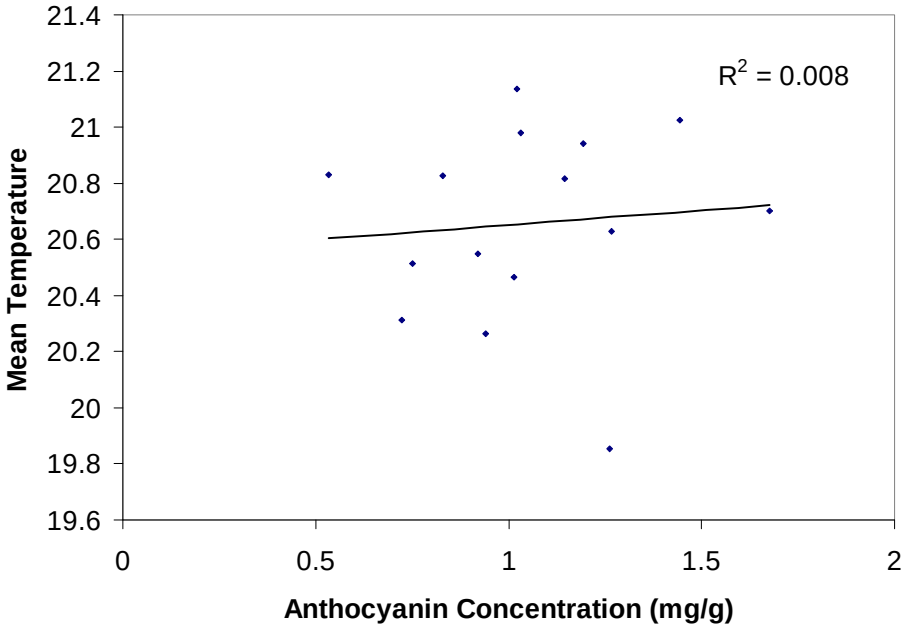


Figure 5: The relationship between mean temperature (˚C) and anthocyanin concentration

5.0 Bunch Structure

Background

It is generally accepted that fruit composition may be affected by various parameters such as bunch exposure, leaf area to crop weight ratio, irrigation and various other viticultural factors. Various authors including May (2000), have commented on the potential for fruit composition of tight bunched varieties such as Pinot Noir to be affected by lack of exposure of the bunch interior. It was also suggested by Heazlewood (2005) that bunch size may be an important determinate of anthocyanin concentration. Chapter 3 of this report presented findings that suggest bunch size has important implications for colour development. The aim of this section is to investigate major bunch structural factors associated with Pinot Noir fruit composition.

Currently gibberellins are used to increase berry size, set, and weight, and also to decrease compactness of tight clusters, to thin, and to induce seedlessness in grapes. Gibberellins are a group of naturally occurring plant hormones that are involved in various aspects of growth and development (Winkler et al 1974). The treatment of compact clustered varieties with gibberellic acid reduces the cluster compactness caused by elongation of cluster parts and decrease in fruit set (Usha et al, 2005).

Tight bunches are regularly observed in varieties such as Pinot noir. As berries enlarge these bunches regularly become so tight as to form solid bodies (May, 2000). To investigate if the tightness of bunches has an effect on Pinot noir fruit composition GA was used to lengthen the bunch rachis and draw out the bunch reducing its tightness with the intention of minimal impact on berry number and berry size; therefore not changing the leaf area to crop weight ratio of the vine.

Methods

In 2007, four concentrations (0, 150, 300 and 600 ppm) of a commercial formulation of Gibberellic Acid (GA) was applied to vines as a foliar spray aimed to the bunch zone and as a bunch dip treatment. Treatments were applied approximately 2 weeks before the first sign of bloom. Bunch volume, mean berry size, bunch density, pH, titratable acidity and anthocyanin concentration were all measured at harvest.

Results:

The method of application was not significant for any of the variables measured. Bunch architecture was significantly affected by treatment application. Bunch width and length were both significantly increased (p=0.05) with increasing concentration resulting in a significant increase theoretical volume and bunch density (Table 1, Plate 1 and Plate 2). Mean berry size in the highest GA concentration was significantly increased, berry number and bunch weight were not significantly affected by GA application.

Table 1, Displaying significant treatment affects of GA application to grape bunches on structural and compositional parameters

Treatment	Mean Berry Size (g)	Volume (cm3)	Bunch Density (Berry Number/ Volume cm3)	pH	Titratable Acidity (g/L Tartaric Acid Equiv.)	Anthocyanin (mg/g)
H2O	0.71a	5017.2a	0.020723a	3.26a	6.45a	0.992a
GA3 150 ppm	0.66a	5541.1ab	0.019481a	3.19ab	5.89b	1.217c
GA3 300 ppm	0.72a	9286.8bc	0.011911b	3.21ab	5.67b	1.028ab
GA3 600 ppm	0.84b	12393.8c	0.009623b	3.13b	5.99ab	1.138bc
LSD (P=0.05)	0.114	3771.3	0.0045	0.078	0.56	0.138

Treatment with GA significantly increased the concentration of anthocyanin and was associated with a significantly reduced pH and increased titratable acidity. No significant difference in Brix°was found. The fact that even with increased berry size the 600ppm treatment was significantly higher in anthocyanin concentration compared with the water control, is counter intuitive to the relationship described in Figure 2 of Chapter 3.



Plate 1: Typical bunches of the vines subjected to the water application (control) as they appeared at harvest



Plate 2: Typical bunches of the vines subjected to the maximum GA application (600ppm) as they appeared at harvest

Gibberellic Acid when applied at concentrations of 300ppm and above appeared to significantly influence bunch architecture, with resulting lower bunch densities. These lower bunch densities were associated with higher anthocyanin concentrations at harvest. These results are preliminary, and further research is required to test the relationship at other concentrations and to determine the effect of GA application on return crop. Gibberellic Acid is used as a crop thinning in other fruit crops, and may cause a decrease in fruitset.

6.0 Outcome/Conclusion

Each of the three experiments assisted in furthering our understanding about the use of different mechanisms for altering the fruit composition of Pinot Noir in cool climates.

Over three seasons there was no influence of defoliation on anthocyanin concentration, titratable acidity, Brix°or pH. In 2007, there was a significant reduction in bunch number for the 100% defoliation treatment, however yield was not effected in any of the other treatments or years. There was a significant correlation between mean berry mass and anthocyanin concentration, with smaller berries having a significantly higher anthocyanin concentration. The decrease in anthocyanin concentration with increasing berry number suggests that colour development may be related more to internal shading within the bunch than to internal shading within the canopy. There was also a significant relationship between mean berry mass and titratable acidity (TA), with smaller berries having lowers TA values.

When bunches were artificially shaded without altering the canopy, anthocyanin concentration increased with increasing light accumulation. Anthocyanin concentration did not appear to be affected by mean temperature in this study. However the temperatures exhibited in this study were not considered extreme, with the highest mean temperature not exceeding 22˚C. It remains to be seen if a decrease in anthocyanin concentration would occur when mean maximum temperature was used.

Gibberellic Acid was effective in altering bunch architecture. When applied at concentrations of 300ppm and above, it appeared to significantly influence bunch architecture, with resulting lower bunch densities. These lower bunch densities were associated with higher anthocyanin concentrations at harvest. These results are preliminary, and further research is required to test the relationship at other concentrations and to determine the effect of GA application on return crop.

Appendix 1: Communication

Robertson, M and Wilson, SJ and Jones, JE, 'Fruit zone leaf removal in cool climate Pinot Noir; Implications for yield and fruit composition', *Proceedings of the 13th Australian Wine Industry Technical Conference*, 29 July - 2 August 2007, Adelaide, South Australia (2007) [Conference Extract]

Robertson, M and Wilson, SJ and Jones, JE, 'The effect of bunch structure on Pinot Noir fruit composition in cool climate South Eastern-Tasmania', *Proceedings of the 13th Australian Wine Industry Technical Conference*, 29 July - 2 August 2007, Adelaide, South Australia (2007) [Conference Extract]

Appendix 2: References

Blesdoe, A.M., W,M. Kliewer and J.J. Marois. 1988. Effects of timing and severity of leaf removal on yield and fruit composition of Sauvignon blanc grapevines. American Journal of Enology and Viticulture. 39, 49-54.

Crippen, D.D., and J.C. Morrison. 1986. The effects of sun exposure on the compositional development of Cabernet Sauvignon berries, American Journal of Enology and Viticulture, 37, 235-242.

Dokoozlain, N.K., and W.M. Kliewer. 1996. Influence of light on grape berry growth and composition varies during development. Journal of the American Society of Horticultural Science 121, 869-874.

Downey, M.O., J.S. Harvey and S.P. Robinson, 2004. The effect of bunch shading on berry development and flavonoid accumulation in Shiraz grapes. Australian Journal of Grape and Wine Research, 10: 55-73.

Haselgrove, L., D. Botting, R. van Heeswijck, P.B. Hoj, P.R. Dry, C. Ford and P.G. Iland, 2000. Canopy microclimate and berry composition: The effect of bunch exposure on the phenolic composition of *Vitis vinifera* L cv. Shiraz grape berries, Australian Journal of Grape and Wine Research, 6: 141-149.

Heazlewood, J. E. 2005. Aspects of *Vitis vinifera L. cv* Pinot Noir Fruitfulness in Tasmania. School of Agricultural Science. Hobart, University of Tasmania**:** PhD Thesis.

Howell, G.S., M.C. Candolfi-Vasconcelod and W. Koblet, 1994. Response of Pinot noir Grapevine Growth, Yield, and Fruit Composition to Defoliation the Previous Growing Season. American Journal of Enology and Viticulture, 45: 188-191.

Hunter, J.J., and J.H. Visser. 1990a. The effect of partial defoliation on growth characteristics of *Vitis vinifera* L. cv. Cabernet Sauvignon I. Vegetative growth. South African Journal of Enology and Viticulture 11, 18-25.

Iland, P.G. 1988. Leaf removal effects on fruit composition, Proceedings Second International Cool Climate Viticulture and Oenology Symposium, Aukland, New Zealand, January, 137-138.

Lakso, A.N. and W.M. Kliewer. 1975. The influence of temperature on malic acid metabolism in grape berries. Plant Physiology 56, 370-372.

May, P., 2000. From bud to berry, with special reference to inflorescence and bunch morphology in Vitis vinifera L. Australian Journal of Grape and Wine Research, 6:82-98.

May, P., N.J Shaulis and A.J Antcliff. 1969. The effect of controlled defoliation in the Sultana vine. American Journal of Enology and Viticulture. 20, 37-43.

Rojas-Lara, B.A., and J.C. Morrison, 1989. Differential effects of shading fruit or foliage on the development and composition of grape berries. Vitis 28: 199-208.

Petrie, P.R., M.C.T. Trought, G.S. Howell, and G.D. Buchan. 2003. The effect of leaf removal and canopy height on whole-vine gas exchange and fruit development of *Vitis vinifera* L. Sauvignon Blanc. Functional Plant Biology, 711-717.

Pirie, A.J.G. 1977. Phenolics accumulation in red wines grapes. Ph.D. Thesis, University of Sydney, Australia.

Price, S.F., P.J. Breen, M. Valladao and B.T. Watson, 1995. Cluster sun exposure and quercetin in Pinot Noir grapes and wine. American Journal of Viticulture and Enology, 46:187-194.

Smart, R.E. 1985. Principles of grapevine canopy management microclimate manipulation with implications for yield and quality. A review. American Journal of Enology and Viticulture. 36: 230-239.

Smart, R.E., and T.R. Sinclair. 1976. Solar heating of grape berries and other spherical fruits. Agricultural Meteorology 17, 241-259.

Smith, S., I.C. Codrington, M. Robertson, R.E. Smart. 1998. Viticultural and oenological implications of leaf removal for New Zealand vineyards. In “Proceedings of the 2nd international cool climate viticulture and oenology symposium’, pp 127-131, New Zealand Society for Viticulture and Oenology: Auckland.

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Usha, K., D. Kashyap, and B. Sungh, 2005. Influence of gibberellic acid and N6-benzyladenine on the development of seed and shot berries in the seedless grape (Vitis vinifera L.) cv. Perlette, Australian Journal of Agricultural Research, 56, 497-502.

Winkler, A.J., J.A. Cook, W.M. Kliewer and L.A. Lider, 1974. ‘General viticulture’. University of California Press: Berkeley, CA.