Which grapevine rootstock performs the best for Mornington Peninsula Pinot Noir?



FINAL REPORT FOR INCUBATOR PROJECT

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Principal Investigator: **Dr Pangzhen Zhang**

Project Supervisor: **Dr Kate Howell**

Research organisation: **The University of Melbourne**

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Author details:
Pangzhen Zhang, Yanan Fei, Alexis Pang, Mark Krstic, Tyson Lewis, Cheryl Lee, Olivia Barrie, Hugh Robinson, Nick Dry, Peter Clingeleffer, Deli Chen, Kate Howell
Contact: Dr Pangzhen Zhang, pangzhen.zhang@unimelb.edu.au

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Pangzhen Zhang [1], Yanan Fei [1], Alexis Pang [1], Mark Krstic [2], Tyson Lewis [3], Cheryl Lee [3], Olivia Barrie [3], Hugh Robinson [4], Nick Dry [5], Peter Clingeleffer [6], Deli Chen [1], Kate Howell [1]

Affiliation:

[1] School of Agriculture and Food, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, Vic 3010

[2] The Australian Wine Research Institute, Waite Precinct, Hartley Grove cnr Paratoo Road, Urrbrae (Adelaide) SA 5064

[3] Mornington Peninsula Vignerons Association, 3/137 Shoreham Road (PO Box 282) Red Hill South 3937

[4] Peninsula Vinecare, 260 Old Moorooduc Rd, Tuerong VIC 3915

[5] Yalumba Nursery, Cnr. Research Road & Nuraip Road, Nuriootpa, SA 5355, Australia

[6] CSIRO, Waite Rd, Urrbrae SA 5064 Australia

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The authors declare no conflict of interest.

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1. Abstract

Phylloxera infestation is a critical risk faced by the Australian wine industry, and phylloxera-resistant rootstocks provides a viable solution. This project compared 14 different types of rootstocks on the physiological performance of Pinot Noir scion grown in the Mornington Peninsula. Preliminary data in the 2018-19 vintage showed clear differences in the timing of flowering, canopy size and plant nutrients, such as magnesium, sodium, potassium, calcium, phosphorus, sulfur, zinc, manganese, copper and boron. As the trial progresses, more insights to support rootstock selection will be found, benefiting the Australian wine industry.

2. Executive Summary

Phylloxera infestation remains a potential hazard for the Australian wine industry, and this is especially true for the Victorian wine regions located in the Phylloxera Risk Zone in close proximity to the phylloxera-infected zone. Adaptation of rootstocks in wine regions such as the Mornington Peninsula is critical to prevent the detrimental impacts of phylloxera, and to ensure the sustainability of the viticultural industry. Existing research has demonstrated the importance of rootstocks to scion performance, especially their role in managing abiotic stresses of drought, high salinity and nutrients deficiency. However, the performance of Pinot Noir scion grafted to new rootstocks in specific growing conditions, such as Mornington Peninsula, remains unstudied. This project compared the impact of 14 different types of rootstocks on the physiological performance of Pinot Noir scion in the Mornington Peninsula, to evaluate the performance of these rootstocks for Pinot Noir production. Phenological, physiological and nutritional parameters were measured for the 2018-19 vintage. Preliminary data showed clear differences in the timing of fruit-set, canopy size and plant nutrients, especially for plant magnesium, sodium, potassium, calcium, phosphorus, sulfur, zinc, manganese, copper and boron. No clear variations were observed for leaf chlorophyll content and root zone soil moisture. The project is the preliminary stage of a long-term viticulture trial; further investigation is required to validate the data over successive vintages. The present study provides initial data reflecting the impacts of rootstock on grapevine performance. As the trial progresses, more insights to support rootstock selection will be found, and benefit the wider Australian wine industry. This project receives financial support from the Australian Grape and Wine Authority through its Incubator Initiative program (UM1801). This project is a six-way collaboration between Wine Australia, The University of Melbourne, The Australian Wine Research Institute, Mornington Peninsula Vignerons Association, Yalumba Nursery and CSIRO.

3. Background and Aims

Phylloxera lurks as a critical risk for the Australian wine industry, as most grapevines in the country are grown on their own roots, rendering particularly susceptible (Buchanan & Godden, 1989). This is especially true for Victorian wine regions. The Mornington Peninsula, for instance, designated as Phylloxera Risk Zone (PRZ), being in relative proximity to the phylloxera-infected zones, such as Yarra Valley. This region is a leading cool-climate wine region in Australia and widely recognized for its high-quality Pinot Noir production. Hence, any phylloxera invasion could lead to devastating effect to local wine industry. Therefore, adaptation of rootstocks is critical to prevent potential detrimental impacts of phylloxera, and to retain the long-term sustainability and resilience of the regional viticultural industry (Arrigo & Arnold, 2007; Walker & Clingeleffer, 2009). Additionally, utilization of resilient rootstocks could help grapegrowers to manage abiotic stresses, such as drought associated with the consequences of climate change, high salinity as a result of long-term irrigation and nutrient deficiencies in association with soil health decline (Corso & Bonghi, 2014). Different rootstocks exhibit varying degrees of tolerance to drought, mainly due to regulation of scion vigour achieved by different hydraulic capacities of root systems, and the control of stomatal closure to reduce water loss during water stress (Gambetta et al., 2012; Marguerit, Brendel, Lebon, Van Leeuwen, & Ollat, 2012). The regulating capacity of different rootstocks to different scion may vary, and need to be assessed case-by-case. Additionally, rootstocks have different capacities in the regulation of potassium in scion, and therefore affect the balance of organic acids and pH in fruit and wine, which is critical for the quality of cultivars such as Pinot Noir (Kodur, 2011). Other nutrients, such as Ca, Mg, Mn, Zn etc in scion may also be influenced by rootstock (Sivritepe et al., 2010). Existing research has demonstrated the importance of rootstocks to scion performance, and therefore rootstock breeding has been conducted for the production of new rootstocks to meet different viticultural needs (Gray, Li & Dhekney, 2014; Jones, Cullis, Clingeleffer & Rühl, 2009; Zhang et al., 2009). However, limited research have been done at this stage to evaluate the viticultural performance of new rootstocks in their impacts on the physiological performance of scion, their tolerance to abiotic stresses, importantly their impacts on grape and wine quality as reflected by grape/wine composition and sensory profile, and their suitability for *Vitis vinifera* cv. Pinot Noir in local climate situation, Mornington Peninsula in this case.

Aims: This project was proposed to investigate the impacts of 14 different rootstocks on scion performance and grape/wine quality using *vitis vinifera* L. cv Pinot Noir MV6 as model plant. Parameters on plant phenology, plant physiology and soil health have been measured at different stages of grapevine growth. The results can be used to evaluate and compare new rootstocks in their impacts on the physiological performance of scion, which reflects the resistance of rootstock to abiotic stress, especially their impacts on plant nutrition. This report

summarized the data in the 2018-19 vintage, which is the first section of a multi-year research project. Upcoming work and future research directions are also included in this report.

4. Materials and Methods

4.1 Location selection and precondition

This study was conducted at two commercial vineyards located in the Mornington Peninsula wine region of Victoria, Australia. The two vineyards are approximately 5 kilometres in distance, one at warmer coastal area (Hugh's vineyard S38.295, E145.058, Elevation 48 m), and one on the cooler hill (Judd vineyard S-38.392, E144.967, Elevation 174 m), reflecting two types of meso-climate at the peninsula. At both vineyards, the scions of *V. vinifera* L. cv Pinot Noir were grafted onto 13 rootstocks in 2014 and 2016 with 3 replicates per treatment and one panel per replicate (**Table 1**). Studied rootstocks include, 101-14, 1103 Paulsen, 5BB Kober, 110 Richter, Schwarzman, 5C Teleki, 3309C, Merbein 5489, Merbein 6262, Merbein 5512, C20, C29, C113 and C114. Grapevine were also planted on own root as control (**Table 2**). The spatial arrangement of rootstocks and planting density were the same in both vineyards. Both vineyards were managed according to industrial practices with no severe pest or disease occurrences in the experimental vintage.



Figure 1. Location of Hugh's vineyard and Judd vineyard, satellite image obtained from Google Earth. (Google LLC, Mountain View, CA 94043 USA)

Table 1. Studied Rootstocks and planting dates

No.	Rootstock	Plantation time	No.	Rootstock	Plantation time	No.	Rootstock	Plantation time
1	101-14	06/11/2014	6	5C Teleki	06/11/2014	11	C20	01/11/2016
2	1103 Paulsen	06/11/2014	7	3309C	06/11/2014	12	C29	01/11/2016
3	5BB Kober	06/11/2014	8	Merbein 5489	06/11/2014	13	C113	01/11/2016
4	110 Richter	06/11/2014	9	Merbein 6262	06/11/2014	14	C114	01/11/2016
5	Schwarzman	06/11/2014	10	Merbein 5512	06/11/2014	15	Own Roots	29/09/2015

Table 2. Rootstock Trial Design

		9			12			6			5			15		
		7			4			2			3			1		
		10			11			14			13			8		

*Each box represents a panel of grapevines (5 grapevines per panel for Hugh's vineyard, 4 grapevines per panel for Judd vineyard)

4.2 Parameters measurement

Plant phenology, plant physiology, plant and soil parameters, including percentage of flowering, percentage of veraison, chlorophyll content, canopy size, pruning mass, chlorophyll content, petiole nutrients and soil moisture, have been measured at key stages of grapevine growth – anthesis, veraison and harvest (**Table 3**).

Table 3. Parameters Measurement During Grapevine Growth

Category	Parameter	Stage	Measurement Date	
			Hugh's vineyard	Judd vineyard
Plant phenology	Flowering (%)	Anthesis	21/11/2018	07/12/2018
	Veraison (%)	Veraison	25/01/2019	11/02/2019
Plant physiology	Chlorophyll content	Anthesis	21/11/2018	05/12/2019
	Leaf area index	Veraison	25/01/2019	Not measured
	Foliage projective cover	Veraison		
	Crown cover	Veraison		
	Crown porosity	Veraison		
	Pruning mass	Harvest	07/05/2019	Not measured
Plant/soil health	Petiole nutrients	Anthesis	25/01/2019	22/02/2019
	Soil moisture	Anthesis	29/11/2018	05/12/2019
		Veraison	25/01/2019	22/02/2019

4.2.1 Percentage of flowering

The percentage of inflorescence of each grapevine was obtained based on visual observation at the stage of anthesis on 21st Nov 2018 at Hugh's vineyard and 7th December 2018 at Judd vineyard.

4.2.2 Percentage of veraison

The front view of each grapevine was recorded using a digital Camera (Huawei Mate 10, Huawei Technologies Co., Ltd) at the stage of veraison, and the number of coloured berries and all berries were counted according to the photos. The percentage of veraison of each grapevine was calculated using the following formula:

$$veraison\ of\ each\ grapevine(\%) = \frac{number\ of\ coloured\ berries}{number\ of\ all\ berries}$$

4.2.3 Chlorophyll content

Leaf chlorophyll content was measured at anthesis using Soil Plant Analysis Development (SPAD) Meter 502DL, with relative chlorophyll content expressed as SPAD numbers (Süß et al., 2015). The leaf opposite to the first bunch of grape on each shoot was selected for measurement. At least 5 leaves were selected for each replicate to establish statistical reliability.

4.2.4 Canopy structure

All the experimental replicates were subjected to canopy structure measurement at veraison using a published image analysis method (Fuentes, Palmer, Taylor, Hunt, & Eamus, 2007). Briefly, upward looking images were taken between every two grapevines from under the grapevine canopy with the camera 20 centimetres above the ground. A digital camera (Huawei Mate 10, Huawei Technologies Co., Ltd) was used to obtain the image. Four images were obtained from each replicate of the experimental group, with all images were saved in JPEG format. An automated procedure was used to process the digital images by using customized code in Mathlab® software (R2017b, Mathwork, NSW, Australia). Canopy data of each grapevine was obtained including leaf area index (LAI), foliage projective cover (f_f), crown cover (f_c), crown porosity (Φ). f_c is defined as the percentage of ground area covered by the vertical projection of crown; f_f is the percentage of ground area covered by the vertical projection of foliage (Scarth, Armston, Danaher, Bartolo, & Edwards, 2008). Φ is defined as percentage of sky within the crown (Pekin & Macfarlane, 2009). Due to the inconsistencies in the trellis system at the Judd vineyard, canopy structure was not measured in the 2018-19 vintage.

4.2.5 Pruning mass

Grapevines were hand pruned, and the pruning weight of each rootstock were measured and recorded. The pruning mass of each grapevine were calculated using the following formula:

$$pruning\ mass\ of\ each\ grapevine = \frac{pruning\ weight\ of\ each\ rootstock}{number\ of\ grapevines}$$

4.2.6 Petiole nutrients

Petiole samples from each experimental replicate were collected at anthesis. To ensure the consistency in sampling, only the petioles opposite to the second bunch on each shoot were collected with a minimum of 15 petioles collected from each replicate. Petiole samples were then prepared for nutrients analysis following

established protocols (Jones Jr & Case, 1990; Wheal, Fowles, & Palmer, 2011; Zarcinas, Cartwright, & Spouncer, 1987). 15 gram of petiole samples were firstly dried and ground to powder. 0.225 g powder was subsampled and digested with the reagents of 2 ml nitric acid and 0.5 ml hydrogen peroxide at room temperature for 24 hours firstly, then at 80℃ for 30 min and at 120 ℃ for 120 min. The sample was then diluted with 18 ml Milli-Q water, and subjected to Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) analysis (Optima 8300, Thermo Fisher Scientific Inc.), which provides the quantities of Aluminium (Al), Iron (Fe), Magnesium (Mg), Sodium (Na), Potassium (K), Calcium (Ca), Phosphorus (P), Sulfur (S), Zinc (Zn), Manganese (Mn), Copper (Cu), Boron (B).

4.2.7 Soil moisture

Soil moisture was measured at both anthesis and veraison using the ML2 Theta soil moisture probe linked to a HH2 Moisture Meter (Delta-T Devices Ltd., Cambridge, England, UK). Each replicate was measured thrice. Measurement was carried out at topsoil under the trellis, and measurement locations were away from irrigation dippers.

4.3 Statistical analysis

All primary data processing was performed using Microsoft Excel™, with Grubb's test performed (Grubbs, 1950, 1969; Grubbs & Beck, 1972) to exclude outliers using Minitab 18 (Minitab, LLC, NSW, Australia). One-way ANOVA was performed at $p < 0.05$ using Minitab 18 (Minitab, LLC, NSW, Australia).

5 Results and Discussion

5.1 Percentage of flowering

The differences in flowering time of the 14 rootstocks were examined (**Table 4**). In Hugh's vineyard, the rootstocks 3309C and C114 showed a slightly slower flowering. In Judd vineyard, the Schwarzman rootstock showed an obvious delay in flowering, while the 101-14, 1103 Paulsen and 5C Teleki rootstock showed slightly faster flowering.

Anthesis is an important growth stage of grapevine, which can significantly influence fruit-set and the yield (Boss, Buckeridge, Poole, & Thomas, 2003). Petrie and Clingeleffer (2005) suggested that vineyard temperature during anthesis stage can influence the number of flowers per inflorescence. Webster (1995) also showed that rootstock could influence flowering times, ostensibly by influencing the temperature requirement for flower buds. Downton and Crompton (1979) suggested that the delay of flowering could be due to the low concentration of chloride in the cane. According to Downton (1977), the chloride concentration of scions grafted to the rootstocks is usually less than the vines on own roots. Therefore, the rootstocks can result in the difference in time of flowering of grapevines, just as observed in both Hugh's vineyard and Judd vineyard.

Table 4. Percentages of Flowering of 14 Rootstocks in Hugh's Vineyard and Judd Vineyard

Rootstocks	Hugh's vineyard	Judd vineyard
101-14	90%	90%
1103 Paulsen	90%	90%
5BB Kober	90%	80%
110 Richter	90%	80%
Schwarzman	90%	70%
5C Teleki	90%	90%
3309C	80%	80%
Merbein 5489	90%	80%
Merbein 6262	90%	80%
Merbein 5512	90%	80%
C20	90%	Not measured
C29	90%	
C113	80%	
C114	90%	
Ctrl	90%	80%

5.2 Percentage of veraison

The progress of veraison of the 14 rootstocks were also investigated (**Table 5**). In Hugh's vineyard, rootstock C114 and Merbein 5489 showed more advanced veraison than the other rootstocks. In contrast, the rootstock 110 Richter entered veraison much later. The percentages of veraison of the other rootstocks ranged from 30

to 40%. In Judd vineyard, Schwarzman, 5C Teleki, 3309C, Merbein 5512 and own root showed faster veraison in the range between 80% and 100%, higher than rootstocks ranged from 60% to 80%. Clear site variations were observed.

Previous research demonstrated that the progress of veraison can be affected by environment factors including temperature, humidity, sunshine and exposure time, and vineyard factors including fruit temperature, humidity, soil characteristics, variety/clone, training and trellising systems, row orientation, canopy management, rootstock and yield components (Bruce Zoecklein, Fugelsang, Gump, & Nury, 2013; BW Zoecklein, Wolf, Duncan, Judge, & Cook, 1992; B. W. Zoecklein, n.d.; B. W. Zoecklein, Wolf, Duncan, Marcy, & Jasinski, 1998; Kliewer & Dokoozlian, 2005; Reynolds, Wardle, & Naylor, 1996). The differences in veraison time in this project between two vineyards might be the differences at two sites, such as the temperature, humidity, soil characteristic and variety/clone. However, further investigation and more data are in need for validation.

Table 5. Percentages of Veraison of 14 Rootstocks in Hugh's Vineyard and Judd Vineyard

Rootstocks	Hugh's vineyard	Judd vineyard
101-14	37.94%	78.02%
1103 Paulsen	27.62%	65.48%
5BB Kober	31.23%	67.76%
110 Richter	10.61%	64.83%
Schwarzman	51.68%	98.16%
5C Teleki	43.21%	90.00%
3309C	22.14%	90.64%
Merbein 5489	64.60%	61.39%
Merbein 6262	34.69%	77.50%
Merbein 5512	27.67%	86.56%
C20	53.41%	Not measured
C29	34.02%	
C113	34.58%	
C114	78.13%	
Ctrl	30.57%	83.78%

5.3 Chlorophyll content

The chlorophyll content of the experimental groups were investigated in both vineyards (**Table 6**). In Hugh's vineyard, no significant difference in chlorophyll content amongst the experimental rootstocks. In Judd vineyard, 5C Teleki and 5BB Kober showed the highest chlorophyll content, while Merbein 5512 had the lowest. The rest rootstocks showed an intermediate chlorophyll content. Chlorophyll plays important roles in physiology, productivity and economy of green plants (Palta, 1990; Steele, Gitelson, & Rundquist, 2008), and it is mainly influenced by the availability of nutrients from the environment, especially nitrogen, and the abiotic stresses

(Keller, Kummer, & Vasconcelos, 2001; Palta, 1990). The rootstock 5C Teleki and 5BB Kober have good performance in nitrogen uptake, and therefore likely higher nitrogen concentration in the scion grafted (Holzapfel & Treeby, 2007; Keller et al., 2001). This explained the higher chlorophyll content in 5C Teleki and 5BB Kober.

5.4 Canopy structure

The canopy structure of the 14 rootstocks were evaluated (**Table 6**). C113 had the lowest LAI, while other rootstocks showed no significant differences. C20 had the highest foliage projection cover and crown, while C29 and C113 had smaller foliage than others. In contrast, C113 had the highest porosity, while 5C Teleki, Merbein 5489, Schwarzman had the lowest.

Canopy size influences the productivity and quality of grape berries (Kennedy, 2002; Kliewer & Dokoozlian, 2005). In the absence of artificial intervention, canopy size is mainly influenced by the nutrient availability and soil moisture (Vance, Reeve, & Skinkis, 2013), and therefore is highly relevant to the nutrient absorption and water stress resistance capacity of the rootstock. Schreiner et al., (2013) reported that nitrogen and phosphorus concentration in plant had a positive relationship with the LAI. However, the same conclusion could not be obtained in this study, where nitrogen and phosphorus concentration may not necessary lead to larger canopy (Table 4, Table 8 and Table 9). This was likely due to the fact that nutrient absorption ability was not the only factor determining canopy size and water retention capacity of the experimental rootstocks. This finding will need to be further investigated in the future stages of the project.

Table 6. Chlorophyll Content and Canopy Size of 14 Rootstocks in Hugh's Vineyard and Judd Vineyard

			Canopy size			
Vineyard	Clone	Chlorophyll content	Leaf area index	foliage projective cover	crown cover	crown porosity
Hugh	101-14	35.49±1.23a	1.19±0.11a	0.47±0.02abc	0.75±0.01ab	0.36±0.04ab
	1103 Paulsen	37.34±1.23a	1.07±0.05ab	0.44±0.01abc	0.75±0.05ab	0.4±0.05ab
	5BB Kober	36.39±0.75a	1.14±0.13a	0.47±0.03abc	0.79±0ab	0.39±0.03ab
	110 Richter	34.71±3.19a	0.89±0.1ab	0.36±0.03bcd	0.6±0.05ab	0.37±0.03ab
	Schwarzman	35.85±1.59a	1.08±0.03ab	0.39±0.02abcd	0.54±0.03b	0.27±0.02b
	5C Teleki	36.93±1.96a	1.06±0.14ab	0.4±0.04abc	0.58±0.02b	0.31±0.03b
	3309C	35.81±0.58a	1.25±0.02a	0.48±0.03ab	0.72±0.12ab	0.32±0.07ab
	Merbein 5489	34.86±1.51a	1.09±0.06a	0.4±0.03abc	0.56±0.04b	0.29±0.02b
	Merbein 6262	35.05±1.17a	0.98±0.13ab	0.38±0.01abcd	0.58±0.05b	0.33±0.07b
	Merbein 5512	35.23±1.56a	1.15±0.37a	0.41±0.08abc	0.62±0.02ab	0.33±0.11ab
	C20	36.63±0.9a	1.22±0.3a	0.5±0.11a	0.82±0.19a	0.39±0.1a
	C29	33.67±0.67a	0.86±0.1ab	0.35±0.01cd	0.56±0.13b	0.39±0.08b
	C113	33.75±0.5a	0.59±0.13b	0.27±0.04d	0.58±0.03b	0.52±0.1b
	C114	35.61±1.2a	0.92±0.11ab	0.37±0abcd	0.68±0.09ab	0.41±0.08ab
	Ctrl	36.23±1.21a	1.15±0.25a	0.41±0abcd	0.67±0.05ab	0.34±0.1ab
Judd	101-14	37.18±1.29abc				
	1103 Paulsen	34.98±0.43cd				
	5BB Kober	39.51±1.18ab				
	110 Richter	35.88±0.81cd				
	Schwarzman	36.03±2.28cd				
	5C Teleki	39.97±0.43a				
	3309C	37.41±0.98abc				
	Merbein 5489	36.15±1.13cd		Not measured		
	Merbein 6262	36.71±0.85bc				
	Merbein 5512	33.11±0.78d				
	C20					
	C29	Not measured				
	C113					
	C114					
	Ctrl	36.07±0.04bcd				

5.5 Pruning mass

The pruning weight of experimental replicates were recorded (**Table 7**). The pruning mass of own root was the highest, followed by 5C Teleki and 101-14, while 110 Richter had the lowest pruning weight. Previous studies reported that 101-14, 5BB Kober, 5C Teleki had moderate to high scion vigour while 3309C, Schwarzman, Merbein 5512 and 110 Richter had low to moderate scion vigour (Clingeleffer et al., 2011; Goldammer, 2018), which was consistent with the present results. Pruning mass is the most direct parameter to evaluate the shoot growth, which further reflects the water status of grapevine (Deloire, Carbonneau, Wang, & Ojeda, 2004). In this project, the rootstocks with higher pruning mass could be regarded as the ones that would provide scion with good water status. It should be noted that the grapevines grafted to rootstock C20, C29, C113 and C114 were planted later than the other grapevines, and therefore the pruning mass was relatively lower than the others due to their younger age. Thus, the performance of the rootstock C20, C29, C113 and C114 in pruning mass should be further evaluated in future vintages.

Table 7. Pruning Mass of 14 Rootstocks in Hugh's Vineyard

Rootstocks	Weight (g/grapevine)
101-14	496
1103 Paulsen	447
5BB Kober	450
110 Richter	241
Schwarzman	382
5C Teleki	503
3309C	329
Merbein 5489	457
Merbein 6262	319
Merbein 5512	252
C20	275
C29	270
C113	257
C114	399
Own Roots	557

5.6 Petiole nutrients

The concentrations of petiole nutrients of the experimental groups were analysed (**Table 8**). Statistically significant differences were observed in some petiole nutrients but not in others. For Hugh's vineyard, no

significant differences were observed in Al, Fe and P among all the rootstocks. For the Judd vineyard, no significant differences were observed in Al, Fe, Na and Zn among experimental groups, but in Mg, K, Ca, S. Variations were also observed between the both experimental vineyards. The reference level of nutrients in grapevine petiole was determined in previous study (Reuter & Robinson, 1997), the nutrients level identified in the current study is compared with the reference level to identify any deficiency or toxic level, which provides information on the nutrient translocation capacity of rootstocks and gives suggestion on the potential needs of specific fertilizer.

For Al, although no significant differences were observed in rootstocks in both vineyards, Judd vineyard had clearly higher Al than that of Hugh's vineyard. A probable reason would be the difference in the soil Al concentration between the two vineyards, which will be confirmed in further soil nutrient analysis. Lin and Myhre (1990) pointed out high Al concentration in soil would limit the growth and density of root. Fortunately, rootstock has been proved to be resist to high soil Al concentration, and the most compelling mechanism is that rootstocks can exclude Al from entering the root by exudation of organic acids, such as citrate at the root surface (and into root apoplastic spaces) (Kochian, Hoekenga, & Pineros, 2004; Kochian, Pineros, & Hoekenga, 2005). However, based on current data, the performance of rootstock in Al resistency could not be evaluated due to the lack of root analysis. Thus, root analysis (i.e., root area, root weight and root Al concentration) and the soil Al analysis need to be conducted in future stage of the project to give indication on rootstock Al resistency.

For Fe, no significant differences were observed among treatment groups. In the case of iron deficiencies, grapevines would suffer from iron chlorosis, which results in yellow leaves with dark green veins (Kumar & Söll, 2000). Some studies (Kolesch, Höfner, & Schaller, 1987; Ksouri, Gharsalli, & Lachaal, 2005) pointed out that grapevine rootstock can resist Fe deficiency, and different rootstocks may have different performance. The ability of rootstocks in Fe deficiency resistance is related to the root diameter and root hair occurrence within the rootstocks (L Bavaresco, Fregoni, & Fraschini, 1991). According to Iland et al. (2011), petiole Fe deficiency level is less than 7mg/Kg. Thus, in this project, no grapevine was in the condition of Fe deficiency, and the performance of different rootstock in resistance of Fe deficiency could not be judged. According to Bavaresco, Giachino and Colla (1999), there is a positive relationship between the iron content and chlorophyll content of leaves. However, the nutrient contents in leaves and petioles are often different (Christensen, 1984), which explained the different results in leaf chlorophyll content and petiole nutrients observed in the current study.

For Mg, the two experimental vineyards showed similar results. In both Hugh's vineyard and Judd vineyard, the petiole Mg quantity of the rootstock 1103 Paulse, Merbein 5512, Merbein 6262, Merbein 5489 and Own root was higher, while Schwarzman and 5BB Kober were among the lowest, which was in consistent to previous finding (Bettiga (2003). According to Garcia (1999), the concentration of other nutrients may influence the absorption of Mg, such as enrichment of Ca in plant leads to the reduction of Mg up-taking in the plant, and low

K concentration contributes to the elevated Mg uptaking. In the current study, all treatments met the reference level of adequate petiole Mg content of 300 mg/kg (Reuter & Robinson, 1997). Previous research reported that the quantity of Mg and K have a positive relationship to the berry size and soluble solid concentration (SSC), and therefore related to the sweetness of grape (Amiri & Fallahi, 2007; Muthukrishnan & Srinivasan, 1974).

For K content, 3309C, 101-14 had the highest level in both vineyards, while Merbein 5489 and Merbein 5512 were the lowest, which was in consistent to previous research (Bettiga, 2003). Compared to the reference level (Reuter & Robinson, 1997), Merbein 5489 in Judd vineyard and Merbein 5512 both in Hugh's vineyard and Judd vineyard showed K deficient, which suggested that K fertilizer might be required for the grapevines grafted into these rootstocks. According to research conducted by Ruhl (1998), rootstock is a key factor of K absorption by affecting the K transportation from the root to scion. Past research (Ruhl, 1989; Walker & Clingeleffer, 2016) also pointed out that there was a positive relationship between petiole K^+ content and grape juice pH, which is related to the acidity of grape. Thus, when considering Mg and K together, C20 and the own root might have lower acidity, while 1103 Paulsen and 3309C are likely to have higher sweetness and lower acidity in the Judd vineyard.

For Na, no significant differences were observed among 14 rootstocks in both vineyards. However, higher sodium content were observed in Judd vineyard compared to that of Hugh's vineyard, which was likely due to the variations in soil Na content between the 2 vineyards, and further experiments are required to explain this difference. Compared to the reference level (Reuter & Robinson, 1997), all the values were in the normal range. Some research addressed that scion petioles of own root may have higher Na content than that of grafted grapevine (Downton, 1977, 1985), which was not observed in the current study. According to Fisarakis(2001), the differences in Na uptake by different rootstocks may be due to genetic differences. High concentrations of Na in leaves and petioles may negatively affect photosynthesis and stomatal conductance (Downton, 1977). Based on the current result, the rootstock 110 Richter might have the worst water stress resistance capacity, which is in consistent with a previous study (Fisarakis et al., 2001).

Significant differences in Ca content were observed in the treatment groups (**Table 8**), with the highest content observed in Merbein 6262 in Hugh's vineyard and lowest observed in 3309C in Judd vineyard. Previous study reported that plant Ca content could be influenced by temperature (Adams, 1987), which explained the differences in Ca between two vineyards. Soil Ca content may be another reason that need to be confirmed. Angyal et al., (2002) found that plant Ca content was not only influenced by the rootstock but also by the scion, as the transportation of Ca from root to scion is affected by both. Muthukrishnan and Srinivasan (1974) pointed out that petiole Ca content showed a positive relationship to the acidity of grape berry, and therefore may

influence grape quality. As mentioned above, Ca enrichment inhibits the absorption of Mg and K, thus high Ca content could contribute to a lower pH.

The normal concentration of P in petiole is in the range of 30,000 mg/kg to 60,000 mg/kg (Cook, Ward, & Wicks, 1983). In both vineyards, the petiole P content of all rootstocks were below the range, with own root showing adequate amounts of P. This may be explained by the fact that the scions grafted could decrease the demand for P, which was in consistent to Grant and Matthews (1996). It has been found that rootstocks showed better performance of absorbing P in the condition of P deficiency (Grant & Matthews, 1996). In Judd vineyard, 5 rootstocks, 101-14, 5BB Kober, 110 Richter， 5C Teleki and 3309C were deficient in P content, with Schwarzman, Merbein 5489 and the own root having adequate petiole P content, while the others had marginal levels. Soil nutrients analysis is needed to ascertain whether there is enough available P in soil. If not, Judd vineyard might need to use P supplement for the grapevines. Previous research suggested a positive relationship between the petiole P content and shoot growth (Grant & Matthews, 1996), which was consistent with the Pruning mass data and P data in the current study.

In both Hugh's vineyard and Judd vineyard, Merbein 6262 had the highest petiole S content, while Schwarzman, 3309C and 110 Richter had the lowest. Sulphur has been considered relevant to flowering and berry ripening and low concentration of S results in delay of flowering and progress of veraison (Rogiers, Greer, Hatfield, Orchard, & Keller, 2006), which was in consistent to the current study.

The petiole Zn contents of all rootstocks were high but not toxic when compared to the reference level (Reuter & Robinson, 1997). Many research showed that Zn absorption was largely influenced by rootstocks (Istvan Fekete, Kovacs, Andrasi, Bodi, & Rakonczas, 2013; Schaller & Löhnertz, 1990), and it may be related to rootstock genetics and the differences in the compatibility of the scion and rootstock (Fekete, Rakonczás, Andrási, Bódi, & Kovács, 2012). In both vineyards, the Zn content of 101-14 was the highest, while 5BB Kober, 110 Richter and own root had the lowest Zn content. This indicated that better Zn absorption capacity in 110-14 and lower capacity in 5BB Kober, 110 Richter and own root. Kozma (1993) suggested Zn as a critical factor in catalysing the synthesis of tryptophan in plant, which is an important amino acid influencing the grape quality. Additionally, Mullins et al. (1992) indicated that Zn deficiency will result in decreased fruit-set, as there won't be enough Zn to sink in the ripening berries.

Mn and Cu are both important micronutrients for grape berry quality, as they are related to the synthesis of carbohydrate and proteins (Istvan Fekete et al., 2013; Kállay, 2010). Compared to reference level (Reuter & Robinson, 1997), the 110 Richter, Merbein 5512, C20 and C29 in Hugh's vineyard were deficient in Mn content and C113 had the marginal content, while the rest rootstocks in Hugh's vineyard and all the rootstocks in Judd vineyard had adequate amount of petiole Mn. The Cu content of all rootstocks experimental groups were high

in both vineyards, with no Cu deficiency. Rootstock may not be the key factor influencing the Mn and Cu content in petiole (Dalbó, Schuck, & Basso, 2011), but may due to the differences in soil Mn content. Another research showed that plant nitrogen content may also affect the amount of Mn being absorbed by plants (Neilsen, Stevenson, & Fitzpatrick, 1989), which suggested the need for nitrogen analysis in the current study.

Boron (B) is closely related to the grapevine growth, with flowering, fruit ripening and fruit yield dramatically influenced by B deficiency (Demir & Serindağ, 2006). By comparing with the reference level (Reuter & Robinson, 1997), B deficiency was identified in both vineyards, with most rootstocks having marginal or deficient petiole B content. Thus, B supplement may be necessary for both vineyards. However, the use of B supplement must be judicious to avoid toxicity at levels over 100 mg/kg. Previous research has suggested that grapevines grafted to rootstocks are more effective in absorbing B than own root (Kidman, Dry, Mccarthy, & Collins, 2014), which was mostly consistent with the observations in this study. Except for Schwarzmann, where the petiole B content was lower than that of the own root in both Hugh's vineyard and Judd vineyard. Previous research reported little information about the performance of the rootstock Schwarzmann in boron uptaking. Thus, further research is needed to evaluate and validate the current data.

Table 8. Concentrations of Petiole Nutrients of 14 Rootstocks in Hugh's Vineyard and Judd Vineyard

Vineyard	Clone	Al (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)	Ca (mg/kg)	P (mg/kg)	S (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	B (mg/kg)
	101-14	12.6±3.3a	36.3±4.4a	6834.7±522.1bcdefg	596.4±36.3abc	20918.4±2170.5ab	16929.7±1473.6bcd	2754.3±523.4a	1878.1±153ab	92.7±8.9a	61.1±9.2ab	74±6.7ab	29±2.1abc
	1103 Paulsen	10.4±0.9a	31.5±4.9a	9172.4±693.5abc	559.5±31.9bc	13912.9±740bc	18959.1±1082.5bc	3156.5±180.5a	1415.5±139.7abcd	77.1±11.7ab	37.7±2.1abcd	76.6±18.2ab	31.8±2.2ab
	5BB Kober	11.2±0.8a	28.8±3a	5665.2±822efg	661.5±25.3abc	18715.1±2972.7ab	20857±1308.8b	2501±610.6a	1929.7±340.3ab	58.2±3.8bcde	63.5±17.6a	77.6±8.8ab	30.9±2.6abc
	110 Richter	9.9±1.2a	26.2±4.9a	4769.7±1004.7fg	770.1±43.8a	14626.3±3619.5bc	13329.1±2563.6d	1601±206.4a	1140.8±68.8cd	49±12.6cde	10.4±3.2d	87.8±17.9a	27.1±4.1abcd
	Schwarzman	11.5±0.4a	30.5±1.7a	6248.3±151defg	761.8±71.8ab	16933.1±2732.6abc	16879.6±1661.4bcd	2744.5±677.6a	1054.9±185.2cd	65.8±5.5bcde	40.9±13.7abc	46.6±10bcd	23.4±1.6cd
	5C Teleki	11.8±1.4a	30.6±4a	6523.9±1172.1cdefg	668.4±65.7abc	15913.4±2862.9bc	20178.8±2986.2bc	1926.8±652.4a	1675.9±145.3abc	65±9.6bcde	32.7±10.4bcd	40±6.4cd	28.2±1.1abcd
	3309C	10.6±0.8a	27.7±0.8a	7173.8±219abcdefg	714.2±107abc	19251.6±5354ab	20418±1243.5bc	1925.8±434.7a	1063.4±306.6cd	69.9±4abcd	25.9±7.6cd	66.4±13.7abcd	28.7±2.6abc
Hugh	Merbein 5489	9.9±1.8a	29.2±4.6a	8490.9±1738.2abcd	593.5±116.6abc	13108.1±5294.4bc	20843.3±3822.9b	2415.4±266.3a	1472.5±512.8abcd	60.4±7.3bcde	32.4±11.7bcd	65.1±7.3abcd	28.8±4abc
	Merbein 6262	10.4±1.4a	30±3.8a	7474.6±1253abcdef	685.1±45.2abc	15417.4±1398.7bc	28362.3±68a	2731.7±1489a	2042±7.9a	64±15.8bcde	26.5±17cd	47.5±19.8bcd	31.9±5.2ab
	Merbein 5512	10.6±0a	32.4±10.1a	9720.3±1081.2a	725.2±54.3ab	8746.8±1467.8c	19131.9±437.2bc	2573.2±948.2a	1711.1±343.6abc	73.1±8.3abc	10.1±5.7d	70.7±10.3abc	25.1±1.7bcd
	C20	10.6±2.1a	29.9±3.4a	8707.5±342.7abcd	672.8±102abc	24811.9±1533.1a	17188.5±512.4bcd	2314.8±100.3a	1181.9±8.7cd	45.7±4.8de	15.9±9.3cd	65.5±4.2abcd	29.6±0.8abc
	C29	10.3±0.7a	28.8±4.8a	4551.2±338.8g	674±68.6abc	17290.6±683.2ab	15265.5±874cd	2175.9±364.3a	891.2±16.4d	41.2±3.4e	16.7±3.3cd	35±2d	21.2±0.3d
	C113	10.9±0.6a	32.6±7.3a	8155.6±894.2abcde	698.6±90.6abc	14295.7±483.6bc	16407.9±857.5bcd	1645.8±490.2a	1259.2±55.4bcd	61.4±7bcde	21.1±4.5cd	71.6±0.2abc	31.7±1.2ab
	C114	9.9±1a	26.6±3.3a	8151.9±1084.7abcde	727.7±32.5ab	14866.9±2968bc	15625.9±959.1cd	1596.9±837.2a	1640.2±237.1abc	81.3±9ab	30.9±6.1cd	74.7±2.5ab	33.1±1.5a
	Ctrl	11±0.4a	28.9±3.3a	9296.2±606.6ab	518.2±20.9c	21330.6±1598.3ab	17312.4±817bcd	3222.5±303.9a	1491.5±75.4abcd	58.7±5.2bcde	33.4±7.5bcd	50.8±4.1bcd	26.2±0.7abcd
	101-14	30.5±0.3a	55.8±3.8a	7647±906.6cd	1765.5±135.2a	18635.2±832.7a	13196.9±1456.5ab	1378.2±552.9bcd	1914.7±3.2ab	77.5±9.9a	106.6±42.5b	55.9±6.4ab	26.9±1.5ab
	1103 Paulsen	30.4±4.3a	72.2±26.4a	12822.6±1198.3a	1687.1±221.4a	13760.8±947.2abc	15950.8±731.8a	1599.6±193.5bcd	1175.9±147.5abc	73±10.5a	164.1±33.4b	50.9±5.9ab	31.2±1a
	5BB Kober	23.6±2.6a	40.9±5a	6923.1±1216d	1339.9±67.1a	14982.1±121.7abc	15036.4±2978.8ab	1039±477.8cd	1432.8±268.3abc	49.6±8.2a	52.7±9.4b	38.9±3.1b	24.6±5.1ab
	110 Richter	27±13.9a	72.8±51.1a	7594.1±552.7cd	1959.1±343.8a	13503.1±861abc	13166±494ab	1166.9±211.4bcd	1066.3±167.2bc	56.3±15.2a	194.3±51.2b	58.2±3.9ab	30.2±0.6a
	Schwarzman	22.1±3.8a	42.3±1.2a	7248.8±271.7d	1758.1±120.2a	18568.7±3385.6a	13108.7±699ab	2584.3±687.6ab	1047.5±184.8c	74.6±7.4a	77.6±36.7b	52.2±4ab	22±0.2b
	5C Teleki	19.1±0.7a	37.2±7.2a	8403.4±813.3bcd	1556.7±225.9a	16916.9±1719abc	14345.3±867.5ab	1207.7±432.7bcd	1806.1±131.2abc	70.8±7.9a	143.4±51.5b	55.7±4.1ab	24.8±0.4ab
	3309C	20.5±3.5a	38.4±6.4a	8222.5±446.7bcd	1647.8±141a	19086.2±3333.6a	11542.9±712.1b	709.2±34.3d	1050.6±46.7bc	74.7±22.3a	307.4±36.5b	61.1±5.3a	25.7±1ab
Judd	Merbein 5489	26.4±10.7a	62.3±20.1a	10399.1±472.1ab	1618.2±187.4a	9076.2±1979c	15594±278.6ab	2206.1±456.4abc	1749.9±348.5abc	78.1±14.6a	34.2±12.4b	60.3±9.2a	26.3±1.4ab
	Merbein 6262	20±3.7a	48.3±0.1a	10742.1±1328.1ab	1616.2±427.6a	12195.7±2551bc	14398.7±1144.9ab	1621±627.8bcd	1943.2±557.5a	54.5±5.1a	776.9±352.1a	47.7±7.2ab	26.6±0.2ab
	Merbein 5512	21.2±3.3a	43.2±6.4a	11493.1±326.1a	1640.6±3.3a	8440±1404.1c	13523.5±574.9ab	1689.2±376.9bcd	1269.4±210.8abc	70.5±7.3a	167.8±9.4b	49.4±6.8ab	25.5±3.2ab
	C20												
	C29						Not measured						
	C113												
	C114												
	Ctrl	17.5±1.8a	39.8±6.4a	10216.5±1365.6abc	1418.5±252a	13930.7±2163.8abc	15269.7±2499ab	3169.4±870.7a	1216.1±283.5abc	57.2±8.4a	71±26.1b	64.1±13.9a	22.3±5b

* The value in orange block represents the content is deficient; the value in yellow block represents the content is marginal; the value in green block represents the content is adequate; the value in blue represents the content is high; the value in pink block represents the content is lower than toxic.

5.7 Soil moisture

The soil moisture of both experimental vineyards were recorded (Table 9). Significant but small differences in the soil moisture were observed between different sampling points at each vineyard, which reflects the small vineyard variations in soils and landscape. According to (Monti & Zatta, 2009), water retention capacity of roots can influence soil moisture. Clearly, it is not the only factor, but soil type, vegetation coverage and root distribution could influence the soil moisture more significantly (Nicholson & Farrar, 1994). The current results of soil moisture values were used as an indicator of the consistency in soil moisture across the vineyard to ensure the validity of the experiment. Soil nutrient analysis and evaluation will be completed in the near future.

Table 9. Soil moisture of 14 Rootstocks at Anthesis and Veraison in Hugh's Vineyard and Judd Vineyard

Vineyard	Clone	Soil moisture (%) at anthesis	Soil Moisture (%) at veraison
Hugh	101-14	0.29±0.01ab	0.1±0.03a
	1103 Paulsen	0.24±0.01b	0.13±0.01a
	5BB Kober	0.29±0.02ab	0.14±0.01a
	110 Richter	0.27±0ab	0.18±0.11a
	Schwarzman	0.28±0.02ab	0.17±0.05a
	5C Teleki	0.26±0.01ab	0.17±0.01a
	3309C	0.28±0.02ab	0.16±0a
	Merbein 5489	0.29±0.01ab	0.08±0.02a
	Merbein 6262	0.3±0.01a	0.13±0.03a
	Merbein 5512	0.29±0.01ab	0.17±0.02a
	C20	0.29±0.01ab	0.16±0.03a
	C29	0.28±0.02ab	0.19±0.08a
	C113	0.28±0.04ab	0.15±0.02a
	C114	0.26±0.02ab	0.12±0.03a
	Ctrl	0.26±0ab	0.11±0.02a
Judd	101-14	0.19±0.03ab	0.06±0.01ab
	1103 Paulsen	0.22±0.03a	0.07±0ab
	5BB Kober	0.21±0.01ab	0.07±0.02ab
	110 Richter	0.21±0.01ab	0.08±0.01a
	Schwarzman	0.18±0.01ab	0.06±0.01ab
	5C Teleki	0.18±0.01ab	0.07±0.01ab
	3309C	0.21±0.01ab	0.07±0.01ab
	Merbein 5489	0.23±0.01a	0.07±0.01ab
	Merbein 6262	0.17±0.01b	0.06±0.01ab
	Merbein 5512	0.21±0.03ab	*Not measured*
	C20	0.19±0.01ab	*Not measured*
	C29	0.17±0.02b	0.05±0.01b
	C113	0.21±0.02ab	*Not measured*
	C114	0.21±0.01ab	*Not measured*
	Ctrl	0.18±0.03ab	*Not measured*

6. Conclusion & Recommendation

This study evaluated the performance of MV6 Pinot Noir grafted onto 14 different rootstocks. Clear differences in grapevine performance in the timing of flowering, progress of veraison, canopy size, pruning mass and petiole nutrients were observed, which can preliminarily reflect the characteristics of the studied rootstocks. Based on the current result, the characteristics of some rootstocks can be preliminarily evaluated. The rootstock 5BB Kober and 5C Teleki with higher chlorophyll content and pruning mass and no obvious delay of flowering and veraison, indicating that they might be a suitably vigorous rootstock for the growth of Pinot Noir. However, the rootstock 5BB Kober might less capable to uptake Mg and Zn. While the rootstock Merbein 5512 had lower chlorophyll content and pruning mass, and importantly low petiole K content, which may be a less vigorous rootstock with higher acidity in grape berries suitable for warmer region. The rootstock 110 Richter might have bad performance in water stress as it had higher petiole Na content, and the pruning mass was the lowest. As for the other rootstocks, the most obvious differences were the ability to absorb different nutrients, for example, the rootstock 101-14 was good at absorbing Al and Zn, the rootstock 1103 Paulsen absorbing Mg and B, 3309C absorbing K and Merbein 6262 absorbing S. Further investigations in future vintages are required to validate the results reported in the current study. Overall, the project in the 2018-19 has achieved the planned objectives.

The information provided by this project pragmatic importance for the Australian grape and wine industry, as the rootstock performance data reported here could provide guidance for grapegrowers to select suitable rootstocks for different viticultural purpose.

This research also possesses economic, environmental and community benefits. The results of this study help grapegrowers to identify phylloxera resistance rootstocks that promise healthy grapevine growth for ultra-premium wine production. This provides a valuable defence against the potential economic loss caused by phylloxera invasion in regions close to phylloxera infected areas, and generates more economic value for local industry by producing better quality wine. Using resilient rootstock is also essential to ensure the sustainability of local viticultural industry, not only to prevent phylloxera, but more importantly providing better tolerance to abiotic stresses caused by climate change and difficult soil conditions. In the long-term, the local community could benefit from this research for better quality fruit/wine and minimized economic losses. This research also helps to educate local communities in rootstock utilization to solve different viticultural challenges.

At this point of time this study was only conducted in the 2018-19 vintage, as the preliminary stage of a long-term viticulture trial. Hence, more data and further investigations are required to evaluate the characteristics of these rootstocks. Further, small-scale vinification and chemical analysis of grape and wine will be conducted to further assess the influences of rootstock on grape and wine quality. Soil profile descriptions and physio-chemical analyses are required for the two vineyards, which will be planned in future stages. This project provides initial data reflecting the impacts of rootstock on grapevine performance. As the trial progresses, more insights to support rootstock selection will be found, therefore benefiting the Australian wine industry in selecting rootstocks.

Valuable information arising from the research: The current research project provides valuable information on Pinot Noir performance grafted onto 14 different types of rootstocks in a premium cool climate wine region at the Mornington Peninsula. The research data collected from this project provides practical information for grapegrowers in making key decisions of rootstock selection. The research data may be published when the results are validated in multiple vintages.

7. Extension

The research outcome of the project has been effectively communicated with the industry collaborators in the following ways:

1. Meeting with Mornington Peninsula Viognier Association and grapegrower on fortnightly basis during vintage, and monthly basis in time other than vintage;
2. Research progress report communicated with all research collabrators on 4th Dec 2018, 25th April 2019 and 12th Jun 2019;
3. Presentation of research data to key research collaborators involved on 26th April 2019;
4. Presentation of research data to the Techincal committee of the Mornington Peninsula Viognier Association;
5. Conference Poster accepted for the Australian Wine Industry Technical Conference to be conducted 21-24 July 2019;
6. Industry workshop planned on the 3rd July 2019 at Mornington Peninsula to present the research data in the 2018-19 growing season to grapegrowers;
7. Publication of the research data requires further valiation in multiple vintages.

8. Researcher Benefit and Feedback

The applicant Dr Pangzhen Zhang is an early career researcher recognized for his viticultural research work in rotundone, which was funded by Wine Australia. This incubator initative early career researcher fund provides a wonderful opportunity for Dr Zhang to establish wider collaborations with local wine community in Mornington Peninsula, to help industry solve real challenges and to continue publishing high impact results. By conducing this research project, Dr Zhang has established a close working relationship with grapegrowers at Mornington Peninsula, and is able to facilitate Wine Australia, the University of Melbourne and the Australian Wine Research Institute in establishing closer collaborations with Victorian wine communities and nurture new industry partnerships. This research could be important for future industry-related funding applications, such as ARC-Linkage. The anticipated outcome from the project will also serve as a milestone for Dr Zhang to apply for the ARC-Discovery Early Career Researcher Award.

11. Appendix 1: References

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