Australian Government

Wine Australia

Evaluating and demonstrating new disease resistant varieties for warm irrigated regions



FINAL REPORT to

WINE AUSTRALIA

Project Number: **CSP 1402**

Principal Investigators: **Mark R. Thomas & Bruno Holzapfel**

Research Organisations: **CSIRO Agriculture & Food / NWGIC**

Date: **December 2017**

Project title: Evaluating and demonstrating new disease resistant varieties for warm irrigated areas

Wine Australia project number: CSP 1402

Period report covers: 01/11/2013 – 31/10/2017

Author details: Mark Thomas (CSIRO)
Bruno Holzapfel (NWGIC)

Postal address:

CSIRO

CSIRO Locked Bag 2, Glen Osmond, SA 5064, Australia

Phone: (08) 8303 8624

Email: mark.r.thomas@csiro.au

NWGIC

Locked Bag 588, Wagga Wagga, NSW 2678

Phone: (02) 6933 4023

Fax: (02) 6933 2940

Email: bruno.holzapfel@dpi.nsw.gov.au

Date report completed: December 2017

Publisher: CSIRO & NWGIC

Copyright statement:
© 2017 CSIRO. To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

Disclaimer:
CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

Table of Contents

1. Abstract 1

2. Executive summary 2

3. Background 4

4. Project Aims and Performance Targets 5

5. Methods 8

5.1 Planting, establishment and monitoring 8

5.2 Vegetative and reproductive assessment 8

5.3 Winemaking and sensory 9

5.4 Presentations and publications 10

6. Results and discussion 13

6.1 Grapevine establishment (seasons 1 and 2) 13

6.2 Initial production - white selections (season 3) 16

6.3 Full production - white selections (season 4) 24

6.4 Winemaking and wine sensory assessment 35

7. Outcomes and conclusions 40

8. Recommendations 41

Appendix 1: Communication 43

Appendix 2: Intellectual Property 44

Appendix 3: References 45

Appendix 4: Staff 46

Appendix 5: Other material and raw data 47

1. Abstract

The project established an experimental vineyard for the evaluation of the first generation of Australian mildew resistant vines in a warm irrigated wine region. A larger scale trial planting of 20 white selections was undertaken in the Riverina (NSW) during the 2013/14 growing season. Detailed field evaluations at the NWGIC experimental vineyard were conducted over three seasons, and experimental winemaking and evaluations were undertaken in the last year of the project (2016/17). Red selections were established at the NSW site from late 2015 for evaluation. No mildews were observed on the unsprayed vines during the term of the project and sensory evaluation of the white wine identified aromatic wines.

2. Executive summary

Breeding new grapevine cultivars with high resistance to fungal pathogens presents an opportunity to substantially reduce the use of plant protection agents, and therefore lower production costs and reduce the impact of viticulture on the environment. Resistance can be achieved by crossing suitable parent cultivars, screening for desired disease resistance and other beneficial traits, and then evaluation of superior selections and their winemaking potential under field conditions for several years before release.

As part of a previous project supported by Wine Australia (CSP 0904), 1200 new selections from the CSIRO breeding program which showed strong resistance to powdery mildew and reduced susceptibility to downy mildew were evaluated under field conditions. Based on disease resistance and other physiological traits, 20 white selections with a range of potential wine quality attributes were identified. These vines represent the first generation of mildew resistant vines produced using marker-assisted selection in Australia. The first larger scale trial planting of these selections in NSW was undertaken in the experimental vineyard of the National Wine and Grape Industry Centre (NWGIC) in cooperation with McWilliam's Wines in the Riverina during the 2013/14 growing season. This initial planting consisted of 20 white selections that had demonstrated superior plant performance at the Barossa site and produced diverse wine flavours identified as of interest by commercial winemakers during sensory evaluation. Red selections required further evaluation at the Barossa site at that time and consequentially were planted in the 2015/16 season adjacent to the white selections. Both selections were trained and managed similarly and the red selections now have an established trunk and cordon after the second season.

After the first season of sprawling of the white selections (2013/14), in winter all vines were pruned to three buds and pruning weights were assessed, these varied considerably by three-fold. In the second season (2014/15), two shoots were left to grow from these buds to mid-spring, and then the best shoot was selected for the trunk and was cut just above the cordon wire. The total shoot length was measured prior to these changes, with the growth between selections varying by about 30%. From the two upper buds and/or laterals the bilateral cordon developed, all vines had reached the appropriate cordon length or more by the end of second season. The training included disbudding, fixing the trunk on stakes and the shoots for the cordon on the wires. The vines were sprayed against mites in spring with wettable sulfur and received fertiliser applications. Weed control was conducted during the season with herbicide sprays in the vine row and the mid row, and frequent mowing occurred. At the end of the first season, the pruning weights were determined and showed four-fold differences between the 20 white and red selections.

In the third growing season (2015/16) the same vineyard management program was undertaken in relation to weed and mite control, but fertiliser application was increased. The longer shoots that were hanging into the rows were shortened in late spring. Basic berry and juice parameters were determined at harvest together with yield and yield components, with the bunch and berry size showing visual variation, being more than two-fold between selections. Berry ripeness was 10° Brix apart in mid-February, consequentially juice pH and TA varied as well with about half a pH unit and 3 g/L for TA. There were also considerable differences between the white selections for yield and pruning weights taken in winter showing more than two- and four-fold differences respectively. The project background and

initial results were presented in talks in the Orange wine region and the Hunter Valley, a seminar and field day was held at the NWGIC in spring 2016.

In the last season (2016/17), the performance of the white selections was further evaluated, there was no sign of mildew in these or the red selections, despite appearance of powdery in the Merlot vines that were located in the adjacent block. However, some damage to the berries and bunches was observed due to heat and sun exposure in mid-summer, but the canopies were still not fully developed due to the vine age. The white selections showed three-fold differences between yields with a harvest time over six weeks due to variation in maturation between these selections. From the middle of February to early April, grapes (about 100 kg) were harvested at suitable berry ripeness (around 22^{o} Brix) from each selection and used for the winemaking, but five selections did not reach a suitable level by early April. Two wines were made from each of the 20 selections and these were assessed two months after bottling in the Riverina at McWilliam's Wines for sensory attributes. This included the ranking of aromas; tropical, citrus, stone fruit and floral as well as attributes for mouth acidity, length of flavour and bitterness. This preliminary assessment of wines showed a considerable difference in the overall scores and preferences. These differences were particularly pronounced in floral aroma and the acidity attribute. The assessment and other information will be published in an industry journal later. These white and red disease resistant selections will be further assessed over the next few growing seasons to ensure a meaningful evaluation of vine performance and wine characteristics.

Regional field trials to evaluate plant performance and wine quality is an important activity to determine the best selections for different regional climates, different management systems and to also engage local viticulturists and winemakers in the assessment of wine made from grapes produced in the different regions. It is recommended that four regional field sites be established for long-term assessment of these new disease resistant selections and future scion and rootstock selections. The four regional field sites would cover the main climates (cool to hot irrigated) where grapes are grown and the major grape growing regions of Australia. It is recommended that sites be established in the Barossa Valley SA, Irymple VIC, Riverina NSW, and Orange NSW. The sites would be managed by CSIRO or State Departments to ensure health of the plants and the collection of research quality data.

It is expected that regional field trials will be an effective pathway to adoption mechanism to help drive industry adoption and uptake of new grapevine selections. The regional sites would also act as mother block plantings for the Australian industry from which healthy cuttings could be sourced.

3. Background

Breeding new grapevine cultivars with resistance to fungal and oomycete pathogens presents an opportunity to substantially reduce the use of plant protection agents in vineyards, and therefore lower production costs and reduce the impact of viticulture on the environment. Resistance can be achieved by crossing suitable parent cultivars, screening for desired disease resistance and other beneficial traits, and then evaluation of superior selections and their wine making potential under field conditions for several years in different regions before release.

The common *Vitis vinifera* wine grape cultivars have little or no natural genetic resistance to the major fungal (powdery mildew - *Erysiphe necator*) and oomycete (downy mildew - *Plasmopora viticola*) pathogens, while wild American grape species such as *Vitis rotundifolia* or *Vitis munsoniana* have natural resistance to these pathogens (Staudt 1997). The reason behind this resistance is that these species have been exposed to both pathogens during evolution, while the diseases were only introduced to European vineyards relatively recently (evolutionary timescale), in the 19th century. The accidental introduction of these pathogens into Europe had a considerable impact on grapevine productivity. Powdery and downy mildew infect both the reproductive and vegetative organs, reducing carbohydrate production and berry quality, with negative consequences for overall productivity (Wan et al. 2007). As a result, the wine industry has a heavy reliance on chemical fungicides to control and prevent outbreaks of these pathogens in the vineyard. Breeding natural genetic resistance against these fungal pathogens into new selections is a high priority for grape and wine producers (Dry et al. 2010). The assessment of these new selections is not only important to evaluate resistance to pathogen attack, but also to determine how they can handle abiotic stress such as heat events and drought, particularly in the warmer grape growing regions. The new disease resistant white selections were selected from crosses between eight premium white selections and a parental line that contains resistance genes for powdery and downy mildew introduced from *Vitis rotundifolia* (Feechan et al. 2013). The evaluation of the wines produced from the grapes of these new selections is essential to determine their marketability.

As part of a previous project supported by Wine Australia (CSP 0904), 1200 new selections from the CSIRO breeding program which showed strong resistance to powdery mildew and reduced susceptibility to downy mildew were evaluated under field conditions. Based on disease resistance and other physiological traits, 20 white selections with a range of potential wine quality attributes were identified. These vines represent the first generation of mildew resistant vines produced using marker-assisted selection in Australia. The first larger scale trial planting of these selections in NSW was undertaken in the experimental vineyard of the National Wine and Grape Industry Centre (NWGIC), in cooperation with McWilliam's Wines in the Riverina during the 2013/14 growing season. The initial planting consisted of 20 white selections that had demonstrated superior plant performance at the Barossa site and produced diverse wine flavours identified as being of interest by commercial winemakers during sensory evaluation. Red selections required further evaluation at the Barossa site at that time and consequentially were planted in the 2015/16 season adjacent to the white selections. Both red and white selections were trained and managed similarly and the red selections now have an established trunk and cordon after the second season.

4. Project Aims and Performance Targets

The project aim was for CSIRO, NWGIC and McWilliam's Wines staff to develop a suitable trial planting arrangement and training system for 20 new white selections and 20 new red selections to ensure that the maximum information is obtained from the project for long-term assessments.

- Monitor vine establishment in the form of shoot growth, bud numbers, nutrient status, pruning weights and collate climatic data from the three seasons of the project. Compile information on vineyard management, including irrigation and nutrient application, record any other inputs and monitor disease levels.
- Determine yields and parameters (bunch numbers per vine, bunch and berry weights), and berry composition parameters such as TA, pH and YAN. Berry composition measurements at harvest will also be done with an OenoFoss to allow comparisons with the same selections planted in the Barossa.
- In the third season of the project undertake sequential harvest using berry sugar accumulation as a physiological indicator to determine the capacity of these selections for different wine styles. Assess the produced experimental wines for their characteristics with the involvement of winemakers from the wine industry, and conduct sensory analysis.
- Assess the potential of the new selections for warm grape growing regions in the view of yield and irrigation water use efficiency and sensitivity of the vine and berries to heat and sun exposure.
- Provide the industry with information on these selections on the suitability and the adaptation of these selections to warm irrigated wine regions and on wine styles, by conducting seminars in the relevant wine regions and publications in industry oriented journals.

Outputs and Activities 2014–15

Year 1	Output	Target Date	Activities
a	Detailed project plan to coordinate activities between research agencies and McWilliam's Wines.	30/9/2014	CSIRO and NWGIC personnel meeting to coordinate project activities and synergies with the Barossa site (data collection). Finalise the project plan for vine, berry and wine evaluation. Discuss longer term option of the planting to also act as a NSW mother block resource for industry.
b	Twenty new white selections planted in a replicated trial.	31/12/2014	Establish suitable trial planting arrangements and a training system for the 20 new selections, following commercial vineyard management practices. Commence collection of climate data.
c	Vineyard and management background information from the first growing season.	30/6/2015	Collect information on vineyard management, including irrigation and nutrient application and other inputs.

d	Record of early vine establishment indicators for the 20 white selections. Disease monitoring protocol established.	30/6/2015	Monitor vine establishment by measuring shoot growth and trunk diameter. Establish monitoring protocol for disease levels (mildews, botrytis).

Outputs and Activities 2015–16

Year 2	Output	Target Date	Activities
a	Appropriate methods established for assessing WUE and the responses of vines to heat events.	31/12/2015	Determine and refine methodology to assess responses to heat and irrigation water use efficiency
b	Results on berry and juice parameters from harvest samples collected	31/3/2016	Measure basic berry and juice parameters (berry size, TSS, pH and TA) from harvest samples.
c	Record of vine establishment for the second growing season of whites compiled.	30/6/2016	Further monitoring and data collection of vegetative and reproductive development and disease levels.
d	Seminar presented and field day held in the Riverina on the initial results for the new selections	30/6/2016	Present the initial results from the first two years of vine establishment to the industry, via a seminar and a field day.
e	The 20 new red varieties planted in the Riverina in a replicated trial.	31/12/2015	Suitable trial planting arrangements and training system established for 20 new red selections.

Outputs and Activities 2016–17

Year 3	Output	Target Date	Activities
a	Detailed berry sugar accumulation curves for the 20 white selections.	31/3/2017	Undertake sequential harvest of the white selections using berry sugar accumulation as a physiological indicator to determine the capacity of the selections for wine styles.
b	Data on yields and parameters and basic berry composition for the 20 white selections. Vine establishment data for the second growing season of the 20 red varieties.	31/3/2017	Determine yields and parameters (bunch numbers per vine, bunch and berry weights), and basic berry composition parameters. Monitoring and data collection of vegetative and reproductive development and disease levels (red varieties).
c	Data on vine water use of the 40 selections and their sensitivity to heat	30/4/2017	Assess the potential of the new white selections for warm grape growing regions in the view of irrigation water use efficiency and responses to heat exposure. Carry out preliminary measurements on the red selections.

d	Two wines from each white selection at two different ripening stages made and characterised. Record of vine establishment for the third growing season of whites and second season of red selections.	30/6/2017	Assess the experimental wines for their sensory characteristics with the involvement of winemakers from the wine industry. Continue with the monitoring of vegetative and reproductive development and disease levels.
e	Seminars presented (including wine tasting) in warm grape growing regions. Article published in an industry orientated journal.	30/6/2017	Provide industry with information on the new selections regarding: • suitability and adaptation to warm irrigated wine regions • potential wine styles • comparison with the same vines grown in the Barossa

Note: all of the above were achieved, with some minor alterations, due to the difficulties to reach a target harvest date and to have more appropriate replications, the two wines from each selection were made at the same time. The seminar and field day were held in spring rather than winter 2016, but two workshop presentations were given in winter 2016. Similarly, the wine assessment/sensory was delayed until September 2017 (two months after bottling) and consequentially the industry publication is still in press. However, one additional industry publication has been already published, not containing the information of the wine assessment.

5. Methods

The project assessed the performance of 20 new selections from the CSIRO breeding program, which are resistant to powdery mildew and show reduced susceptibility to downy mildew. These were planted in the NWGIC experimental vineyard in late spring 2013, and in late spring 2015, a similar planting of 20 new disease resistant red selections followed. The vines were not sprayed to control powdery/downy mildew to allow evaluation of resistance levels to pathogen pressure in the warm irrigated region, but some sulfur sprays were applied for mite control in spring. The evaluation of these selections included basic berry composition and wine composition and ultimately wine styles. This assessment will determine the suitability and the adaptation of these selections to warm irrigated regions.

5.1 Planting, establishment and monitoring

The NWGIC in consultation with McWilliam's Wines designed the planting layout, the choice of a training and vineyard establishment program (Figure 5.1). Each selection was replicated six times in four vine plots, with spacing between vines of 2.25 m and between rows of 3 m (planting density 1,481 vines per hectare). The vines showed considerable growth in the first season (Figure 5.2) with only a few vines lost, which were replaced in the winter of 2014. The white selections were monitored for two growing seasons during establishment and small scale vinification and sensory analysis were undertaken in the third year (2016/17). The red selections were planted later in December 2015 and were also monitored for the second growing season (2016/17). The establishment and training was similar for both red and white selections, but differed between years as the reds were planted two years later (Table 5.1). The amount of fertiliser and water applied is summarised for each growing season. After the first season of sprawling of the white selections, all vines were pruned to three buds and pruning weights were assessed from each plot. In the second season (i.e. whites in 2014/15 and reds in 2016/17), two shoots were left to grow from these buds to mid-spring, and then the best shoot was selected for the trunk and was cut just above the cordon wire. The total shoot length was measured prior to these changes in each plot (whites only). From the two upper buds and/or laterals the bilateral cordon was developed, with all vines having reached the appropriate cordon length or more by the end of second season. The training included disbudding, fixing the trunk on stakes and the shoots for the cordon onto the wires. The trunk circumference was measured and pruning weights were also determined. The vines were sprayed against mites in spring with wettable sulfur and received fertiliser applications. Weed control was conducted during the season with herbicide sprays in the vine row and the mid row, and frequent mowing. The climatic conditions were collected by BOM weather stations nearby and are summarised for the relevant seasons (Figure 5.3), the seasonal mean temperatures and total seasonal rainfall were highest in seasons 1 (2013/14) and 3 (2015/16) respectively. However, in season 4 (2016/17) the most rainfall was recorded in early spring. Only in the 2014/15 season 2 the mean January temperature was in the normal range for the Riverina wine region.

5.2 Vegetative and reproductive assessment

In the 2015/16 season (season 3 for the white selections), the vegetative growth was assessed by determining trunk circumference (average of two measurements, 30 cm above the irrigation line and 30 cm below the cordon), pruning weights in winter and in mid spring

shoot growth (two shoots per vine) from each plot. Initial vine water use efficiency measurements were conducted in summer using a gas analyser (Li6400 Portable Photosynthesis system, LiCor, Nebraska, USA) between approximately 11 a.m. and 3 p.m. on a sunny day on 18 January. A 50 berry sample was collected from each plot on 28 January to determine berry ripeness and on 17 February for basic berry and juice parameters (berry weight, TSS, pH, TA and YAN) – see below for further details. At this time, the yield and yield parameters were estimated by counting bunches per plot and weighing 12 bunches from each plot.

In the final season (2016/17) vegetative growth was assessed again by determining shoot growth, trunk circumference and pruning weights as in the previous season. Nutrient status was monitored around flowering by using a chlorophyll meter in spring and vine water use efficiency in summer using a gas analyser (15 December). Berry sugar accumulation was monitored from veraison every two weeks until suitable maturity was reached (around 22° Brix). This assessment together with berry weight was done on 50 berry samples from each plot for each selection until harvest, using a bench refractometer (PR-101, Atago, Tokyo, Japan). At each harvest, two 50 berry samples were collected, one for TSS and berry weight determination and another for pH, TA and YAN. These later samples were frozen and the assessments were conducted in winter using an autotitrator (841 Titrando, Metrohm, Herisau, Switzerland). The ammonium and α-amino acid concentrations (NOPA) of the juice were determined by using commercially available enzymatic assay kits, designed for a Konelab 20XT Autoanalyser (Thermo Fisher, Scoresby, Australia) for calculation of YAN concentration. In addition, the fruit sensitivity to sunburn and heat stress was assessed twice during grape maturation (in one cordon of each two middle vines in a plot). There was some mite damage in spring which required a sulfur spray, but no mildew was detected on the new selections, despite a severe incidence in adjacent non-resistant grape selections. Yield and yield parameters were determined by harvesting each plot and determining the bunch number per plot and berry weight at each harvest date, when each selection reached suitable ripeness for experimental winemaking. All field data were collected separately from each of the six replicates (except the gas exchange from three replicates), with standard error calculated for each mean.

5.3 Winemaking and sensory

The aim was to produce experimental wines at similar maturation levels (around 22° Brix), but five selections did not reach 20° Brix by early April. From the middle of February to early April, grapes were harvested at suitable berry ripeness and 80 to 100 kg of grapes from each selection was used for the winemaking. Two 30-40 L ferments were done in 100 L variable capacity stainless steel tanks for each of the 20 selections. Parcels of grapes were pressed with an electric stainless steel basket press (Zambelli 70 litre, Camisano Vicentino, Italy). After the first racking, the must was inoculated with yeast DV10 that was rehydrated with Go-Ferm®, Fermaid A (Lallemand Wine Nutrients, Scott Laboratories Inc., Petaluma, California) and tartaric acid was added to the ferments as required. Prior to fermentation the must was analysed for pH and TA with an autotitrator (Titrando System, Metrohm Ltd., Herisau Switzerland), Baume was measured using a portable density meter (DMA 35N, Anton Paar, Graz, Austria) and YAN calculated using an Arena discrete analyser. After the end of the fermentation process the wines were stabilised in a cool room at 4 °C for four weeks. Bentonite was added after the third racking and the bottling followed after two further rackings. The free SO_2 was adjusted to approximately 30 mg/L prior to bottling, the pH and

TA were assessed again from all 40 wines, alcohol concentration was determined by using an Alcolyser (DMA 4500, Anton Paar density meter (NIR) and also acetic acid and residual sugars were determined with a Konelab 20XT Auto analyser (Thermo Fisher). The wines were assessed two months after bottling in the Riverina at McWilliam's Wines for sensory attributes. All wine data were collected separately from each of the two ferments, with standard error calculated for each mean. This included the ranking of the aromas; tropical, citrus, stone fruit and floral as well as attributes for mouth acidity, length of flavour and bitterness. In addition, overall preference (1 to 9) and score (100 point scale) were assessed by the winemakers at McWilliam's Wines.

5.4 Presentations and publications

The findings in relation to grapevine performance and grape/wine composition were reported to the industry at regional, state and national level in the form of seminars, a field day and industry publications (see Appendix 1 for details). This provided growers with opportunities to familiarise themselves with the benefits of these selections for their business operations; this process is on-going.

Row \ Vine	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	W10	W10	W10	W10	W15	W15	W15	W15	W18	W18	W18	W18	W11	W11	W11	W11	W19	W19	W19	W19
2	W7	W7	W7	W7	W12	W12	W12	W12	W20	W20	W20	W20	W17	W17	W17	W17	W5	W5	W5	W5
3	W3	W3	W3	W3	W14	W14	W14	W14	W1	W1	W1	W1	W6	W6	W6	W6	W16	W16	W16	W16
4	W4	W4	W4	W4	W8	W8	W8	W8	W13	W13	W13	W13	W2	W2	W2	W2	W9	W9	W9	W9
5	W5	W5	W5	W5	W3	W3	W3	W3	W12	W12	W12	W12	W10	W10	W10	W10	W15	W15	W15	W15
6	W14	W14	W14	W14	W2	W2	W2	W2	W7	W7	W7	W7	W4	W4	W4	W4	W20	W20	W20	W20
7	W19	W19	W19	W19	W8	W8	W8	W8	W6	W6	W6	W6	W9	W9	W9	W9	W1	W1	W1	W1
8	W11	W11	W11	W11	W18	W18	W18	W18	W13	W13	W13	W13	W16	W16	W16	W16	W17	W17	W17	W17
9	W1	W1	W1	W1	W7	W7	W7	W7	W17	W17	W17	W17	W3	W3	W3	W3	W4	W4	W4	W4
10	W16	W16	W16	W16	W10	W10	W10	W10	W8	W8	W8	W8	W20	W20	W20	W20	W5	W5	W5	W5
11	W2	W2	W2	W2	W13	W13	W13	W13	W15	W15	W15	W15	W11	W11	W11	W11	W6	W6	W6	W6
12	W18	W18	W18	W18	W19	W19	W19	W19	W9	W9	W9	W9	W12	W12	W12	W12	W14	W14	W14	W14
13	W6	W6	W6	W6	W9	W9	W9	W9	W11	W11	W11	W11	W20	W20	W20	W20	W3	W3	W3	W3
14	W19	W19	W19	W19	W1	W1	W1	W1	W4	W4	W4	W4	W7	W7	W7	W7	W8	W8	W8	W8
15	W15	W15	W15	W15	W16	W16	W16	W16	W5	W5	W5	W5	W13	W13	W13	W13	W12	W12	W12	W12
16	W17	W17	W17	W17	W10	W10	W10	W10	W2	W2	W2	W2	W18	W18	W18	W18	W14	W14	W14	W14
17	W13	W13	W13	W13	W20	W20	W20	W20	W19	W19	W19	W19	W14	W14	W14	W14	W10	W10	W10	W10
18	W9	W9	W9	W9	W4	W4	W4	W4	W17	W17	W17	W17	W16	W16	W16	W16	W11	W11	W11	W11
19	W12	W12	W12	W12	W18	W18	W18	W18	W6	W6	W6	W6	W8	W8	W8	W8	W7	W7	W7	W7
20	W1	W1	W1	W1	W5	W5	W5	W5	W3	W3	W3	W3	W15	W15	W15	W15	W2	W2	W2	W2
21	W20	W20	W20	W20	W12	W12	W12	W12	W4	W4	W4	W4	W19	W19	W19	W19	W13	W13	W13	W13
22	W8	W8	W8	W8	W11	W11	W11	W11	W14	W14	W14	W14	W1	W1	W1	W1	W3	W3	W3	W3
23	W7	W7	W7	W7	W6	W6	W6	W6	W16	W16	W16	W16	W5	W5	W5	W5	W18	W18	W18	W18
24	W15	W15	W15	W15	W17	W17	W17	W17	W10	W10	W10	W10	W2	W2	W2	W2	W9	W9	W9	W9

Figure 5.1 Experimental plan of the white disease resistant selections planted at the NWGIC in the Riverina. Vines planted in late spring 2013.

Table 5.1 Establishment and management schedule (2013 to 2017) for the white and red disease resistant selections with the annual application of irrigation and fertiliser amounts.

2013/2014	**White selections (Season 1)**	
	Planting/sprawl	
November	Planting of new white selections (3m x 2.25m)	
December	Mega mix liquid fertiliser (diluted 4mL in 200mL water)	
January	Pivot 400 Fertiliser (15g/Vine)	
March	Pivot 400 Fertiliser (15g/Vine)	
August	Pruning back to three buds	
Irrigation *Fertiliser*	*not recorded* *N10.8, P2.8, K4.3 kg/ha*	
2014/2015	**White selections (Season 2)**	
	Trunk/cordon training	
October	Training vines to wire	
	Desuckering and training to wire (leaving two shoots)	
November	Cordon training and vine maintenance (reduce to one shoot cut above the cordon wire)	
December	Pivot 400 Fertiliser (15g/Vine)	
	Wettable sulfur spray (5g/L)	
January	Training cordon to wire	
	Pivot 400 Fertiliser (30g/Vine)	
August	Pruning and training vines	
Irrigation *Fertiliser*	*2.5 ML/ha* *N15, P3.3, K5.1 kg/ha*	
2015/2016	**White selections (Season 3)**	**Red selections (Season 1)**
	First crop	Planting/sprawl
October	Wettable sulfur spray (5g/L)	
	Pivot 400 Fertiliser (40g/Vine)	
December	White selections trimmed (low hanging shoots)	Planting Red selections (3m X 2.25m)
January		Mega mix liquid fertiliser (diluted 4mL in 200mL water)
March	Pivot 400 Fertiliser (40g/Vine)	Pivot 400 Fertiliser (20g/Vine)
March	Yield assessment Harvest all fruit	Spray with wettable sulfur
July	Pruning white selections	
August		Pruning to three buds
Irrigation *Fertiliser*	*2.95ML/ha* *N26.0, P5.6, K9.0 kg/ha*	*2.75ML/ha* *N 7.25, P2.0, K3.2 kg/ha*
2016/2017	**White selections (Season 4)**	**Red selections (Season 2)**
	Full crop	Trunk/cordon training
September	Wettable sulfur spray (5g/L) - twice	Wettable sulfur spray (5g/L) - twice
October	Pivot 400 Fertiliser (60g/vine)	Pivot 400 Fertiliser (30g/vine)
	Wettable sulfur spray (5g/L)	Wettable sulfur spray (5g/L)
		Desuckering and training to wire (leave two shoots)
November		Cordon training and vine maintenance (reduce to one shoot cut above the cordon wire)
December	Trimming	
February to April	Harvest over six weeks	
April	Pivot 400 Fertiliser (60g/Vine)	Pivot 400 Fertiliser (30g/Vine)
		Desuckering
June	Pruning	
July		Pruning
Irrigation *Fertiliser*	*2.94ML/ha* *N 39.0, P8.4 K13.6 kg/ha*	*2.94ML/ha* *N19.5, P4.2, K6.8 kg/ha*

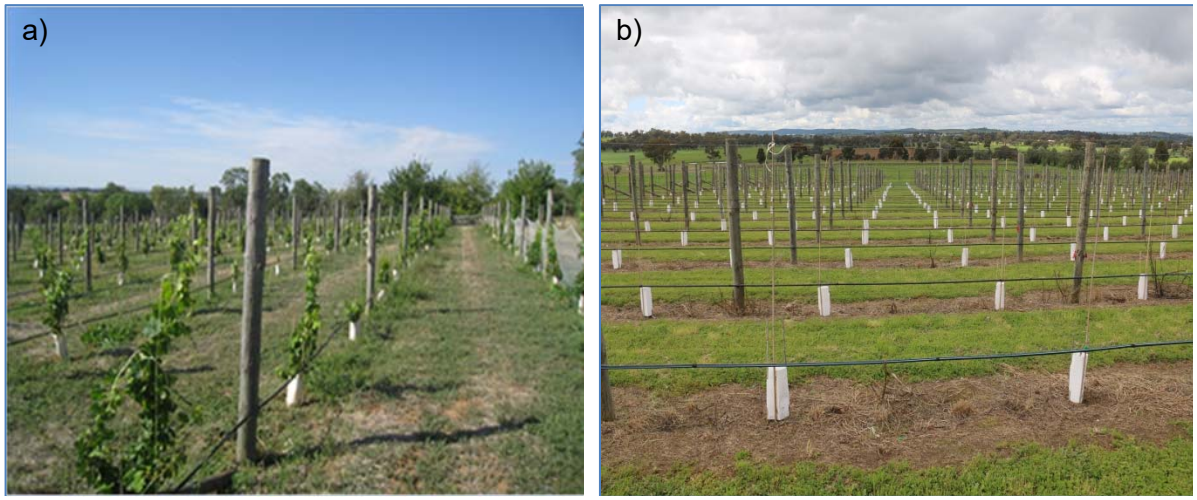


Figure 5.2 New plantings of the new disease resistant selections in the experimental vineyard of the NWGIC. White selections late summer 2014 (a) and red selections at budburst 2016 (b), both within season 2.

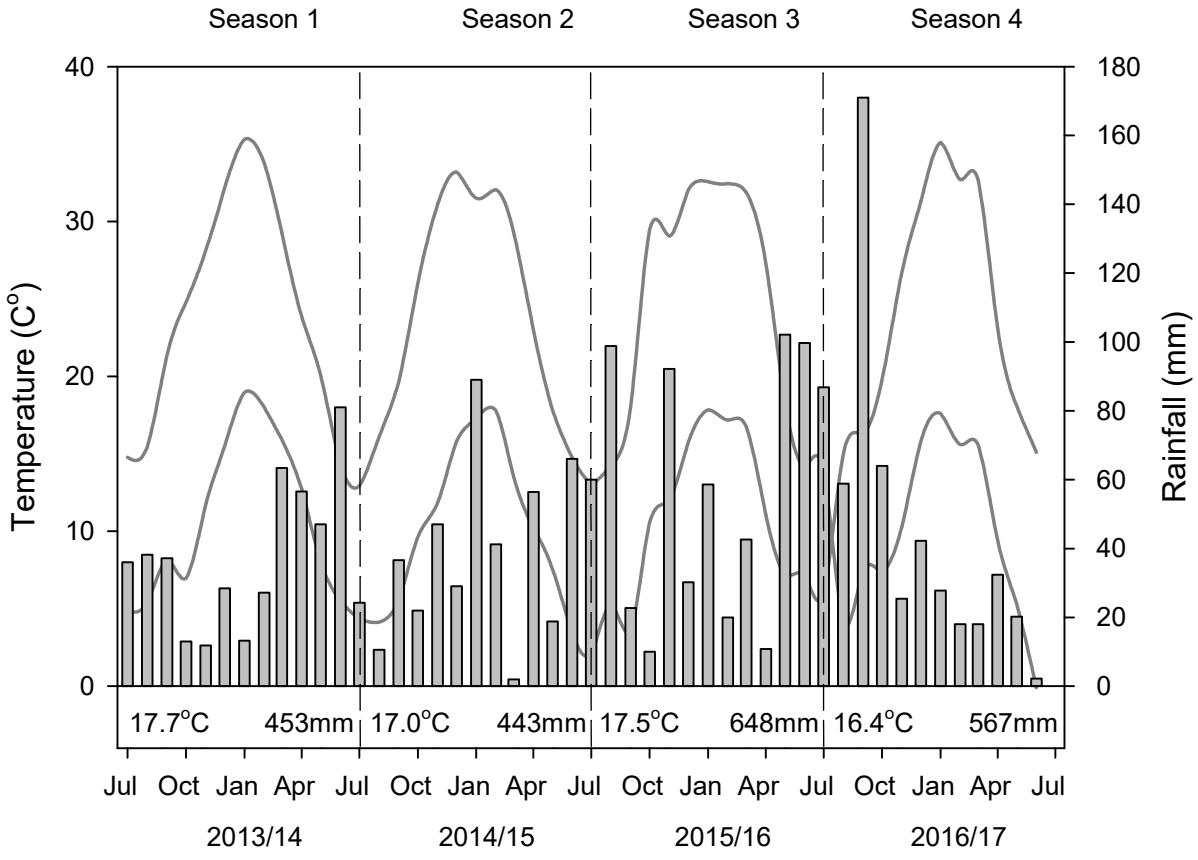


Figure 5.3 Summary of seasonal temperature (maximum/minimum) and rainfall for the four seasons from planting to first vintage of the white disease resistant selections. Seasonal average temperature and total seasonal rainfall (mm) in box below each season.

6. Results and discussion

6.1 Grapevine establishment (seasons 1 and 2)

The white grapevine selections were planted in spring 2013 and the red selections in spring 2015, therefore the second season for the whites was 2014/15 and for the reds it was 2016/17. During these seasons the establishment and development of the vines were monitored to determine some of the variation in vegetative growth.

For the white selections, all vines were pruned in winter to three buds and pruning weights were assessed, these varied considerably between 0.19 to 0.61 kg/vine, with selection 13 the lowest and 20 the highest (Figure 6.1a). Two shoots were left to grow from these buds to mid-spring, and then the best shoot was selected for the trunk and was cut just above the cordon wire. The total shoot length was measured prior to these changes, with the average shoot length varying considerably, less than 70 cm to just over 100 cm, between selections compared to the pruning weights (Figure 6.1b). Selection 5 had the lowest and selection 2 had the highest shoot length. The pruning weights and shoot length often showed the same pattern between selections, this indicated that pruning was evening out the larger differences between selections observed for the pruning weights. From the two upper buds and/or laterals the bilateral cordon developed, with about 80% of all vines reaching the appropriate cordon length or more by the middle of the growing season (end of 2014). The training included disbudding, fixing the trunk on stakes and the shoots for cordon development onto the cordon wire. By the end of the season, nearly all vines had fully established bilateral cordons and in most cases additional growth in the form of main and lateral shoot growth (Figure 6.3a). The pruning weight prior to next season is reported in the following section and the extremes in shoot length were also reflected in these measurements. This again suggested that growth behaviour of the selections was consistent between seasons.

The establishment and training was undertaken similarly in the red selections; the most suitable shoot from each vine (thickness, position) was pruned in winter to three buds, but the initial shoot growth in spring was more inconsistent than for the white selections. It was observed that more than two shoots were developing and laterals were present earlier than in the whites, therefore shoot length was not assessed. The pruning weight varied also more after the first season, between 0.17 to 0.83 kg per vine, with selection 11 the lowest and selection 16 the highest (Figure 6.2a). At the end of the season 2 these selections were still the two extremes, but the pruning weights nearly doubled (Figure 6.2b), being 0.49 and 1.73 kg/vine respectively. Overall the pattern between the selections between seasons was present for most of them, indicating that the variation was not considerably reduced by the pruning at the beginning of season 2 and was consistent between seasons. However, as for the white selections the bilateral cordons were established for most vines of the red selections by the end of season 2 (Figure 6.3b).

Overall for both selections the trunk and cordon were established at the end of season 2, but the reds showed higher pruning weights after season 2 than the white selections (1.08 versus 0.70 kg/vine). Although there were some differences in growth and development observed, particularly more laterals in the reds, this could have been due to more favourable climatic conditions, as more rainfall occurred in spring 2016. Water use efficiency (WUE) was assessed by gas exchange measurements in six red selections in summer, intrinsic (A/gs) and instantaneous (A/E). The choice was based on winter pruning levels low, medium

and high. The most vigorous selection had considerable high ratios in WUE (data not presented). Despite the wetter conditions during 2016/17, no mildew was observed in the red or white selections.

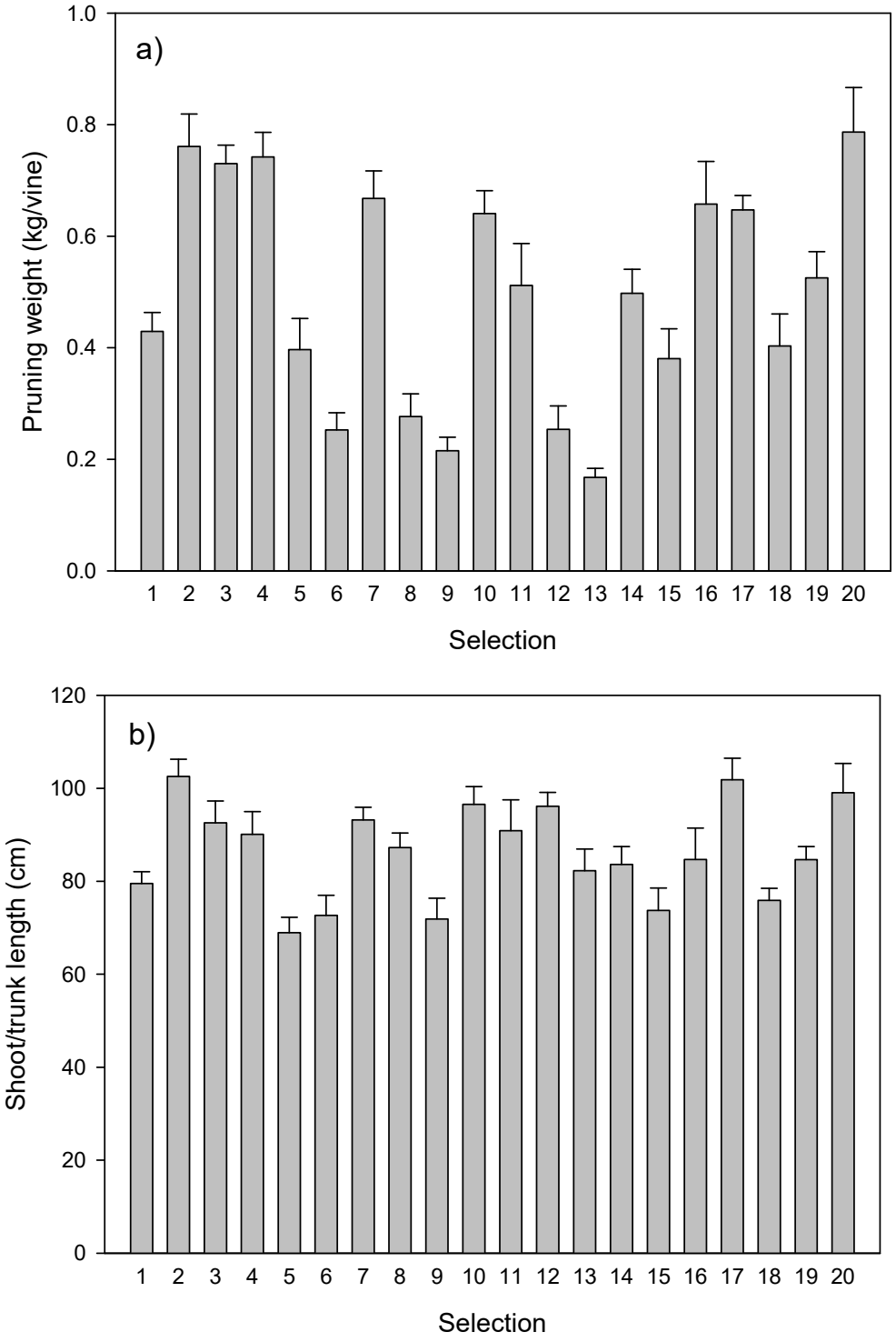


Figure 6.1 Pruning weights of the various white selections in winter 2014 (a) and shoot length in spring 2014 (b), these became trunks and cordons at the end of season 2.

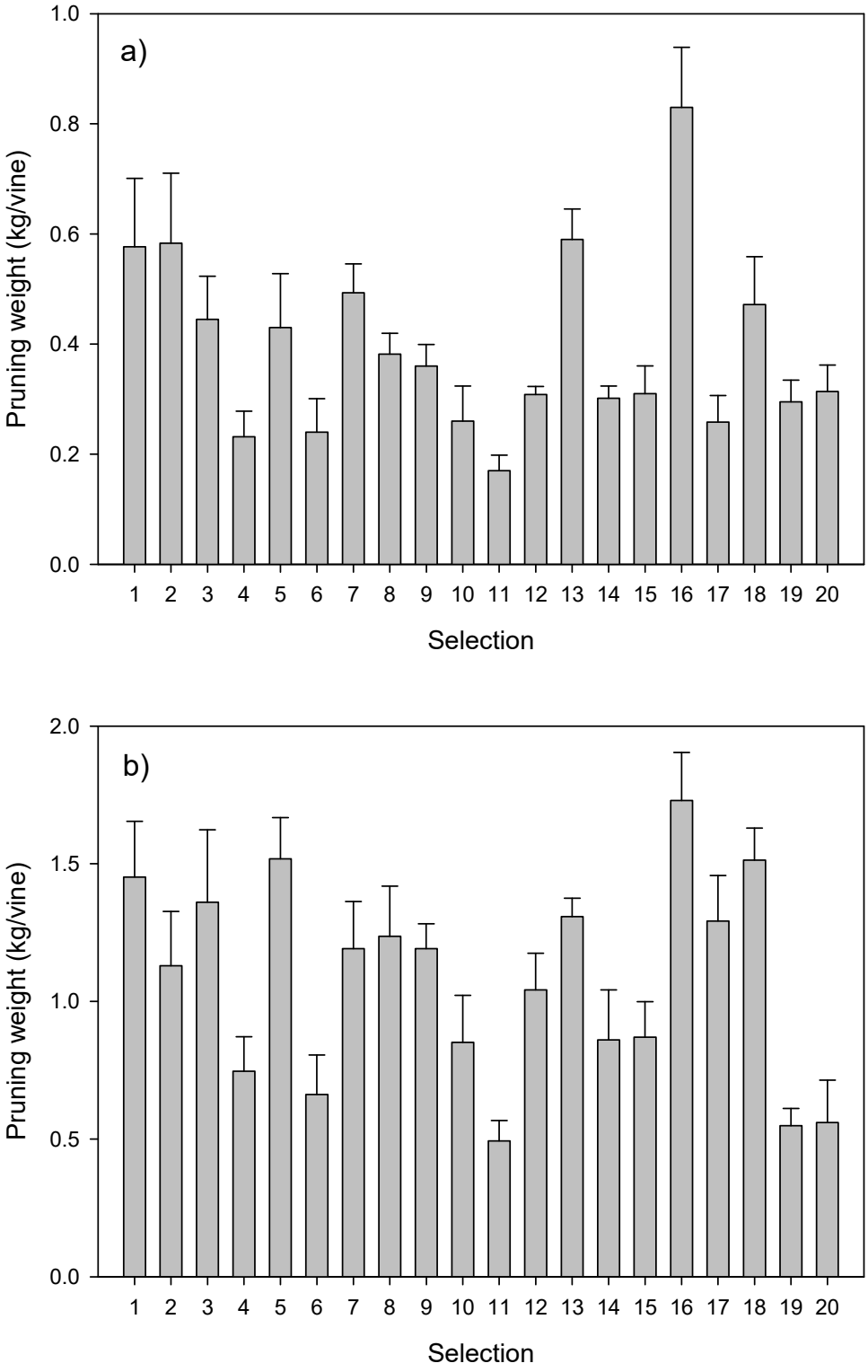


Figure 6.2 Pruning weights of the various red selections in winter 2016 (a) and 2017 (b), one and two years after planting in late 2015 at the NWGIC experimental vineyard.



Figure 6.3 White (a) and red selections (b) during the second season (summer 2015 and 2017 respectively), the trunks and cordons were well established towards the end of season 2.

6.2 Initial production - white selections (season 3)

In the third growing season (2015/16) the same vineyard management program was undertaken in relation to weed and mite control, but fertiliser application was increased as the perennial structure was further developing and the size of annual organs was expanding. The canopies of the vines developed further in size and were yielding their first grapes; the vegetative growth was again monitored. In addition, this also allowed for assessment of basic berry juice characteristics, initial yield and yield components. However, in this season some longer shoots that were hanging into the rows were shortened in late spring and would have evened out the pruning weights slightly.

There were considerable differences between pruning weights taken in winter and shoot growth in spring of the white selections as observed in the previous season, showing more than two and four-fold differences respectively. The selections 2, 11 and 20 had about 1.0 kg pruning weight per vine, while selection 5, 9, 12 and 18 had weights below 0.4 kg per vine (Figure 6.4a). The differences in shoot growth were slightly less pronounced, varying from close to 50 cm to just over 100 cm (Figure 6.4b). The average trunk circumference had increased to 6.25 cm from the previous year by about 2 cm, with the range being nearly two-fold from 4.4 to 8.1 cm (data not presented). The water use efficiency (WUE) was assessed by gas exchange measurements in summer (Figure 6.5a, b) instantaneous (A/E) and intrinsic (A/gs), but the differences were relatively small and close to 3 µmol CO_2/mmol^{-1} H_20 (A/E) and around 100 µmol CO_2/mmol^{-1} H_20 (A/Gs) respectively. However, there was no attempt made to implement any water stress as the main emphasis was to bring the selections to production as quickly as possible for experimental winemaking the following season (2016/17).

Bunch and berry size showed visual variation, berry weight and yield showed close to two-fold differences and berry ripeness varied about one third in the middle of February between the selections (Figure 6.6). Yield ranged from 2.9 to 7.9 kg per vine (4.3 to 11.7 t/ha), bunches per vine from 23 to 45, bunch weight varied between 82 and 251 g and berries per

bunch from 75.5 to 173.4, while berry weights ranged from 0.73 to 1.7 g/berry (Table 6.1). The highest yielding selection (7) had the highest bunch weight and berry weight, while the lowest yield selection (13) had the lowest bunch weight and the second lowest berry weight. Overall, more than half the selection had yields between 4 and 5 kg per vine, six were below 4 kg per vine and three were above 5 kg per vine. This indicated that even the lowest yielding selections produced enough berries for two ferments (70 to 85 kg).

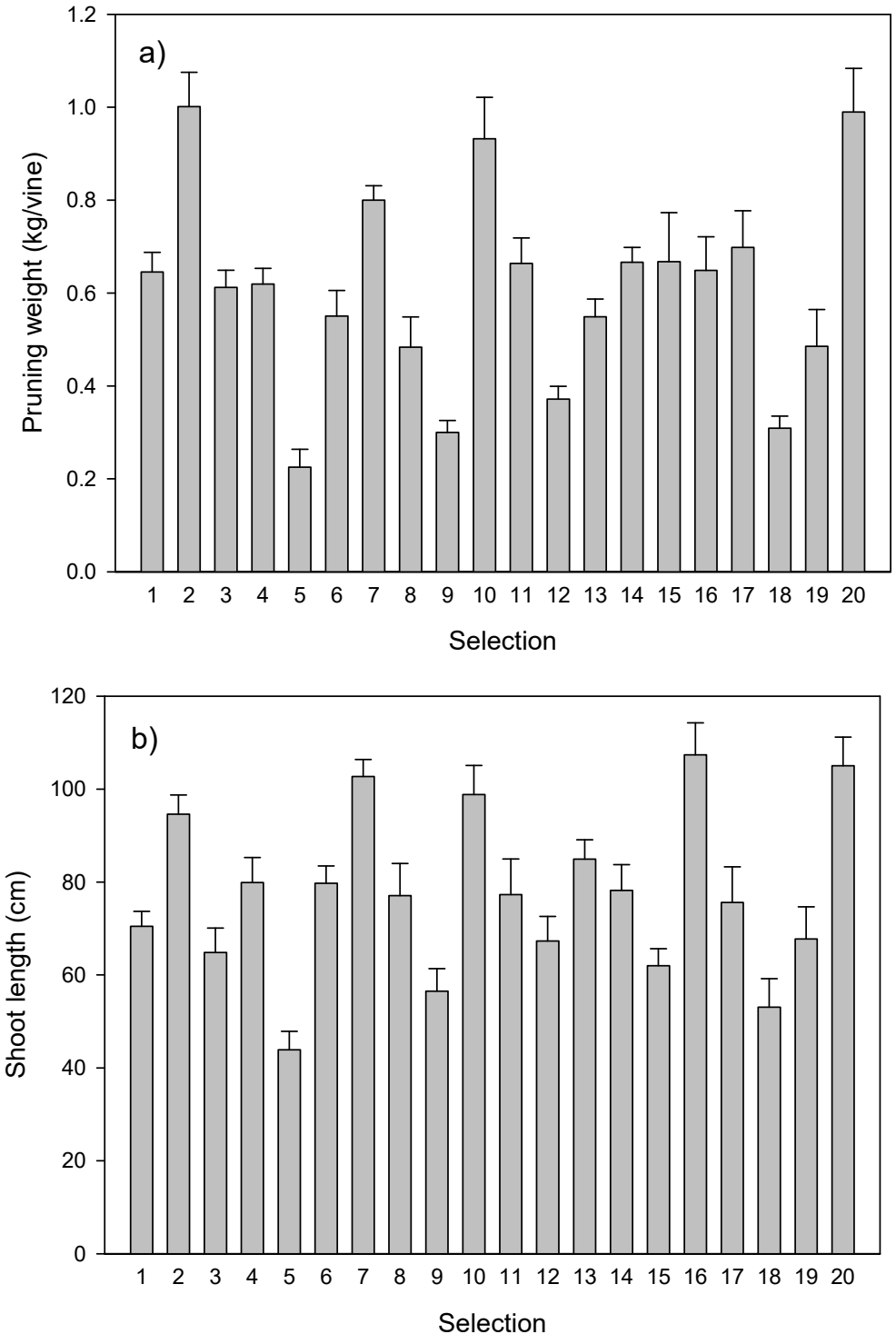


Figure 6.4 Pruning weights of the various white selections in winter 2015 (a) and shoot length (b) in spring 2015 (season 3).

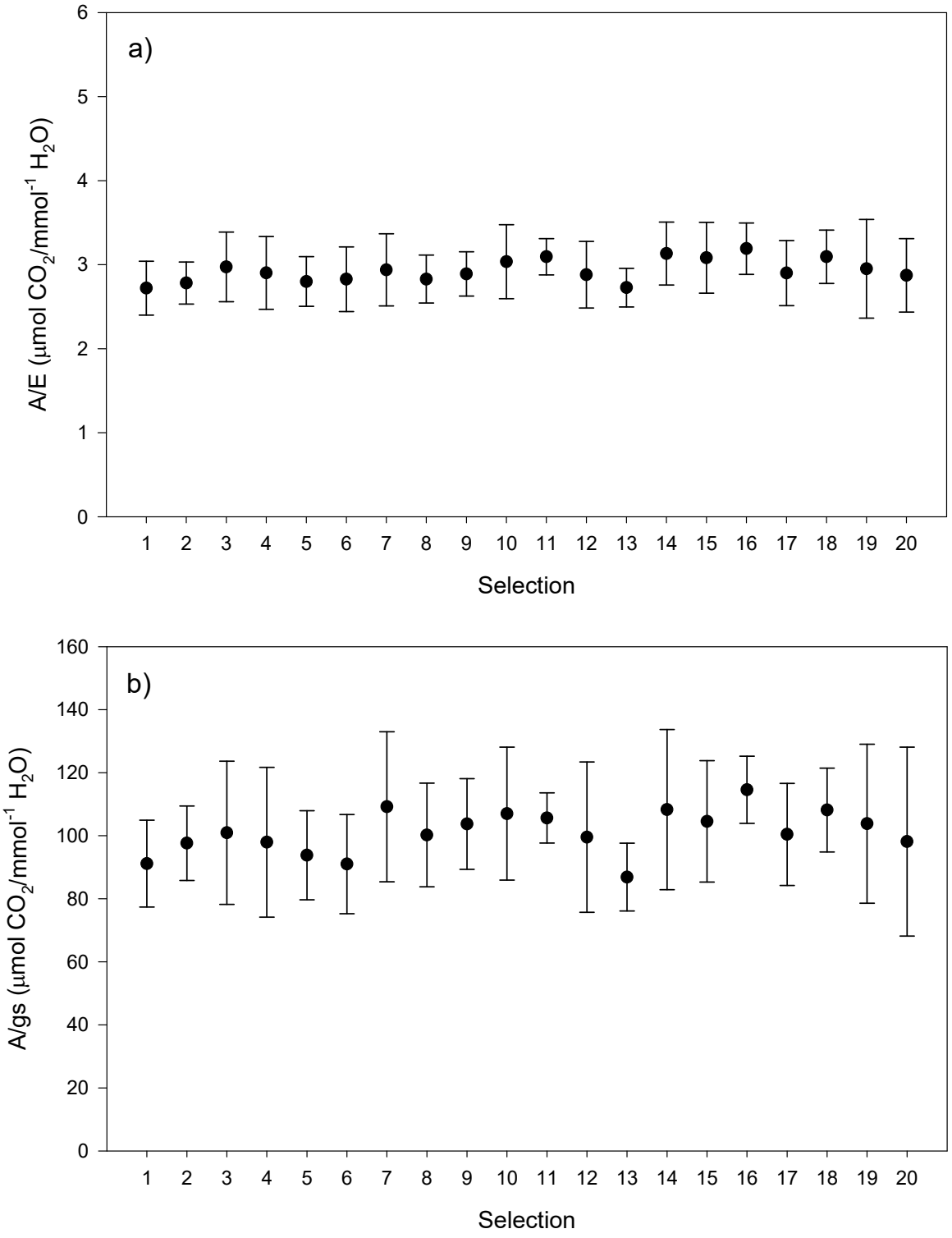


Figure 6.5 Water use efficiency (WUE) assessed by gas exchange measurements in the 20 white selections in summer, instantaneous (a) and intrinsic (b) - 18/1/2016.

Table 6.1 Yield and yield parameters from 20 disease resistant white selections, including bunches per vine, berries per bunch, average bunch and berry weight.

Variety	Yield (kg/vine)		Bunches/ vine		Bunch wt. (g)		Berries/ bunch		Berry wt (g)	
1	4.2	0.21	38.0	2.12	111.0	7.94	88.3	7.99	1.27	0.035
2	4.1	0.33	32.6	2.26	125.3	5.76	81.3	5.00	1.55	0.031
3	5.0	0.35	41.1	1.97	121.9	5.96	128.9	4.27	0.94	0.022
4	3.2	0.20	23.0	0.86	139.7	8.68	90.4	4.38	1.54	0.042
5	3.5	0.30	35.8	1.46	99.3	8.41	96.4	6.59	1.03	0.054
6	5.8	0.49	33.3	2.24	174.2	8.00	140.0	4.03	1.24	0.026
7	7.9	0.33	32.1	1.80	251.1	16.50	158.6	12.86	1.59	0.037
8	3.1	0.28	35.6	1.37	85.8	7.03	87.1	5.66	0.98	0.025
9	4.4	0.50	35.0	2.48	124.8	9.95	125.2	8.99	1.00	0.028
10	4.0	0.13	33.7	1.26	119.8	3.43	123.6	4.56	0.97	0.013
11	3.4	0.47	36.0	2.89	93.2	7.48	75.5	7.03	1.24	0.037
12	3.6	0.30	38.5	2.04	94.7	6.46	130.6	8.69	0.73	0.017
13	2.9	0.11	35.0	1.14	82.2	2.48	102.6	2.90	0.80	0.019
14	4.2	0.17	42.3	1.54	99.9	3.78	102.2	5.02	0.98	0.020
15	5.0	0.29	41.1	2.32	122.8	5.23	128.0	4.39	0.96	0.019
16	4.1	0.27	31.6	0.63	129.2	7.29	107.8	6.43	1.20	0.026
17	4.7	0.21	37.4	2.23	126.0	5.60	146.2	5.64	0.86	0.017
18	4.5	0.33	45.0	2.17	101.1	5.82	123.9	7.33	0.82	0.025
19	5.8	0.43	34.6	1.01	167.2	10.78	173.4	11.28	0.97	0.010
20	4.5	0.13	30.0	1.79	152.2	11.36	129.5	11.19	1.18	0.025

Figure 6.6 Visual differences in bunch and berry size between some of the selections.



Measurements of the basic berry and juice parameters in the white selections (berry size, TSS, pH and TA) from harvest samples were undertaken in mid-February (Table 6.2). Berry ripeness was still considerably different between the various selections at the first harvest assessment of these selections, ranging from 19.3 to 29.3^{o} Brix. Consequentially, considerable differences were observed for all other basic juice parameters, sugar/berry varied from 152 to 395 mg, juice pH from 3.13 to 3.59, total acidity (TA) from 4.14 to 7.20 g/L and yeast assimilable nitrogen (YAN) ranged from 72.5 to 168.6 mg/L. Sugar per berry was generally strongly related to berry ripeness and berry size, for instance the ripest selection 4 had also the second largest berries, this was not always consistent for the other basic parameters. Selection 10 that had 23^{o} Brix in mid-February had one of the lowest observed pH values and the highest TA and YAN levels. In addition, similar yields were produced with a range of canopy sizes across the selections indicated by pruning weights. The pruning weights ranging from 0.2 to 1.0 kg determined after season 3 (Figure 6.7a). It was also found that a range of yields had similar berry maturation levels at two separate time points when assessed (Figure 6.7b).

This first year of initial production indicated that suitable yield levels for two ferments would be reached in the following season. However, it was also obvious that the difference in berry ripeness was only partially driven by difference in yields. Although the yield to pruning weight ratios varied between 4.2 and 17.5 and half of the selections were outside of the traditional range (5 and 10) for old European varieties, most at the higher end (more than 10) did ripen reasonable well. This indicated that harvest at a set maturity level that is required to ensure comparability between selections would mean that harvest of the various selections would stretch over several weeks. This maturity date spread is also of potential benefit to industry which is facing compressed harvest dates with traditional European wine grape varieties.

Table 6.2 Basic berry and juice parameters from 20 disease resistant white selections at one time point in summer 2016 (17 February).

Variety	TSS Brix		Sugar/berry (mg)		pH		TA (g/L)		YAN (mg/L)	
1	25.0	0.35	305.1	8.43	3.38	0.021	5.73	0.172	130.1	5.81
2	25.7	0.61	393.1	8.50	3.46	0.053	4.85	0.263	102.5	7.29
3	24.4	0.38	225.0	5.78	3.52	0.039	4.14	0.134	90.8	4.31
4	29.3	0.27	395.2	14.68	3.59	0.027	4.62	0.096	94.4	1.99
5	23.6	0.58	217.8	12.41	3.28	0.030	5.49	0.167	95.7	6.13
6	23.6	0.19	294.6	8.16	3.29	0.017	5.54	0.137	93.3	5.27
7	23.1	0.30	393.6	19.92	3.26	0.033	5.59	0.185	118.8	3.72
8	23.7	0.05	224.1	5.25	3.43	0.034	4.59	0.224	149.0	6.83
9	20.2	0.26	191.4	8.70	3.43	0.016	3.69	0.093	72.5	6.03
10	23.0	0.71	235.3	3.73	3.14	0.018	7.20	0.211	168.6	11.12
11	23.0	0.18	285.2	6.01	3.28	0.022	5.61	0.114	121.9	3.93
12	22.1	0.33	151.7	5.87	3.28	0.021	5.56	0.226	99.6	1.56
13	23.9	0.23	182.8	4.16	3.36	0.022	5.09	0.256	111.0	5.95
14	19.3	0.42	202.0	5.18	3.18	0.016	6.46	0.199	135.6	5.45
15	22.8	0.28	211.3	14.87	3.31	0.020	5.43	0.101	127.4	6.10
16	23.6	0.31	282.8	5.89	3.31	0.017	5.46	0.126	129.0	7.88
17	25.0	0.35	201.0	6.21	3.28	0.033	6.47	0.233	122.0	35.80
18	22.8	0.36	194.1	7.81	3.20	0.029	6.54	0.240	124.9	6.97
19	24.0	0.16	199.9	6.57	3.13	0.016	7.01	0.172	145.5	9.27
20	23.4	0.37	263.6	4.34	3.36	0.024	5.16	0.123	143.6	3.12

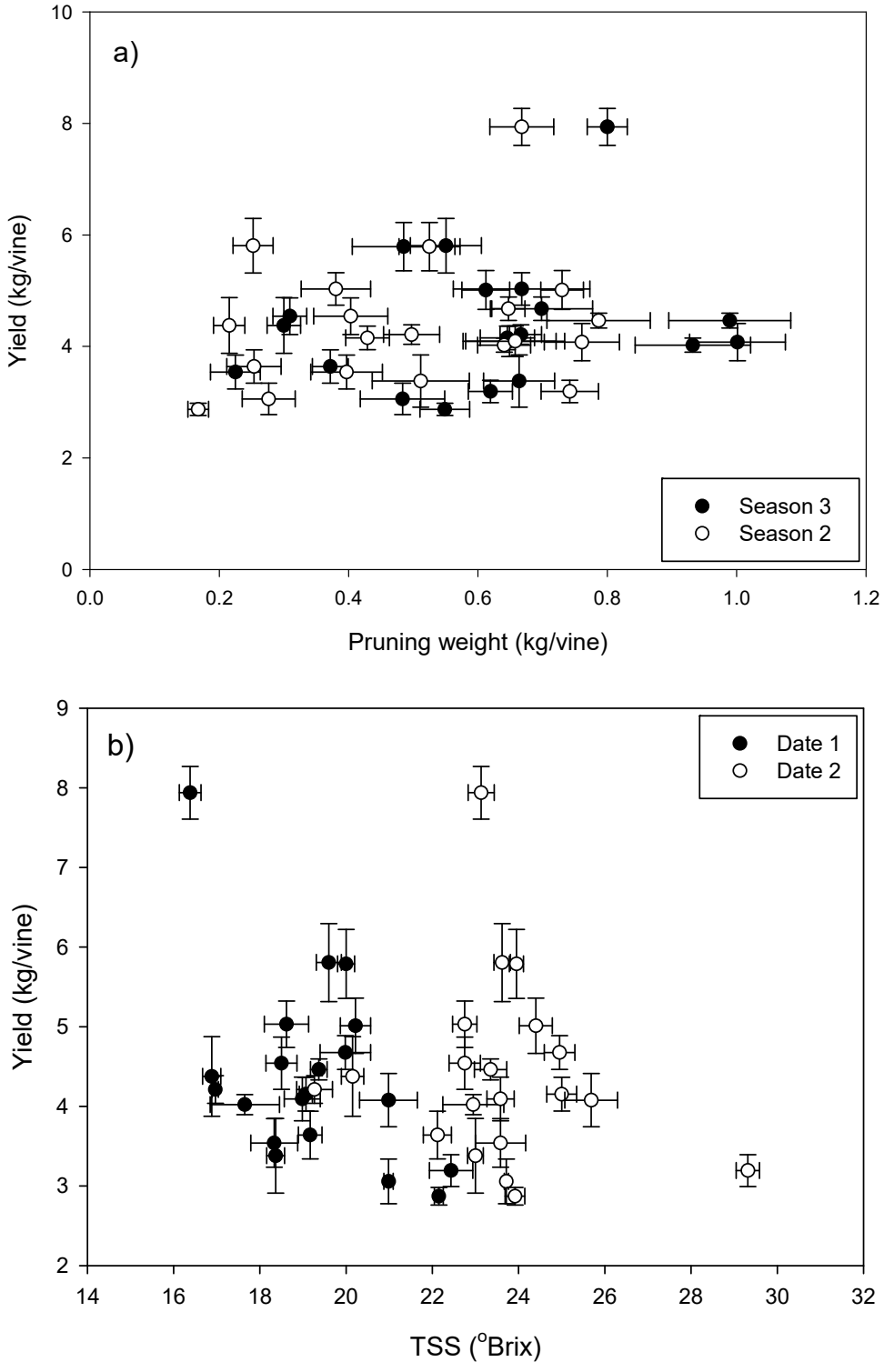


Figure 6.7 Relationship between yield/pruning weights (a) prior and after the growing season (14/8/15 - season 2 and 26/7/16 - season 3) and yield/total soluble solids (b) at two dates (28/1/16 and 17/2/16).

6.3 Full production - white selections (season 4)

Season 4 was the first season where it was expected to have sufficient grapes to produce two wines from each selection, so that a sensory assessment could be undertaken with the industry. Therefore, the grapes were also monitored more closely with regard to bunch and berry damage and the maturation from veraison onwards. The vegetative development continued to be monitored in this season in winter and spring as was the assessment of water use efficiency (WUE) in summer.

There were considerable differences between pruning weights taken in winter and shoot growth in spring of the white selections as observed in season 3, showing more than two and four-fold differences again. However, the shoots were shorter overall, ranging between 30 and 60 cm, because these were measured slightly earlier, but also as there were more shoots present (Figure 6.8a). The latter was indicated also by the pruning weights, which ranged in this season from 0.5 to 2.0 kg per vine, being about double that of the previous season (Figure 6.8b). The selections 2 and 20 had close to 2 kg pruning weight per vine, these were two of the highest in previous season 3, but selection 13 had the highest pruning weights observed in this season. Selections 5, 9 and 18 again showed the lowest weights below 0.8 kg per vine (while 12 was close to the overall average this season), selection18 also had shorter shoots in spring. Trunk circumference showed a further increase in the perennial structure, increasing close up to 2 cm (see Figure 13.1 in Appendix 5), with a range of 5.68 and 9.86 cm between the selections. Water use efficiency (WUE) was again assessed by gas exchange measurements in summer (Figure 6.9a and b) and the differences were a fraction larger than in season 3 between the selections and were between 3 and 4 µmol CO_2/mmol^{-1} H_20 (A/E) and around 50 and 80 µmol CO_2/mmol^{-1} H_20 (A/Gs) respectively. However, the size of the standard error indicated that there might be few significant differences between selections. As in the previous season there was no attempt made to implement water stress, to ensure good production for experimental winemaking in this and the following season.

The disease levels were assessed during the season, and despite considerable disease pressure, particularly for powdery mildew, no incidence was observed on the white disease resistant selections. However, there was considerably berry and damage due to high temperature and exposure and this increased during maturation (Figure 6.11a and b). The incidence varied from 0% at the end of January for selections 1 and 17 to over 30% in mid-February for selection 18 (Figure 6.10a). This result was similar for severity at the earlier assessment date but was most pronounced at the second date for selection 12 (Figure 6.10b). It is likely that the extent of damage was due to the relatively small canopies and was expected. It is likely that canopies will be larger and bunch exposure reduced over the coming seasons resulting in a reduction in berry damage due to exposure to the sun. Berry weight determination started in early January and varied between 0.4 and 1.1 g per berry between the white varieties. Yield, yield components and basic composition parameters were assessed at harvest, which was sequential due to the different ripening times of the selections and stretched over a six week period. The yields ranged from 7.5 to 20.1 kg per vine (11.1 to 29.8 t/ha), being nearly three times those of the previous season 3. Bunches per vine increased three-fold and varied from 75 to 276. Bunch weight differed between 75 and 276 g and berries per bunch from 75.5 to 179, while berry weights varied from 0.79 to

2.08 g/berry (Table 6.3), being only a small increase from the previous season. The maximum yielding selection was again number 7, having the highest bunch weight and berry weight, while the lowest yield was observed for selection 12. Overall, nine selections had yields between 10 and 15 kg per vine, seven were below 10 kg per vine and three were above 15 kg per vine. This was a considerable yield increase and despite some of the damage due to heat and exposure, enough grapes (more than 100 kg) were available for small lot winemaking.

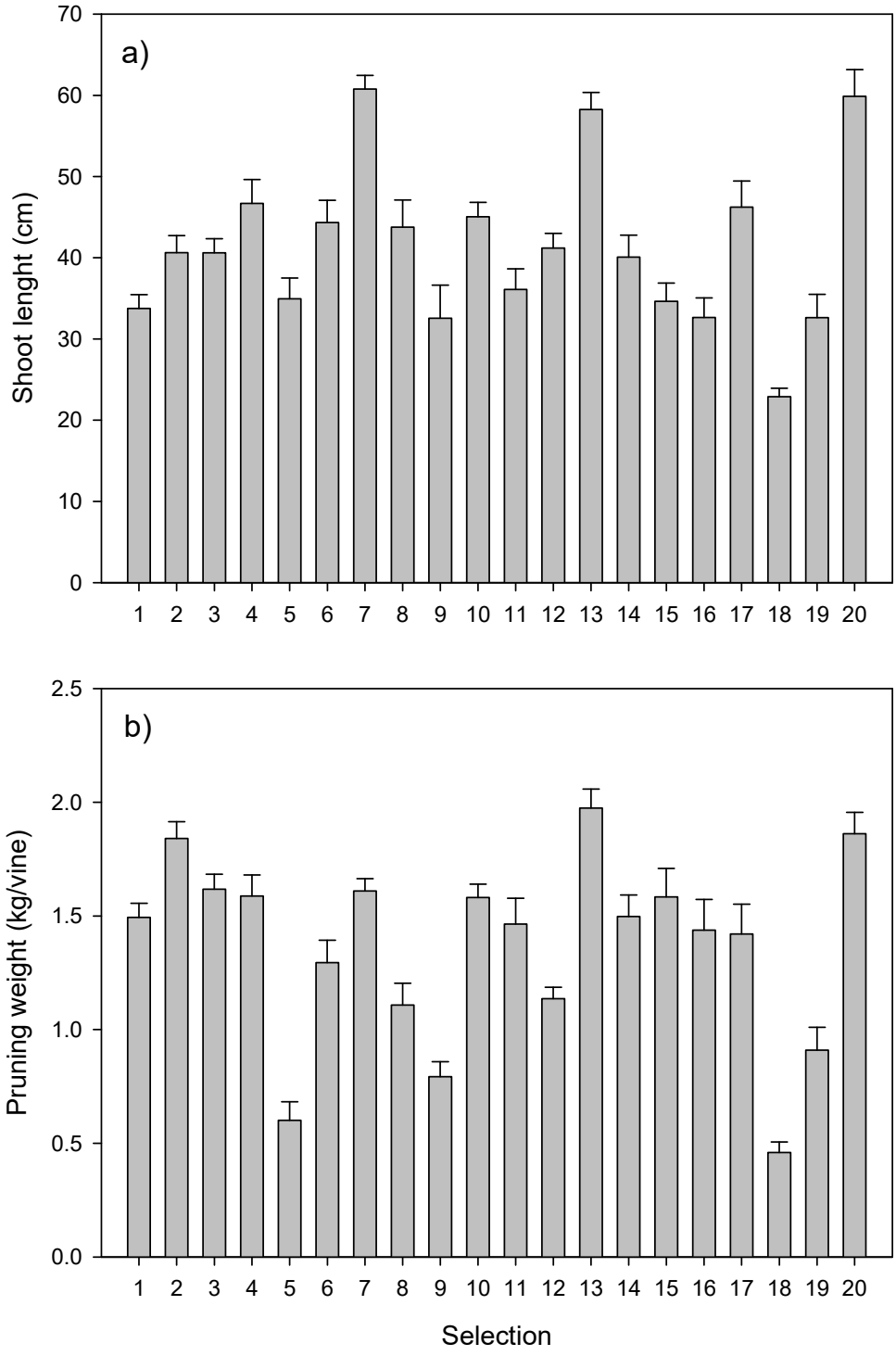


Figure 6.8 Shoot length (a) and pruning weights (b) of the various white selections in spring 2016 and in winter (season 4).

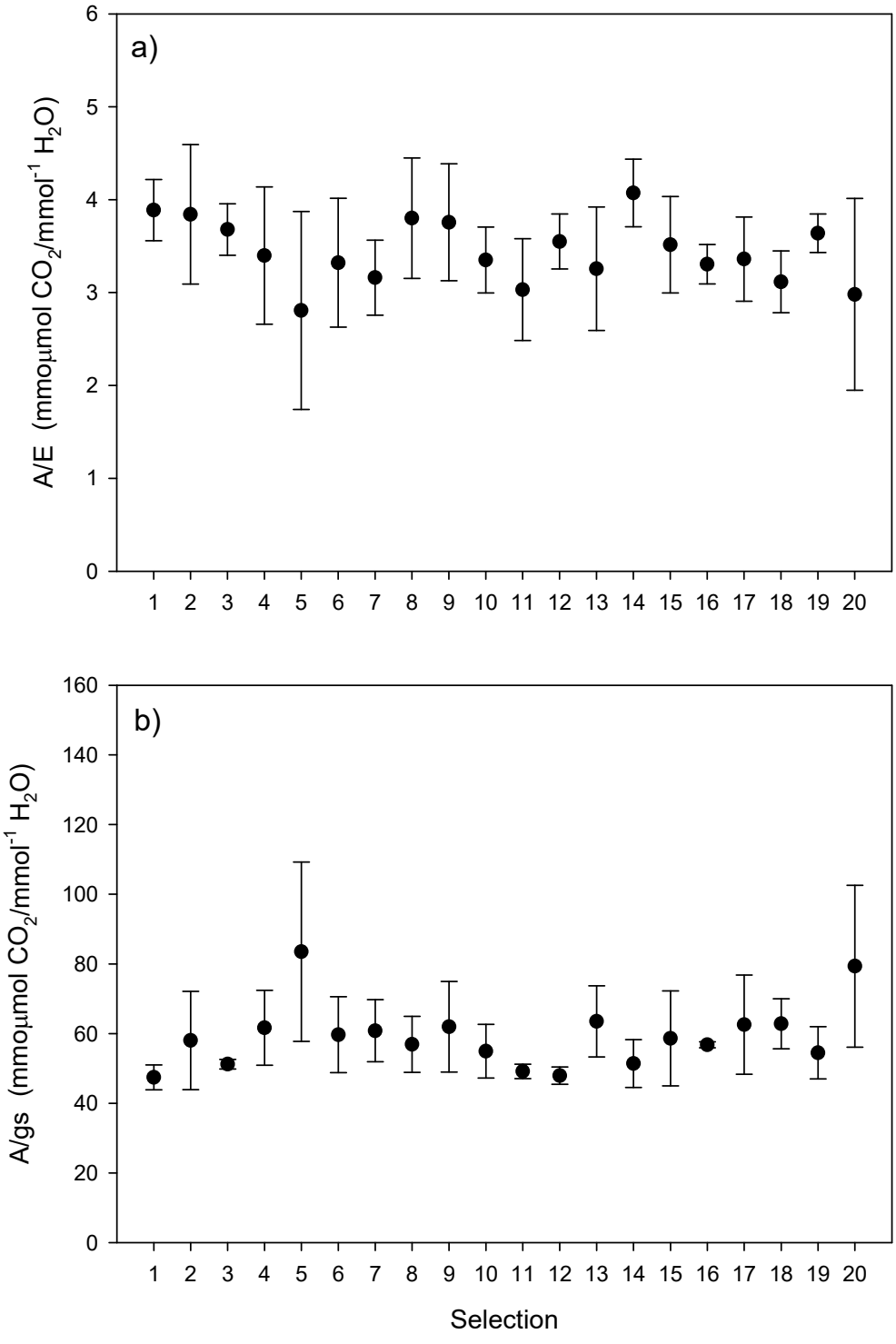


Figure 6.9 Water use efficiency (WUE) assessed by gas exchange measurements in the 20 white selections in summer, instantaneous (a) and intrinsic (b) - 15/12/2016.

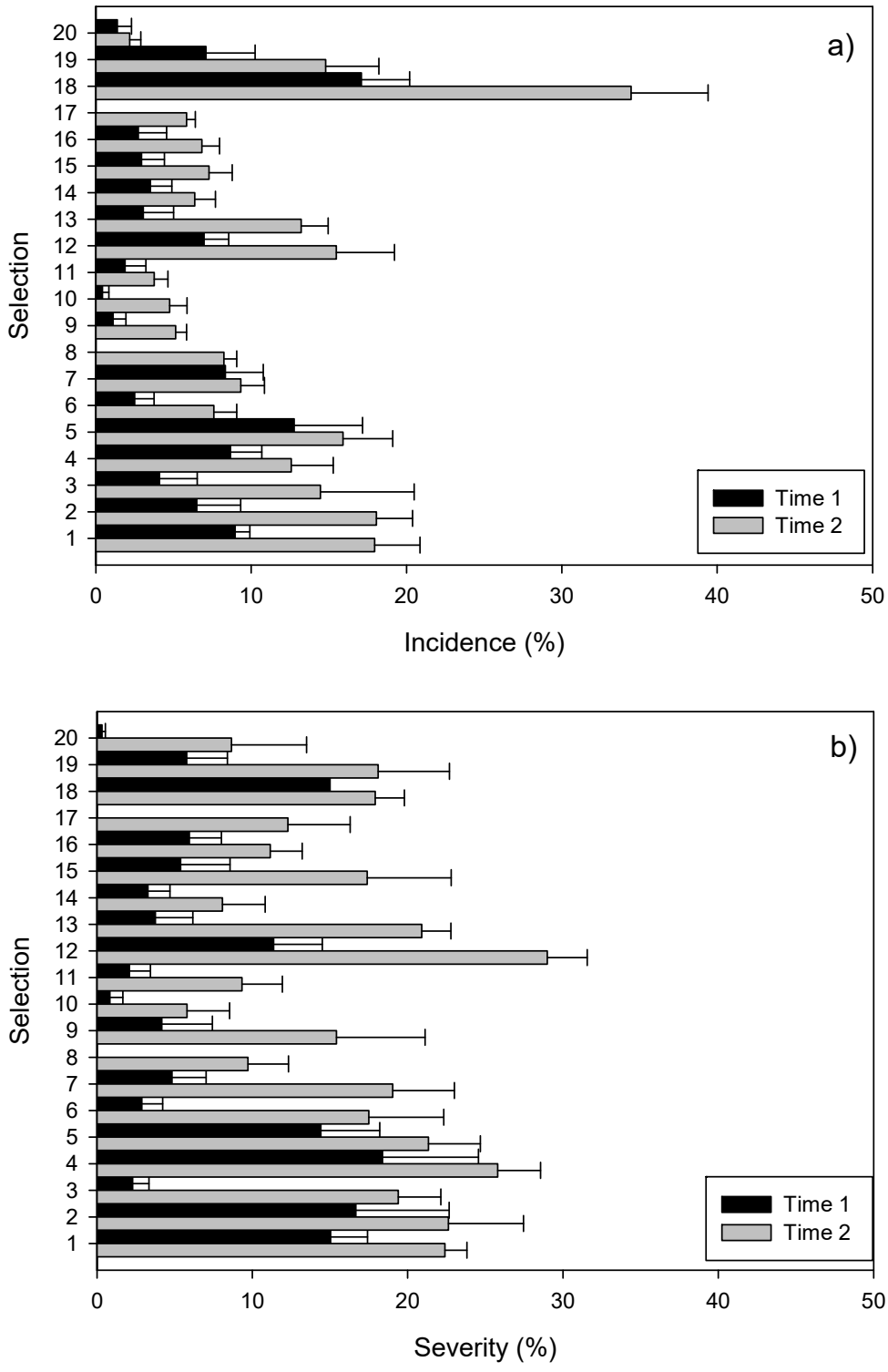


Fig 6.10 The incidence (a) and severity (b) of bunch/berry damage due to high temperature and exposure in the various white selections in summer 2017, assessed on 31 January (time 1) and 15 February (time 2).



Fig. 6.11 Heat and sun exposure damage of bunches and berries on one of the white selections (a) and the appearance of powdery mildew in Merlot vines adjacent to the new selections (b).

Table 6.3 Yield and yield parameters for 20 disease resistant white selections, including average bunch and berry weight (season 4).

Variety	Yield (kg/vine)		Bunches/ vine		Bunch wt. (g)		Berries/ bunch		Berry wt (g)	
1	14.3	0.42	117.5	1.90	121.4	2.88	97.4	1.35	1.25	0.028
2	16.8	0.78	90.2	3.28	186.6	6.03	105.2	2.08	1.78	0.069
3	9.4	1.27	92.7	3.60	100.0	11.69	95.6	10.50	1.04	0.031
4	11.9	1.18	67.7	2.54	175.5	15.54	113.5	6.22	1.53	0.076
5	7.6	0.81	58.5	5.38	130.0	9.17	127.6	7.61	1.02	0.019
6	14.6	0.93	91.1	4.10	162.1	13.02	139.2	10.90	1.16	0.017
7	20.1	1.08	73.0	1.14	275.9	14.58	133.4	7.51	2.08	0.083
8	7.6	0.28	81.1	2.64	93.4	1.73	87.2	3.63	1.08	0.026
9	8.8	1.45	76.0	4.86	112.6	16.20	110.7	15.94	1.02	0.032
10	12.0	0.67	71.0	2.34	170.7	11.12	145.3	8.25	1.17	0.024
11	10.4	0.33	93.8	3.91	111.3	4.22	75.3	3.93	1.48	0.022
12	7.5	0.53	88.0	4.46	84.5	2.71	97.2	3.25	0.87	0.020
13	9.8	0.37	98.1	2.54	100.1	4.02	121.0	4.77	0.83	0.031
14	16.6	1.67	149.8	5.55	110.5	9.05	84.7	7.09	1.31	0.024
15	12.9	1.31	102.2	6.56	125.0	4.85	129.2	5.01	0.97	0.028
16	12.8	0.58	87.8	5.71	147.4	6.16	131.5	5.97	1.12	0.029
17	10.0	0.41	75.6	3.32	132.5	2.19	150.5	3.20	0.88	0.013
18	7.9	0.55	105.2	3.89	75.2	3.53	95.4	3.58	0.79	0.017
19	10.7	1.58	66.5	9.81	159.3	7.35	178.9	8.06	0.89	0.019
20	15.6	0.57	100.4	2.73	155.5	6.89	118.6	4.30	1.31	0.028

For harvest, the aim was to collect grapes from the various selections at similar maturation levels, aiming for around 22° Brix. The maturation was monitored every two weeks from all replicates, while additional measurements were taken if a selection came close to 22° Brix (Figure 2.12a). Although full berry samples were only taken every two weeks, when a selection was above 20° Brix, an assessment was done on a sample across all six replicates to make the most appropriate harvest decision. Most selections had the appropriate TSS level between 21.5 and 22.5° Brix at harvest, with a few just below and one above that range. However, a number of selections did not advance to this Brix level and this may have been due to rain events occurring during the harvest period. Selections 8, 9, 11, 12, 14 and 19 were harvested at the end of March/early April, as there was not much further ripening expected and waiting much longer would have increased the berry/bunch damage already present (Table 6.4, Figure 2.12a). There was even a small reduction in berry Brix levels observed in these six selections to the previous measurement, with the exception of 14. This was likely due to a further increase in berry size or weight (Figure 2.12b), which would have been influenced by rainfall during late March. This slow ripening was not due to yield levels or vine balance (yield to pruning weight ratio) as indicated (Figures 6.13a, b and 6.14a, b). Due to the variation in berry ripeness, but particularly berry size, a considerable range was observed in sugar per berry from 167 to 445 mg, with selection 18 having the smallest and selection 7 having the largest berries respectively. The juice pH ranged from 3.17 to 4.80, while the TA ranged from 3.22 to 6.87 g/L, despite selection 18 reaching nearly the targeted TSS levels, it had the lowest pH and highest TA (Table 6.4). These were similar ranges as observed in the previous season, but it has to be emphasised that the season 3 measurements were only conducted at one date and not at similar berry ripeness levels. However, considerably lower YAN levels were observed in this season, ranging from 42.7 to 114.4 mg/L. This was in some respects unexpected as chlorophyll measurements in spring indicated good leaf N levels and over 30 kg N was applied between season 3 and season 4 harvest. However, these were young vines with limited N storage and developing the perennial structure. In addition, the yields increase considerably two to four-fold depending on the selection and this would have required N for the grapes around 30 to 60 kg/ha. Based on this experience the nutrient application will be considerably increased for the next season and an application at mid-range yields would be more appropriate.

A relationship between yields and pruning weights was indicated to be generally present, particularly within the same season, but there are exceptions with some of the selections (Figure 6.13a). The majority of these sections are in the optimal range for yield to pruning weight ratio (5 to 10), for instance selection 5 has a ratio close to 15 and selection 13 about 5 with similar yields and harvest dates (Figure 6.13b). The yield levels and berry ripeness from two times during maturation indicate that similar ripeness levels can be reached from selections that produce 8 and 20 kg of grapes per vine, while medium yielding selections can be up to 5 °Brix different in ripeness (Figure 6.13b). However, these differences are less pronounced at suitable TSS levels when only about one week of difference is present between harvests (Figure 6.13a). For instance, selection 4 can be seen as the fastest to reach the targeted maturity level, which is consistent with the previous season, while selection 9 is the slowest with one of the lowest yields in season 4. The variation in yield and berry maturation suggests that these selections might need to be managed differently in relation to yield targets, but for this assessment it would be aimed at the medium level of productivity as for the nutrition.

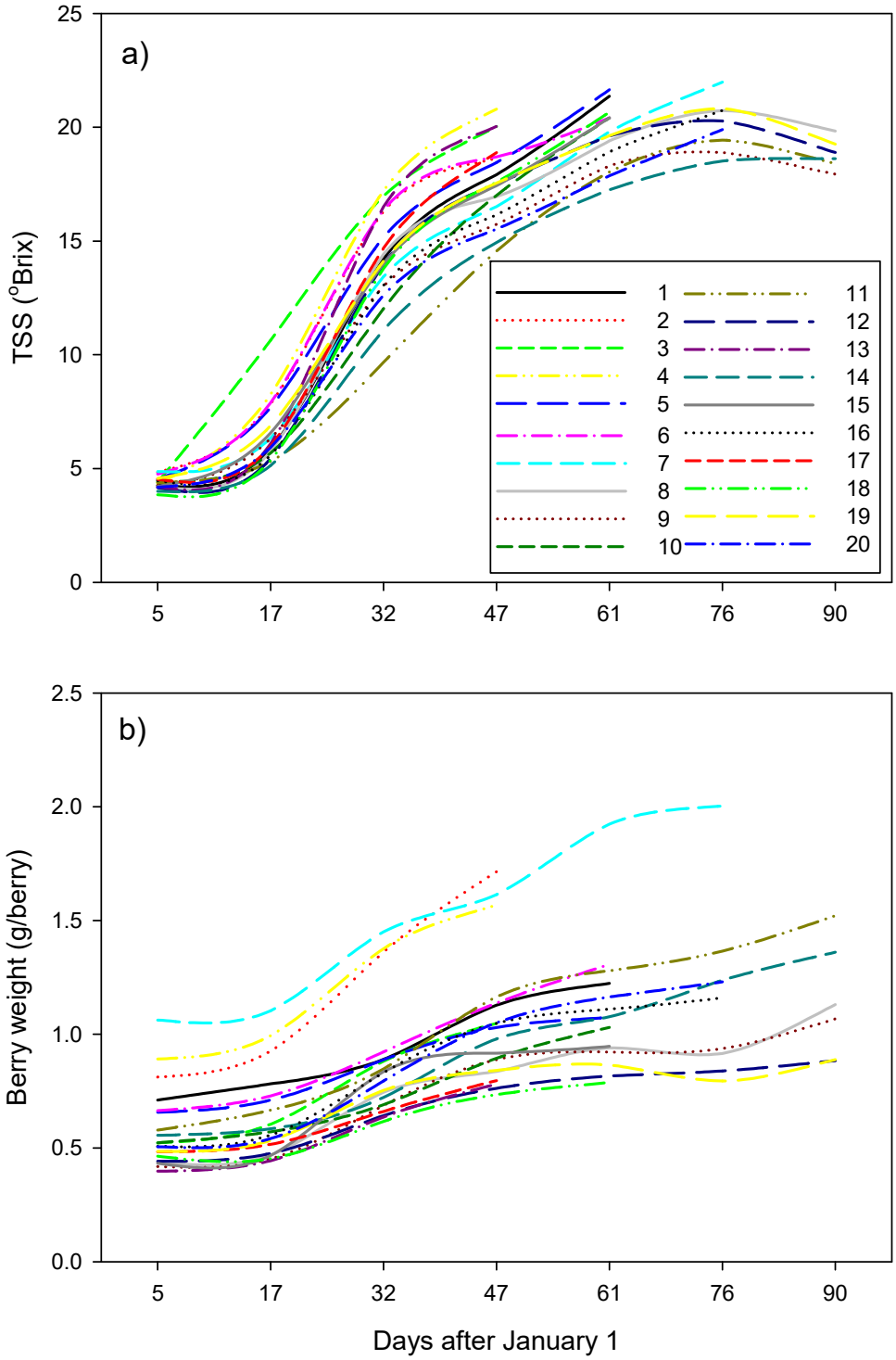


Figure 6.12 Berry maturation (a) and berry weight (b) curves of the 20 white selections from early January to late March 2017 (season 4).

Table 6.4 Basic berry and juice parameters from 20 disease resistant white selections at various harvest times in summer 2017.

Variety	TSS Brix		Sugar/berry (mg)		pH		TA (g/L)		YAN (mg/L)	
1	21.3	0.19	266.2	7.29	3.43	0.017	4.61	0.083	62.6	3.73
2	21.7	0.15	385.0	16.89	3.65	0.050	3.65	0.089	72.8	4.04
3	21.7	0.33	225.9	9.22	3.80	0.017	3.45	0.085	88.3	13.81
4	23.1	0.39	352.8	17.18	3.65	0.024	4.13	0.107	76.9	5.24
5	21.7	0.38	220.7	5.41	3.50	0.042	4.53	0.119	67.1	4.84
6	21.6	0.21	250.7	4.21	3.52	0.024	4.10	0.099	51.3	4.22
7	21.5	0.30	445.9	20.83	3.40	0.039	4.21	0.119	64.6	2.82
8	20.4	0.50	220.0	9.97	3.72	0.039	3.44	0.116	95.8	3.94
9	18.1	0.55	184.5	9.59	3.61	0.026	3.22	0.065	42.7	2.74
10	21.4	0.13	251.2	6.02	3.29	0.019	5.17	0.170	68.8	5.05
11	18.8	0.17	279.2	5.69	3.61	0.019	3.55	0.150	54.4	4.38
12	19.1	0.37	166.3	6.79	3.70	0.021	3.62	0.093	50.2	1.77
13	22.3	0.24	184.9	6.72	3.50	0.018	4.41	0.063	60.0	3.85
14	19.1	0.16	249.0	5.68	3.43	0.016	4.00	0.110	55.7	4.64
15	21.5	0.25	208.4	7.82	3.44	0.037	4.43	0.163	87.5	4.08
16	21.5	0.49	241.3	9.83	3.44	0.027	4.49	0.127	71.5	3.18
17	22.3	0.18	196.1	3.76	3.45	0.029	5.22	0.148	88.3	3.79
18	21.1	0.15	166.5	4.43	3.17	0.019	6.87	0.175	73.2	6.62
19	19.4	0.14	173.2	4.07	3.26	0.024	5.95	0.107	114.4	7.34
20	20.5	0.15	268.2	4.76	3.62	0.025	3.85	0.070	90.8	6.51

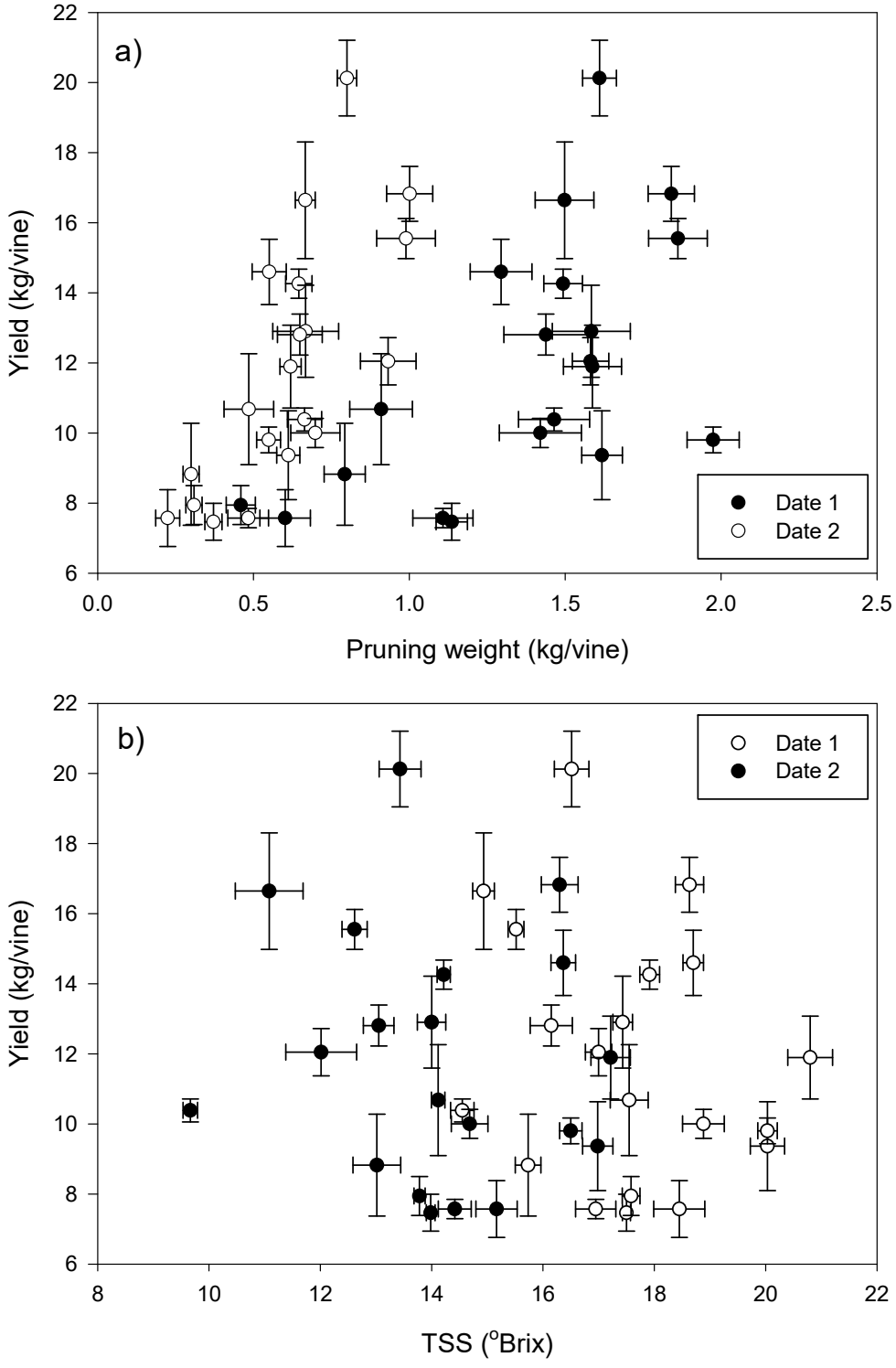


Figure 6.13 Relationship between yield/pruning weights (a) before and after season 3 (26/7/16 and 22/6/17) and yield/total soluble solids (b) at two dates (1/2 and 15/2).

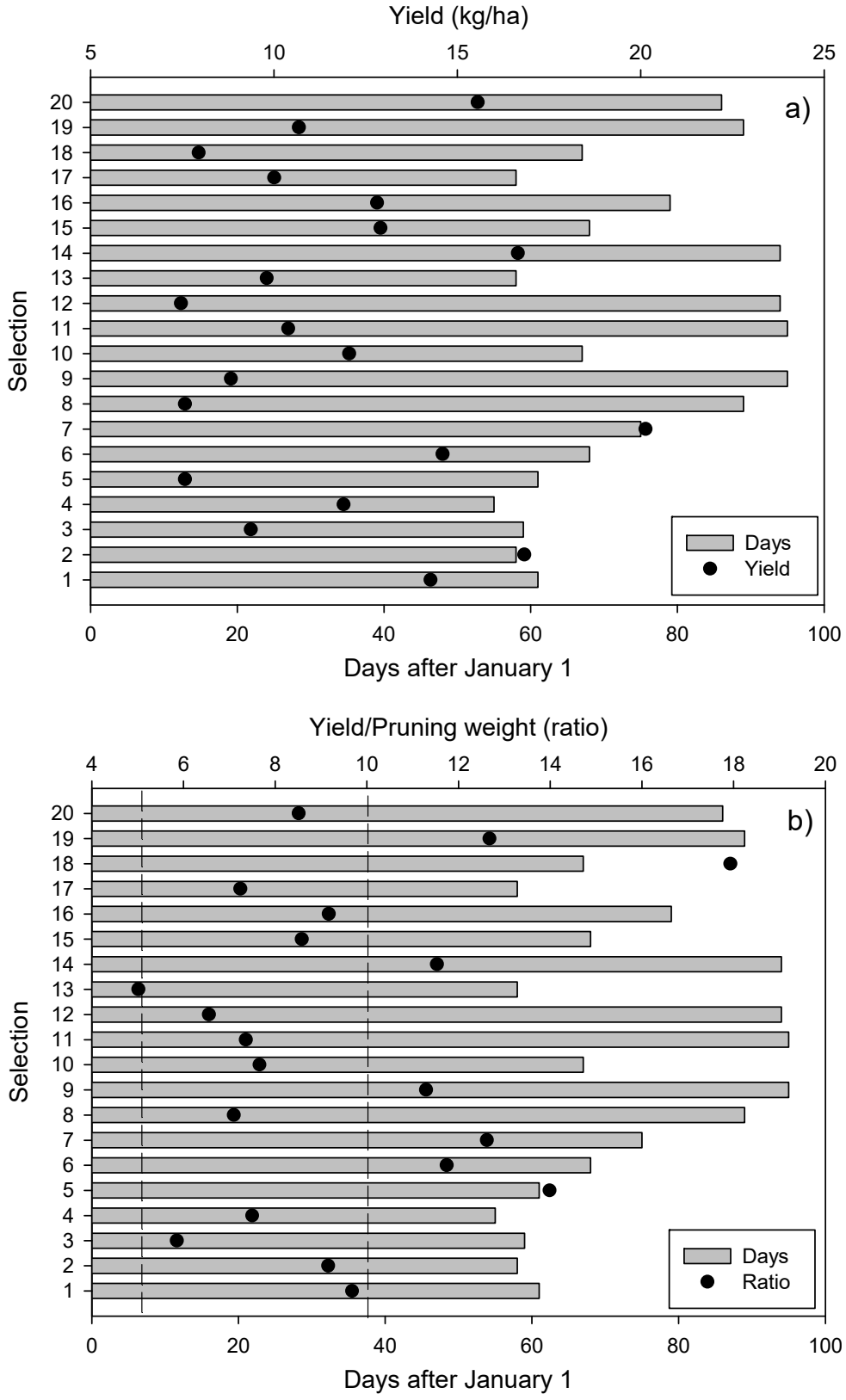


Figure 6.14 Timing of harvest and yield (a) or yield to pruning weight ratio (b) in 20 white selections (season 4), broken lines indicate traditional optimal range (5 to 10).

6.4 Winemaking and wine sensory assessment

The grape harvest stretched over six weeks due to the differences in maturation as indicated in the previous chapter (Figure 6.14a and b). All selections produced enough grapes for two ferments of approximately 50kg each. The must of each ferment was assessed for basic juice parameters, and these varied slightly from analyses undertaken on the 50 berries reported earlier and showed that 14 selections were between 12 and 13 Baume, one selection was slightly below 11 and one slightly above 13 (Table 6.5). The differences in pH and TA were also less pronounced, being 3.05 to 3.23 and 4.85 to 6.5 g/L respectively. YAN levels (41.5 to 106.5 mg/L) were similar between must from the ferments and 50 berry juice samples and FAN ranged from 25.5 to 80 mg/L being somewhat proportional to the YAN levels. Results from the OenoFoss did not often match; particularly the YAN levels were considerably higher (see Table 13.1 and 13.2 in Appendix 5). However, the analysis with the OenoFoss indicated ranges of malic acid (0 to 1.30 g/L) and tartaric acid (3.65 to 7.55g/L) and in some must, gluconic acid was detected (0.0 to 0.45 mg/L). OenoFoss results for the same selections grown at two regional sites, Barossa Valley and at NWGIC are also presented (Table 13.1 and 13.2 in Appendix 5). Both similarities and differences were found between the two sites for the same selections and this was expected for different regions at two different regional sites. Comparison across regional sites for a number of seasons may allow the identification of selections that show less regional and seasonal effects for some of the traits measured if the trait is under strong genetic control and weak environmental control.

The wines prior to bottling showed a range of alcohol concentrations from 11.2 to 13.8%, which was related to the Baume levels described above, but also to the residual sugars ranging from 0.08 to 1.41 g/L (Table 6.5). The wine pH was between 0.14 to 0.29 units lower and this could be due to the DAP and tartaric acid additions during the wine making process. Some acid adjustments were made which would have contributed to the range of TA determined in the wine (5.45 to 6.55 g/L). After the reported measurements and initial tasting the wine was bottled for sensory evaluation.

The wines were assessed two months after bottling in the Riverina at McWilliam's Wines for sensory attributes in mid-September. This included the ranking of aromas; tropical, citrus, stone fruit and floral as well as attributes for mouth acidity, length of flavour and bitterness (Figure 6.15). In addition, overall preference (1 to 9) and wine score (100 point scale) was assessed by the winemakers at McWilliam's Wines, with the average values ranged from 3.8 to 6.8 and 83.5 to 87.4 respectively (Figure 6.16). The sensory assessment of wines showed a considerable difference in the overall scores and preferences, but also in the aroma and attributes and these differences were particularly pronounced in floral aroma and the acidity attribute.

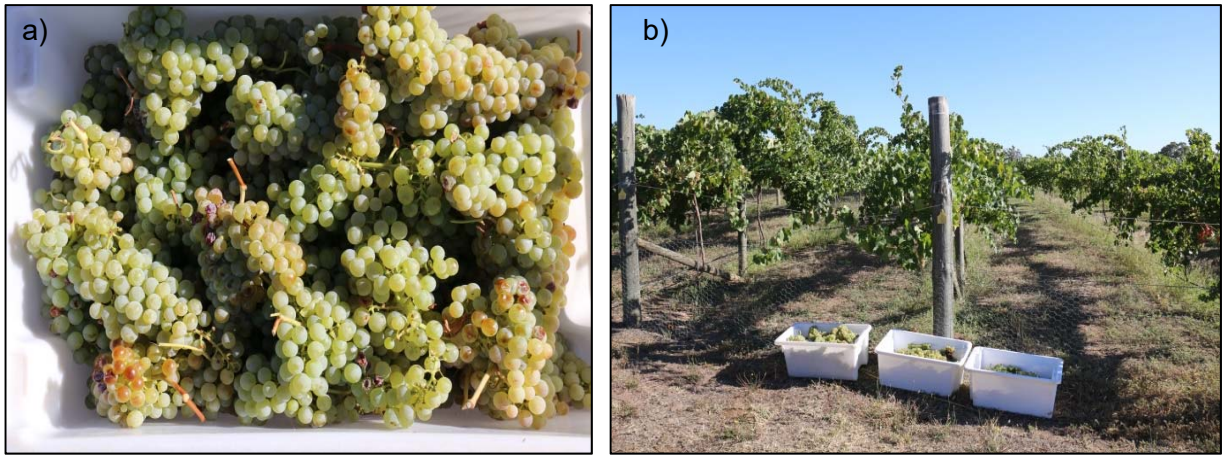


Figure 6.14 First vintage of the new disease resistant white selections in 2017, with the harvest stretching over six weeks for the different selections.

Table 6.5 Baume, pH, FAN, YAN and total acidity (TA) in must of the new disease resistant selections.

Variety	Baume	pH	TA (g/L)	FAN (mg/L)	YAN (mg/L)
1	11.5 0.00	3.23 0.005	6.00 0.100	40.0 5.00	49.5 5.50
2	12.3 0.00	3.16 0.005	5.90 0.000	56.0 2.00	68.5 2.50
3	12.8 0.00	3.14 0.010	5.80 0.100	46.0 0.00	60.5 0.50
4	12.6 0.10	3.21 0.010	6.00 0.000	38.5 0.50	45.5 0.50
5	12.1 0.10	3.19 0.015	5.60 0.100	33.5 0.50	54.5 0.50
6	11.7 0.00	3.08 0.010	5.65 0.050	40.5 0.50	48.5 0.50
7	11.3 0.00	3.05 0.000	6.45 0.050	36.0 1.00	85.0 34.01
8	13.1 0.05	3.20 0.025	5.20 0.100	78.0 4.00	104.5 5.50
9	10.9 0.00	3.14 0.010	4.85 0.050	25.5 0.50	41.5 1.50
10	12.2 0.10	3.05 0.020	6.40 0.100	56.0 1.00	80.5 0.50
11	12.4 0.05	3.19 0.010	5.30 0.000	42.0 2.00	59.0 1.00
12	12.3 0.20	3.17 0.005	5.70 0.200	37.0 0.00	52.0 0.00
13	12.8 0.05	3.06 0.005	6.00 0.100	67.5 2.50	88.5 2.50
14	12.3 0.05	3.17 0.010	5.40 0.100	55.0 4.00	72.0 2.00
15	12.6 0.00	3.12 0.005	5.30 0.000	48.0 1.00	79.0 1.00
16	12.6 0.05	3.22 0.005	5.20 0.000	46.0 0.00	76.0 0.00
17	12.5 0.20	3.15 0.000	6.50 0.100	80.0 2.00	106.5 1.50
18	12.2 0.05	3.07 0.000	6.00 0.000	50.0 2.00	83.5 3.50
19	11.8 0.10	3.08 0.015	5.90 0.100	58.0 1.00	98.5 1.50
20	12.6 0.10	3.12 0.005	5.65 0.050	53.0 0.00	79.0 0.00

Table 6.6 Alcohol concentration, pH, total acidity (TA), acetic acid and residual sugars in wines made from the new disease resistant selections.

Variety	Alcohol (%w/v)	pH	TA (g/L)	Acetic Acid (g/L)	Residual Sugars (g/L)
1	12.3 0.00	2.98 0.000	5.95 0.050	0.10 0.010	0.19 0.005
2	13.0 0.30	2.96 0.020	6.05 0.050	0.06 0.000	0.08 0.020
3	13.8 0.00	2.92 0.010	6.10 0.100	0.07 0.005	0.83 0.020
4	13.6 0.10	3.09 0.000	6.10 0.100	0.06 0.010	0.09 0.005
5	13.0 0.25	2.88 0.015	6.45 0.250	0.04 0.035	0.64 0.015
6	12.4 0.15	2.89 0.000	5.75 0.150	0.12 0.015	0.90 0.360
7	11.6 0.05	2.76 0.005	6.50 0.100	0.11 0.015	0.33 0.065
8	14.1 0.05	3.01 0.040	5.60 0.100	0.16 0.010	1.24 0.110
9	11.2 0.05	2.87 0.035	5.60 0.300	0.05 0.005	0.36 0.105
10	12.9 0.10	2.90 0.005	6.55 0.050	0.12 0.005	1.41 0.260
11	12.9 0.00	2.99 0.005	5.45 0.050	0.05 0.000	1.23 0.165
12	12.8 0.15	3.06 0.015	6.35 0.050	0.14 0.005	1.09 0.025
13	13.8 0.10	2.93 0.015	6.05 0.050	0.15 0.000	0.12 0.015
14	12.9 0.05	3.00 0.030	6.55 0.050	0.14 0.010	1.02 0.315
15	13.5 0.00	2.95 0.005	5.70 0.100	0.05 0.050	1.00 0.155
16	13.3 0.00	2.97 0.005	5.35 0.050	0.11 0.000	0.71 0.000
17	13.4 0.30	2.97 0.015	6.35 0.150	0.13 0.050	1.08 0.305
18	12.6 0.15	2.81 0.005	6.45 0.050	0.08 0.005	1.00 0.200
19	12.3 0.05	2.87 0.010	6.30 0.100	0.15 0.030	0.88 0.100
20	13.4 0.20	2.96 0.005	6.05 0.050	0.16 0.030	1.08 0.215

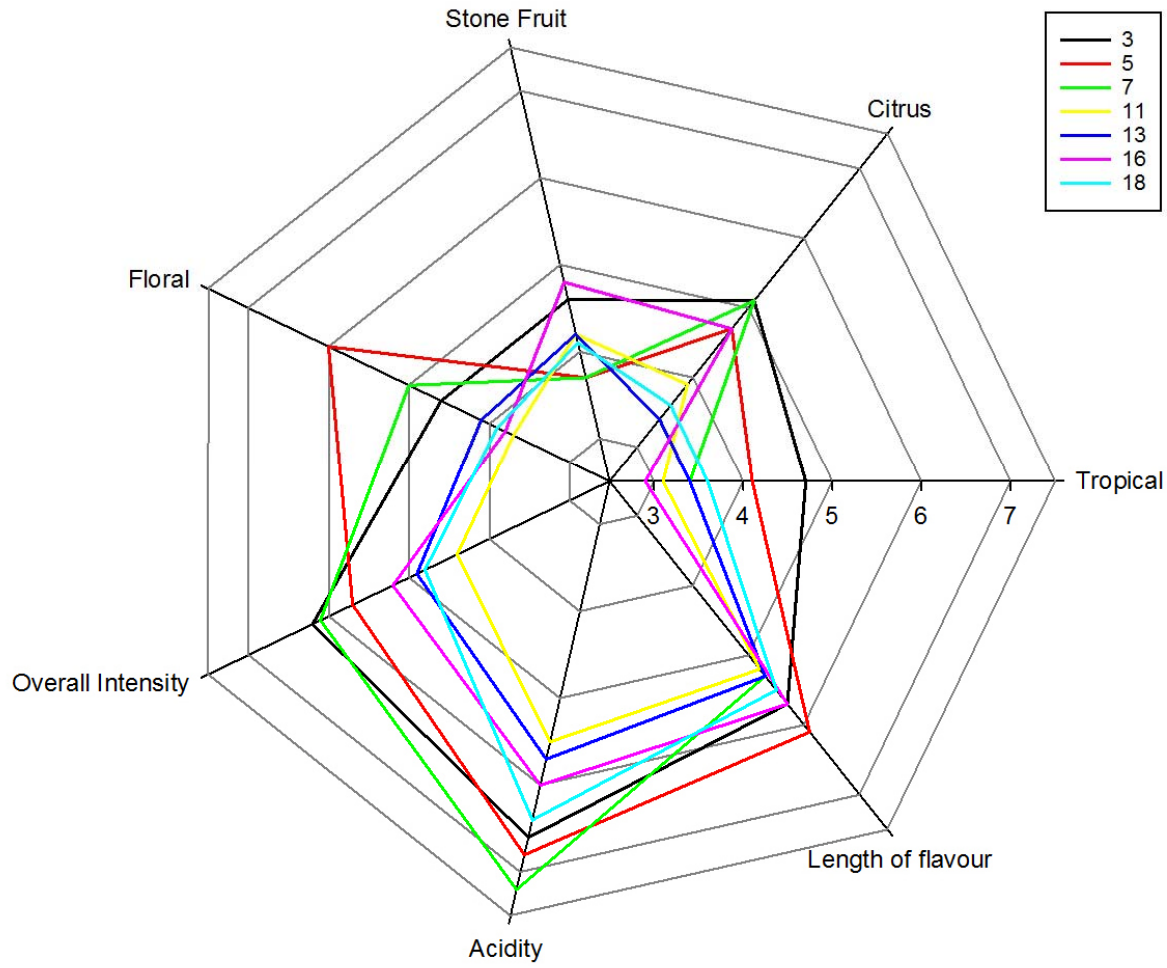


Figure 6.15 The intensities of five aroma and attributes of the seven highest ranked wines made from grapes coming from the 20 white selections, assessed in the Riverina (September 2017).

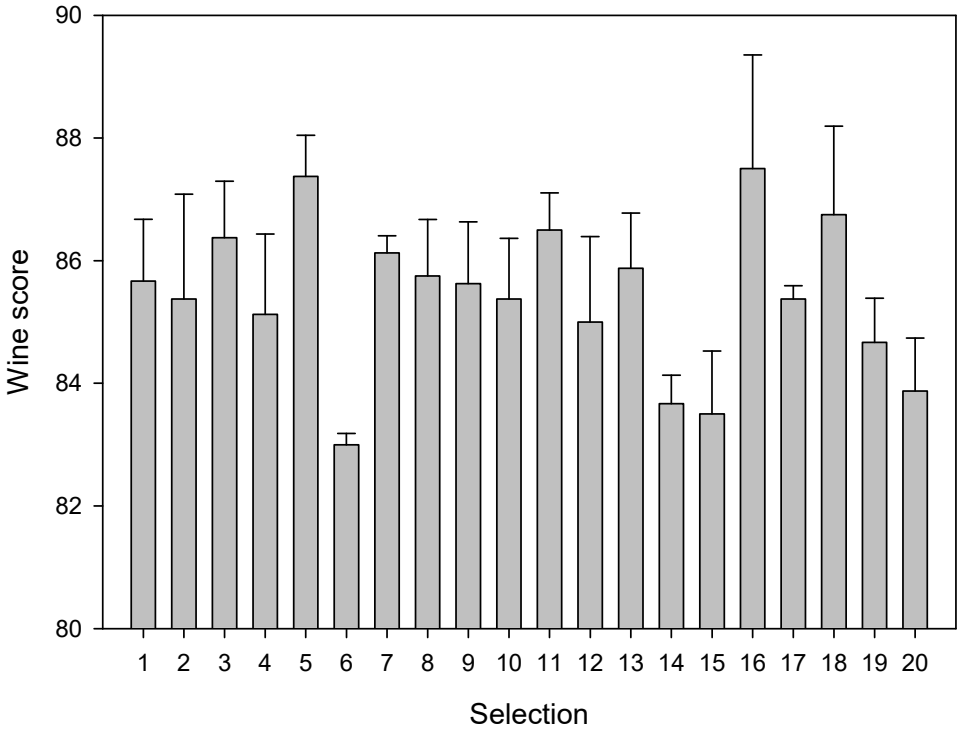


Figure 6.16 Wine scores from wines made from the new disease resistant selections. Assessed two months after bottling in the Riverina (five tasters).

7. Outcomes and conclusions

The establishment, initial and full production stretched over four growing seasons for the white selections with the vines planted in late 2013. The red selections were added to the project in year 3 (2015/16), with the vines planted in late 2015. This allowed for an assessment of the establishment phase over two growing seasons for both white and red selections.

The establishment phase of both white and red selections was monitored and management information compiled for the vines grown in a vineyard that was not sprayed for mildews. There was some mite damage to the vines, but no incidence of downy or powdery mildew was observed. Yield and yield parameters were determined within the last two seasons of the project for the white selections together with basic composition parameters, both showing considerable differences between them. Two wines were made and basic compositional parameters determined from each white selection. These 40 wines were assessed a few months after harvest with the industry in the Riverina. There was considerable variation observed in maturation of the 20 selections in season 3 and this was a good indicator for season 4, in which the harvest stretched over six weeks. This demonstrated that the new selections had a range of maturity dates and that this might be of benefit to industry for adoption of selections that were either early or late ripening, to spread the harvest period.

Under full irrigation there were only minor differences in water use efficiency (WUE), but berry sensitivity to heat events varied and was more pronounced later during maturation. The severity of the damage would be less likely in the future as the canopy size increases and therefore bunch exposure would be reduced. However, the range of yields and pruning weights observed for the white selections indicated that different management requirements for water and nutrient applications would be more appropriate. For instance, the average yield WUE ranged from 3.8 to 10.1 t/ML, but it has to be emphasised that the rainfall in 2016/17 was considerably above average in spring. Similarly, the range of yield would require an N application rate just for the selections with grape production between 20 and 60 kg/ha of nitrogen. The findings of the project allow an initial evaluation of yield potential and suitability for warm irrigated production areas in Australia. In addition, preliminary assessment of the wines indicated different styles with considerable differences in aromas recorded. A number of presentations were given in NSW towards the end of the project, including a larger event held at the NWGIC in November 2016. Some of the most recent information has been submitted to an industry oriented journal and the article will be published by the end of the year.

Further assessment is necessary for vine assessment and winemaking to have comprehensive data to determine consistency between seasons, for both production and grape/wine composition. More detailed assessments regarding vine water and nutrient status would be beneficial, but was out of the scope of this project. However, the trial set up would allow the capture of more details, if the possibility arises in the future. Further, it will be important to evaluate the selections in different climates and further refine the measurements that are the most critical for characterising these selections under resource limitations (e.g. water) that might occur in the future if industry is faced with another long drought event. This would include incorporating more digital technology at the evaluation sites to assist with vine monitoring and data collection. The interest in these selections from

industry suggests the benefits in their use in view of reducing production costs and impact on the environment is considerable.

8. Recommendations

Regional field trials to evaluate vine performance and wine quality are an important activity to determine the best selections for different regional climates and different management systems. Such field trials are common in other crop improvement programs but have not previously been implemented as a long-term plan for grapevine improvement in Australia. It is recommended that four regional field sites be established for long-term assessment of these new disease resistant selections and future scion and rootstock selections. The four regional field sites would cover the main climates where grapes are grown (cool to hot irrigated) and the major grape growing regions of Australia. It is recommended that sites be established in the Barossa Valley SA, Irymple VIC, Riverina NSW, and Orange NSW. The sites would be managed by CSIRO or State Departments to ensure health of the plants and the collection of research quality data. A suitable location in the Orange wine region has been selected as a cool climate site. Plant establishment at the Orange site will be similar to the Riverina site at the NWGIC and allow for meaningful comparisons between the sites. However, some late maturity selections identified in this project will need to be replaced by other selections that mature earlier to ensure the best selections are matched to the climate and environment. The addition of a cool climate regional site will provide a better evaluation to determine the most suitable selection with regard to productivity, maturation and flavour development for regions of various climatic conditions. This approach will provide further feedback on suitable traits during the selection process for current and future breeding selection programs of disease resistant grape varieties undertaken by CSIRO.

It is also recommended that these white and red disease resistant selections be further assessed over the next five growing seasons to ensure a meaningful evaluation of vine performance and wine characteristics.

The regional sites would also be part of a pathway to adoption process. Local viticulturists and winemakers in each region would be engaged in the assessment of wine made from grapes produced at the different sites. It is expected that the regional field trials would help drive industry adoption and uptake of new grapevine selections. In addition, the regional sites would also act as mother block plantings for the Australian industry.

The range of productivity levels, in yield and canopy size and the combination of both (vine balance) requires further consideration. The length of grape maturation, which based on the data from these new selections appears to be only partially driven by the yield to pruning weight ratio, would need further clarification in the view of internal resource allocation differences between the selections. This suggests that there are genetic differences controlling these traits and the traditional vine balance recommendations based on old European varieties might not apply to new selections that have a higher yield, less canopy and earlier maturity dates. It would be beneficial for some of the most outstanding selections to undergo further assessment to determine optimum vineyard management for optimising canopy size, yields, nutrition and irrigation. Such an approach, however, might vary between the various wine regions in Australia. The use of more digital technology would provide the

opportunity to capture more information from these selections in the future and likely reduce resources for monitoring and data collection.

Appendix 1: Communication

In June 2016 as part of a NSW DPI workshop program (Re-working vines) in Orange and the Hunter Valley the project background and establishment as well as some initial results were presented.

A seminar and field day was held at the National Wine and Grape Industry Centre (NWGIC) on 16 November. There were four presentations which included new tools to assess grapevine powdery mildew, bunch rots and differentiation and thresholds for grape and wine contamination, practical management of grapevine trunk diseases, breeding and evaluating new disease resistant grape selections. The presentations were followed by a vineyard walk through the plantings of the new white and red disease resistant selections in the NWGIC experimental vineyard.

Holzapfel, B., Thomas, M. and Dry, I. (2017): Evaluating and demonstrating new disease resistant varieties for warm irrigated areas. Grapevine management guide 2017-18 (ISSN 1036-7551), 58-59

Holzapfel, B., Thomas, M. and Dry, I. (2017): Further evaluation of disease-resistant scion selections in NSW wine regions. Wine & Viticulture Journal, November/December (in press)

Appendix 2: Intellectual Property

The majority of the IP produced by this project is in the form of new knowledge that can be disseminated to industry so that both growers and winemakers can make informed decisions about the suitability of the new varieties for growing in hot irrigated regions of Australia and the type of wine produced and yields that can be achieved under hot climates with fewer sprays to control mildew.

Appendix 3: References

Dry, IB, Feechan, A, Anderson, C, Jermakow, AM, Bouquet, A, Adam-Blondon, AF and Thomas, MR (2010) Molecular strategies to enhance the genetic resistance of grapevines to powdery mildew. Aust. J. Grape Wine Res. 16:94–105

Feechan A, Anderson C, Torregrosa L, Jermakow A, Mestre P, Wiedemann-Merdinoglu S, Merdinoglu D, Walker AR, Cadle-Davidson L, Reisch B, Aubourg S, Bentahar N, Shrestha B, Bouquet A, Adam-Blondon A-F, Thomas MR, Dry IB (2013) Genetic dissection of a TIR-NB-LRR locus from the wild North American grapevine species Muscadinia rotundifolia identifies paralogous genes conferring resistance to major fungal and oomycete pathogens in cultivated grapevine. Plant Journal 76:661-674

Staudt, G, (1997) Evaluation of resistance to grapevine powdery mildew (*Uncinula necator* [Schw.] Burr., anamorph *Oidium tuckeri Berk.*) in accessions of Vitis species. Vitis 36:151-154.

Wan Y, Schwaninger H, He P, Wang Y (2007) Comparison of resistance to powdery mildew and downy mildew in Chinese wild grapes. Vitis 46:132–137

Appendix 4: Staff

Project Supervisors:

Mark Thomas (10%) and Bruno Holzapfel (20%)

Chief investigators:

Jason Smith (10%) contributed to the project until November 2015; this role was taken over by Bruno Holzapfel (with an additional 10%) and Gerhard Roussow (CSU lecturer since December 2016)

Other staff:

Alain Deloire (former Director of the NWGIC) left towards the end of the project in September 2016, his role was taken up by Leigh Schmidtke (Acting Director NWGIC since December 2016).

Suzy Rogiers and Rob Lamont (an additional in-kind resource not listed in the Final Project Application, but added when the red selections were included in the project) were present throughout the project, each with a 10% contribution.

Geoff McCorkelle from McWilliam's Wine Group, Technical Viticulturist was superseded by Andrew Higgens in the last year of the project.

Appendix 5: Other material and raw data

Table 13.1 OenoFoss results from the 20 white selections from must samples taken prior fermentation (TSS, pH and acids). Note "B_" are data from the same selection grown at the Barossa Valley site.

White Selection	pH	B_pH	Total Acid	B_Total Acid	Malic acid	B_Malic acid	Tartaric acid	B_Tartaric acid	TSS	B_TSS
1	3.35	3.46	5.1	4.9	0.8	1.2	4.5	5.3	18.8	21.2
2	3.49	3.55	4.3	3.6	0.7	0.5	4.3	5.5	19.1	20
3	3.55	3.68	3.1	4.1	0.3	1.2	3.5	5.7	17.6	22.7
4	3.53	3.53	4.3	5.5	1.3	3	4.3	4.7	20.3	23.5
5	3.38	3.4	4	5.3	0.5	1.9	4.1	4.3	14.2	19
6	3.44	3.61	4.3	3.8	0.3	1.2	4.7	4	19.1	20.5
7	3.37	3.73	4.3	3.4	0.2	0.8	4.9	4.8	17	21.2
8	3.77	3.89	2.7	3	0.2	0.9	4	4.7	20.3	22
9	3.55	3.47	3.7	4.3	0	0.5	5.3	4.1	18.1	19.1
10	3.29	2.79	5.3	10.4	0.1	2.6	5.4	4.1	17.5	22.4
11	3.53	3.78	3.6	3.5	0.4	1.8	4.1	4.1	18.9	21.2
12	3.69	3.61	3.4	6.1	0.5	4	4.5	4.6	20.6	21
13	3.42	3.75	4.4	3.7	0.3	0.9	4.6	4.2	20.9	21.6
14	3.44	3.68	4.9	4.3	0.4	1.1	5.9	3.7	20.1	19.7
15	3.44	3.66	4.4	3.7	0.1	1	5.8	4.1	21.1	20.8
16	3.4	3.33	3.9	6.4	0	1.5	4.6	7.3	16.9	20.9
17	3.31	3.51	5.9	4.9	1	1.7	6.8	3.9	21	21.4
18	3.27	3.53	5.7	3.6	0.1	0.2	7.8	5.2	20	19.9
19	3.3	3.28	5.7	6	0.2	0.3	7.4	6.7	19.3	20
20	3.51	3.95	4.3	2.5	0.3	1	5.8	5.3	20	21.4

Table 13.2 OenoFoss results from the 20 white selections from must samples taken prior fermentation (VA, YAN, gluconic acid, amino and ammonium N). Note "B_" are data from the same selection grown at the Barossa Valley site.

White Selection	VA	B_VA	YAN	B_YAN	Alpha Amino	B_Alpha Amino	Gluconic acid	B_Gluconic acid	Ammonia	B_Ammonia
1	0.03	0.06	101.3	182	50.8	99.3	0	0	61.7	100.7
2	0.04	0.05	127.2	173.1	70.3	115	0	0	69.4	70.9
3	0	0.06	112.7	307.9	49	182	0	0	77.7	153.5
4	0.04	0.1	94.6	180.3	54	122.9	0	0.1	49.6	70.1
5	0	0.04	86.6	167.3	29.3	93.7	0	0	69.9	89.8
6	0.04	0.01	115.9	168.4	57.3	109.1	0	0	71.5	72.3
7	0.02	0.05	111.3	194.4	50.1	135.3	0	0	74.6	72.1
8	0.06	0.12	151.8	279.3	88.2	201.9	0	0.5	77.6	94.3
9	0.02	0.05	107.2	151.1	48.5	82.4	0	0	71.6	83.7
10	0.04	0.1	129	348.6	64.1	171	0.1	0.6	79.1	216.5
11	0.03	0.1	109.3	227.4	52.9	168.9	0	0	68.8	71.3
12	0.07	0.12	110.6	205.7	62.1	149.3	0	0.2	59.1	68.8
13	0.03	0.08	126.6	288.1	62.7	191.4	0.3	0.4	77.9	118
14	0.07	0	136.3	236.4	77.2	146.2	0.5	0.2	72	110
15	0.02	0.07	145.7	251.2	69.6	170.2	0	0.4	92.8	98.8
16	0	0.02	113	301	51.6	157.1	0	0	74.9	175.4
17	0.06	0.1	140.5	244.1	75.8	175	0.4	0.3	78.9	84.3
18	0.06	0.04	145.2	172.4	72.6	105.8	0	0	88.5	81.2
19	0.06	0.09	162.1	217.6	82.4	120.1	0	0.3	97.3	119
20	0.07	0.1	138.8	256	73.9	185.6	0.4	0.3	79.2	85.9

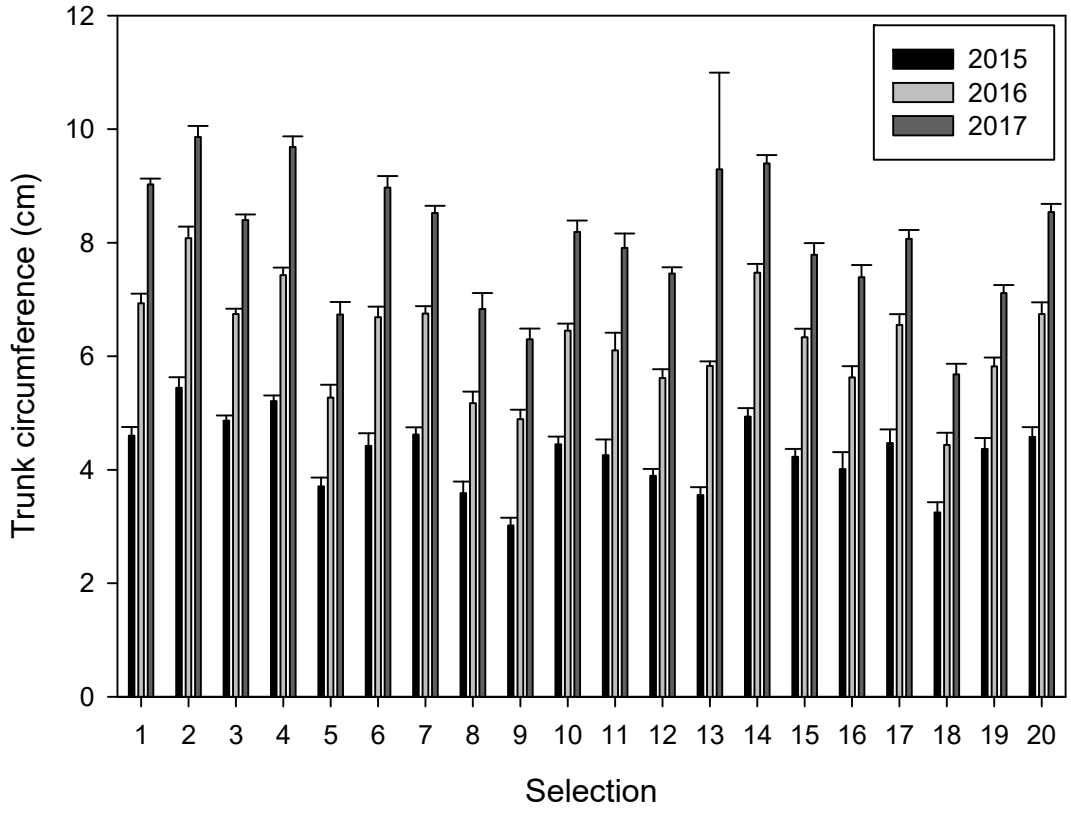


Figure 13.1 Trunk circumference of the 20 white selections measured in the middle of the years 2015, 2016 and 2017 at experimental vineyard of the NWGIC.

Raw data are kept at NSW DPI.