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Wine Australia

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Taking grapevine yield forecasting into the digital age



FINAL REPORT TO WINE AUSTRALIA

Project Number: **UT1601**

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Contents

1.0 Abstract 3

2.0 Background 4

3.0 Project Aims 5

4.0 Methods 6

Bud Fruitfulness prediction using NIR scanning 6

Model development for bud fruitfulness prediction 12

Development of Software package for forecasting in the field 12

5.0 Results/Discussion 13

Bud Fruitfulness prediction using NIR scanning 13

Development of Software package for forecasting in the field 23

6.0 Outcome / Conclusion 26

7.0 Recommendations 27

8.0 Appendix 1: Communication 28

8A: Communication with industry 28

8B: Communication with scientific community 33

9.0 Appendix 2: Intellectual Property 33

10.0 Appendix 3: References 34

11.0 Appendix 4: Staff 36

12.0 Appendix 5: Acknowledgements 36

1.0 Abstract

The technology of Near Infrared Spectroscopy (NIRS) can be a powerful analytical technique for the rapid analysis of various compositional parameters in wine grapes, must and grapevine tissues. This study investigated the feasibility of using NIRS technology to non-destructively predict grapevine bud fruitfulness. Discriminant Analysis models to categorise buds were prepared using Principle Component Analysis reduced spectra and were compared against microscopic bud dissection data and actual fruitfulness measured in the field at flowering.

Accurate predictions were obtained for the bud fruitfulness of both Pinot Noir and Chardonnay varieties over 4 consecutive seasons, utilising three different instruments. As indicated by good prediction accuracy values, portable NIRS technology has the potential to predict grapevine bud fruitfulness. In the final year of prediction the Bruker MPA instrument employed in the laboratory demonstrated an accuracy of 97.32% when predicting the fruitfulness of Pinot Noir and Chardonnay buds. In the field scanning buds in situ, the ARCoptics Rocket portable instrument demonstrated an accuracy of 100% for predicting bud fruitfulness of Pinot Noir buds in 2018 and an accuracy of 79.65% in 2019 when predicting fruitfulness of Pinot Noir and Chardonnay buds. In 2018 when there were sufficient unfruitful buds to create a category of their own and when calibrations were prepared using 'yes' or 'no' for presence of inflorescences the prediction rate was 80% correct. This high accuracy for predicting unfruitful buds would be particularly valuable for industry.

Overall the challenges with the technique include orientation of the probe, confusion due to compound buds, and confusion created by the shoot apex contributing to the spectral signal.

Software developed to use alongside the technology has demonstrated proof of concept that the tools can be employed in the vineyard to scan a representative number of buds and predict the level of fruitfulness to inform pruning decisions on a block level. The software can be found at https://digiviti.indicium.cloud/ A video clip to assist with demonstrating the ease of application of the research for industry was also produced https://www.youtube.com/watch?v=https://www.youtube.com/watch?v=fAa1MnR26yY

Digital technology will increasingly support decision making for management and this project has demonstrated the potential use of NIRS in supporting pruning decisions in vineyards for the wine industry.

2.0 Background

Yield variation is a major source of uncertainty in viticultural production and is a key management concern in cool climates (Dunn et al. 2004). Bud fruitfulness has remained a focus of crop yield studies for the past 30 years (Sanchez and Dokoozlian 2005). Yield variability continues to be a major issue for the Australian wine industry, leading to difficulty in decision making for block selection for different labels, complication with intake scheduling for wine making and even difficulties with marketing and lower prices in high yield years.

Inter-annual yield variation in vines has generally been explained by year-to-year fluctuations in the number of inflorescences per vine (Clingeleffer et al. 2001). In Victoria (Australia), the largest source of seasonal variation in grape yields was bunch number per vine, accounting for approximately 60 per cent of the variation, with berries per bunch the next highest source of yield variation (Martin et al. 2000).

Flower formation in grapevines involves three well defined steps: (i) anlagen, or uncommitted primordial, are formed in the apices of latent buds on shoots of the current season; (ii) these specialised meristematic structures may differentiate inflorescence primordial (IP); and (iii) individual flowers are formed on IP (Barnard 1932; Barnard and Thomas 1933). The first two steps are completed during the previous season for grapevines grown in temperate climates. Individual flowers however, are not formed until during budburst in the current season (Barnard 1932, Snyder 1933, Winkler 1958, Scholefield and Ward 1975, Srinivasan and Mullins 1981).

Fluctuations in the number and size of inflorescences per vine can explain the majority of inter-annual yield variation (Clingeleffer et al. 2001). Therefore, the conditions during the initiation and differentiation phases of inflorescence primordia in latent buds in the previous season exert an important influence over the number of inflorescences in the current season, and hence yield. Furthermore, it is likely that conditions during these critical developmental stages also exert some control over the potential size (number of flowers) of the inflorescences (Palma and Jackson 1981, Dunn and Martin 2007).

As inflorescence number is set prior to vine dormancy in winter, knowledge of bud fruitfulness at pruning has the potential to inform better pruning decisions and in turn allow growers to prune vines according to their yield targets. Yet, industry lacks the ability to make a reliable, early-season prediction of yield. Currently yield prediction prior to pruning relies on staff to remove buds from the vines and dissect them microscopically to determine the number of inflorescences, which requires skill and is time consuming. Due to the destructive nature of this technique, the fruitfulness measures obtained can only ever be an indication of the actual fruitfulness of the buds being retained at pruning. This fact, combined with the error related to sample size limitations, has resulted in a slow uptake of bud dissection by industry. There has also been limited uptake of remotely sensed imagery for yield prediction, due to a variety of factors including cost and reliability.

Methods of yield prediction with greater degrees of accuracy are carried out much later in the season. Growers typically make an estimate after fruitset, which then requires bunch removal if yields are too high, and the vine's compensatory effects on the quality of the remaining bunches is debatable.

Near-infrared (NIR), nuclear magnetic resonance (NMR), ultraviolet–visible (UV–vis), Raman, and hyperspectral imaging, all have potential for detection, qualification, and quantification of target

physical and chemical attributes of agricultural products (Ambrose et al 2016). Spectroscopy has been shown to have potential for predicting grapevine parameters in a quick and simplistic manner (Jones et al, 2013). NIRS is a powerful technique that has enabled rapid analysis of various compositional parameters in wine grapes, must and grapevine tissues (Cozzolino et al 2006, Dambergs et al 2015, Urraca et al 2016), grapevine water potential (De Bei et al 2011, Giovenzana et al 2018, Deago et al 2018) and starch (Jones et al 2020).

Raman spectroscopy has proved to be a powerful analytical technique for studying biological materials, allowing non-invasive, rapid and high-resolution acquisition of biochemical and structural information through the generation of point spectra or spectral images (Ellis et al 2013). Although previously applied to analytical chemistry, there has been a significant rise in the use of this technique for biological studies, particularly in the field of biomedicine (Kraft and Popp, 2014).

The advantages of spectroscopic techniques (that detect data from below the surface of samples), relative to conventional methods, include high accuracy and precision, non-invasiveness, and rapidity (Ambrose et al, 2016). The ability to predict bud fruitfulness early in the season is a high priority for the Australian wine industry, and spectroscopy offers advantages in terms of speed and simplicity for routine analysis, as has been shown with the measurement of other parameters. The overarching objective of this study was to investigate a proof of concept through development to allow scanning of buds in the vineyard. The desired outcome is to enable decision support on pruning for vineyard managers, that will lead to alleviation of excessively high- and excessively low-yielding years.

3.0 Project Aims

The objectives of this study were to:

a) Provide proof of concept of the identification of bud fruitfulness by spectral analysis

b) Demonstrate the feasibility of prediction of bud fruitfulness prior to pruning through the use of a portable hand-held device

c) Encourage avoidance of a blanket approach to pruning

d) Provide useful decision support which would lead to a reduction in late season bunch removal for achieving target yields

4.0 Methods

Bud Fruitfulness prediction using NIR scanning

All field work was carried out at a commercial vineyard (Lat 42˚ 45 S, Lon 147˚ 23E) near Richmond, in southern Tasmania, Australia. Cane pruned Pinot Noir (clone D5V12) vines and Chardonnay (clone I10V1) vines were used. Vines were all on own roots and ranged between 15 and 30 years old.

In the winter of 2016 a scoping study commenced in an attempt to provide a proof of concept that bud fruitfulness could be detected by spectral analysis. Both Raman Imaging and NIR were trialled in this first year.

Grapevine buds were excised during winter dormancy and prepared for examination by cutting sections of cane separated into 3cm lengths containing one bud per sample. All imaging was performed at the Central Science Laboratory at the University of Tasmania.

Buds were first scanned using Raman Imaging. This confocal microscopy technique was selected for testing due to the ability to achieve a very small focal spot. Unfortunately, fluorescence was a major issue and prevented a clear image being obtained during testing despite the investigation of four different excitation wavelengths: 532, 633, 785 and 830 nm. The method proved unsuitable for detecting inflorescences inside dormant buds at this time. Further attempts to alter the technique and bud preparation methods were not successful so the technique was abandoned.

NIR Imaging for scanning inflorescence primordia in buds was then tested using a Bruker MPA as shown in Plate 1.

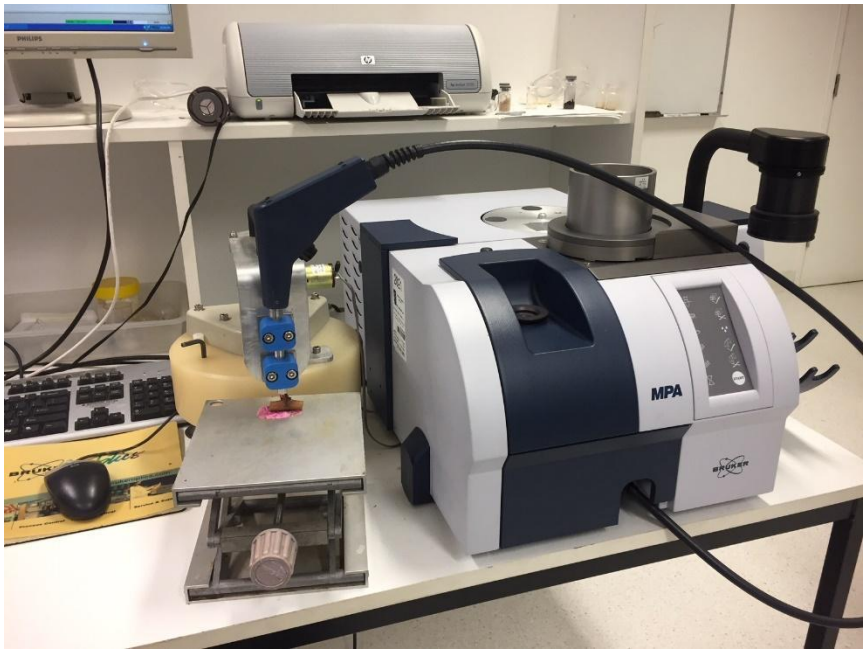


Plate 1: Bruker MPA instrument used for bud scanning.

Light from a tungsten lamp was directed onto the sample with fibre optics. Reflected light was directed back to NIR detector via fibre optics. The instrument is a high-performing benchtop instrument and is not field portable. It is an FT-NIR instrument utilising the wavelengths of 800-2500 nm.

NIR scanning was then repeated using an Ocean Optics Jaz UV-Vis-NIR (shown in Plate 2). This instrument has a built-in battery for field operation and is a post-dispersive spectrophotometer with

strobing from a Xenon flashlamp light source that avoids interference from ambient light. The instrument can be operated in reflectance or transmission mode and utilises the wavelengths of 190-1000 nm.

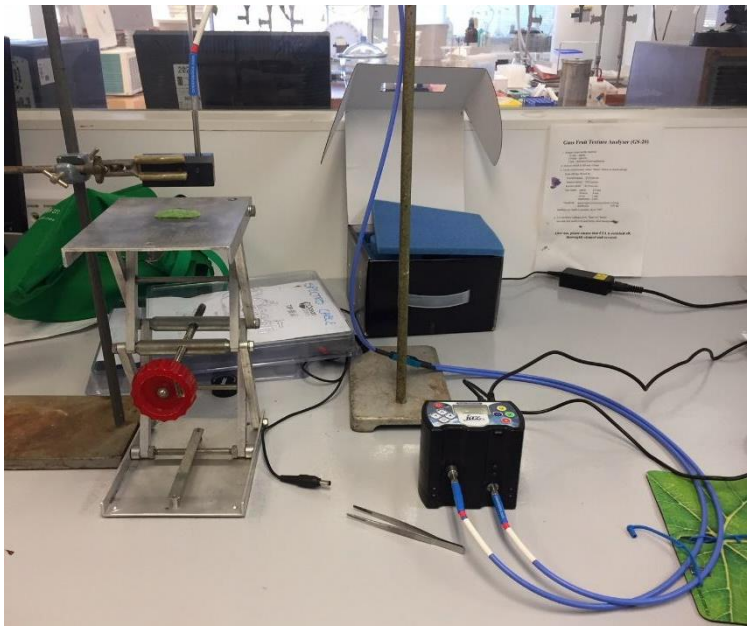


Plate 2: Ocean Optics Jaz instrument used for bud scanning.

The technique appeared to work well in the first year of testing, using an instrument on loan from Lastek, and the decision was made to progress the investigation using NIR. One hundred spectral scans of both Chardonnay and Pinot Noir buds were obtained using NIR. Images were taken of whole buds (as shown in Plate 3) as well as buds with the bud scales removed to test clarity.

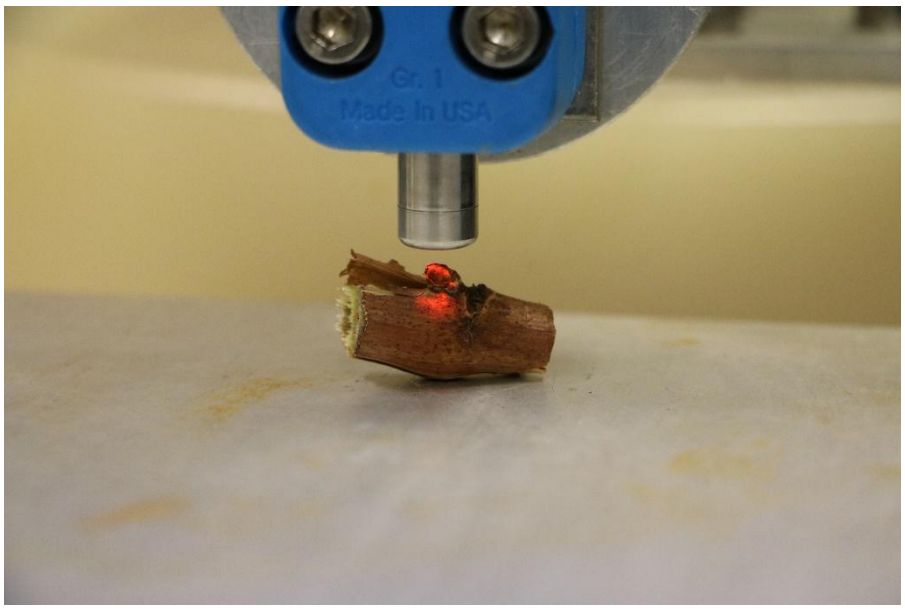


Plate 3: Chardonnay bud scanning performed using Bruker MPA.

Buds were contained in labelled chambers (shown in Plate 4) to allow for refrigeration between measurements done with different instruments and to ensure that the scans were accurately catalogued against bud dissection assessments.



Plate 4: Pinot buds in labelled chambers to allow cataloguing between scanning and dissection.

Buds were then dissected using a longitudinal dissection technique under a light microscope as shown in Plate 5.

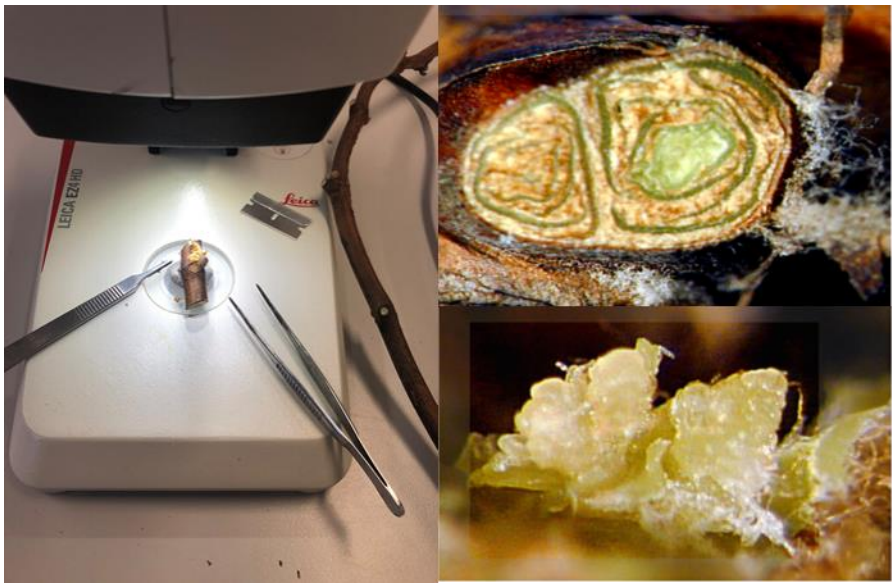


Plate 5: Longitudinal bud dissection under light microscope, exposing two inflorescences.

For each bud, the measure of actual fruitfulness was recorded. The number of inflorescences was recorded, as well as each inflorescence being assigned to a size category of small, medium or large.

Any necrosis was also noted. An initial model was created using Principle Component Analysis in the software Unscrambler.

In the winter of 2017 two hundred Chardonnay and two hundred Pinot Noir buds were harvested from the vineyard and prepared as in the previous season for scanning. Each bud was scanned using the Bruker NIR and the Jaz NIR in the laboratory. This year the bud scales were left intact as the first-year results showed no difference in spectral scan quality with or without bud scales. Spectral scans were stored in an image library. All buds which were excised and scanned were then destructively dissected and the number and size of inflorescences recorded. Inflorescence size categories were extra small, small, medium and large. And inflorescence numbers were either zero, one, two or three.

A refined model correlating bud dissection and spectral data was generated using Unscrambler.

In the 2017 season a field trial was established, with seventy-five Chardonnay buds, from a range of bud positions being tagged and then scanned using the Ocean Optics Jaz UV-Vis-NIR (190-1000nm) in the field. NIR spectral scans were recorded. These vines were cane pruned and bilateral VSP trained. The scanning of buds in the field required two people at this stage of the trial, as great care was taken to ensure that the probe was orientated correctly on the bud to ensure a clear spectrum was obtained (Plate 6). One week prior to flowering in December 2017 the tagged shoots were re-visited to record the number and size of each inflorescence. Inflorescences were photographed and placed into one of three categories; small, medium and large.

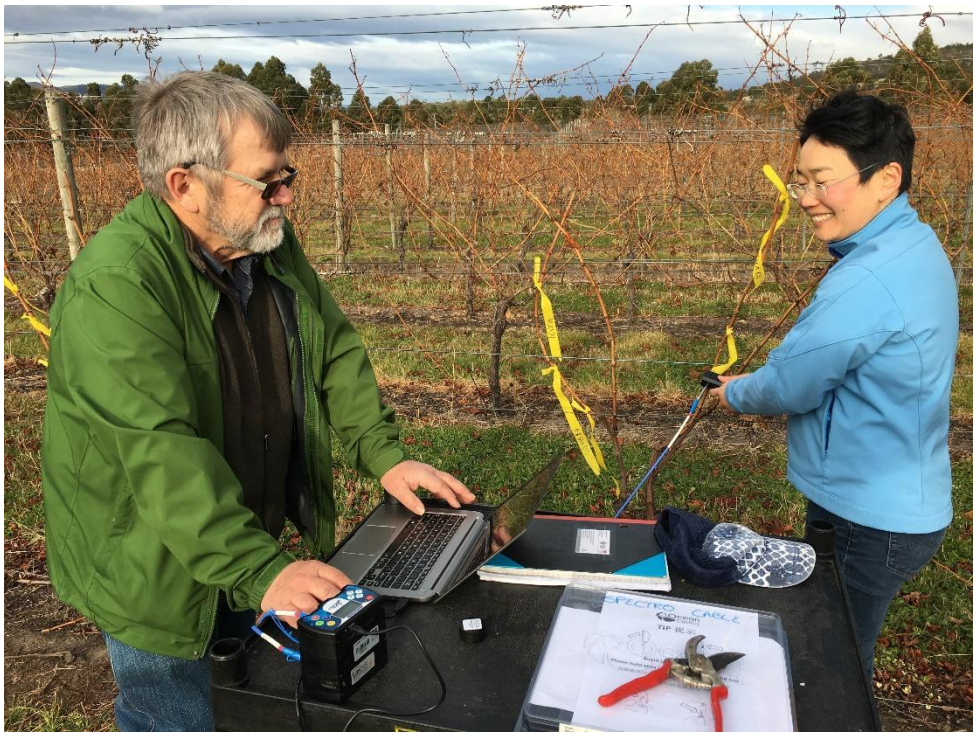


Plate 6: In the first year of scanning in the field buds were scanned using the Ocean Optics Jaz and required two people to collect spectra.

A new model of prediction correlating actual inflorescence numbers and spectral scans for the seventy-five Chardonnay buds was generated using Unscrambler.

In the winter of 2018 one hundred and sixty Chardonnay buds and one hundred and sixty Pinot Noir buds were removed from vines. These buds were again scanned using the Bruker Benchtop NIR and

the Jaz Spectrophotometer in the laboratory and the spectral scans obtained. Once scanned the buds were dissected under a light microscope to determine the actual fruitfulness of each bud as had occurred in previous years. A refined model correlating bud dissection and spectral data was generated using Unscrambler.

A second field study was designed and implemented, whereby 50 Pinot Noir buds were tagged and then scanned using two instruments, the Ocean Optics Jaz Spectrophometer and a newly acquired ARCoptics Rocket Portable FT-NIR (plate 7). The 50 buds scanned in the field were revisited in November to record the number of inflorescences per bud. At the time of recording, inflorescences were fully formed and flowers were just approaching capfall, thus the inflorescences were as large as possible but before any of the inflorescence caps had fallen or flowers opened (typically EL18). In the field, the number of shoots which had eventuated from each bud was recorded, as well as the number of inflorescences on each shoot. Inflorescence size was estimated using the method of Lui et al (2018). Each inflorescence was photographed on black card with a 4x4 chequerboard grid in the corner (as in plate 8) and sent to Dr Mark Whitty's research team at the University of New South Wales for analysis. Flower number estimating software was used and a count of flowers was obtained and used to class the inflorescences into size categories small, medium and large.



Plate 7: ARCoptics Rocket Portable NIR being used to scan buds in the field.



a)



b)

Plate 8a: Each inflorescence was excised and photographed on the backing board and sent for flower number analysis using software b) example of an inflorescence having been analysed by the software, with each red mark a 'flower count' predicted by the software.

In the winter of 2019 one hundred Chardonnay buds and one hundred Pinot Noir buds were removed from vines. These buds were again scanned using the Bruker Benchtop NIR and the Jaz Spectrophotometer in the laboratory and the spectral scans obtained. Once scanned the buds were dissected under a light microscope to determine the actual fruitfulness of each bud as had occurred in previous years. A refined model correlating bud dissection and spectral data was generated using Unscrambler.

A final field study occurred, whereby 90 Pinot Noir buds and 90 Chardonnay buds were tagged and then scanned in the field using two instruments, the Ocean Optics Jaz Spectrophometer and the ARCoptics Rocket Portable NIR. A 3-D printed trigger was created to insert onto the fibre-optic cable of both instruments, this allowing for easy single user operation, more precise orientation of the probe over the buds and automatic capturing of the scan when the trigger button was pressed (plate

9). The 180 buds scanned in the field were revisited in November to record the number of inflorescences per bud. Inflorescence size was determined non-destructively by capturing images in the vineyard without removing the inflorescences.



Plate 9: 3-D printed trigger was created to insert onto the fibre-optic cable to enable better orientation of the probe and single-handed capture capability.

Model development for bud fruitfulness prediction

Spectral data from the Ocean-Optics Jaz, Bruker MPA and ARCoptics Rocket were imported to Unscramber 11.0 (Camo Analytics, Oslo) for calibration modelling. For the Ocean-Optics Jaz instrument only the wavelengths between 350 and 950 nm were used without any spectral pre-treatment. For both NIR spectrometers, Bruker and ARCoptix, the spectral range between 1060 and 2350 nm were used where an extended multiplicative scatter correction (EMSC) was applied prior to analysis. The dissected primordia were placed in Small, Medium and Large categories based on physical measurements. For the field samples the categories were based on size of inflorescences. Discriminant Analysis models to categorise buds were prepared using PCA reduced spectra.

Development of Software package for forecasting in the field

Local software development company Indicium Dynamics were employed to create a software platform for use with the NIR technology. The software platform was designed to demonstrate to growers how the tool works, and then with a log-in, provide an interface for entering vineyard details, capturing data, and reporting a bud fruitfulness prediction for each block analysed.

5.0 Results/Discussion

In this study the Raman method proved unsuitable for detecting inflorescences inside dormant buds. After attempting to alter the technique and bud preparation methods the technique was abandoned. Raman is a scattering technique, so based on theory could be an effective tool for obtaining spectra for buds. The instrument we had access to for this trial was not well suited for this application due to the highly focussed laser used for microscopy. Newer, portable Raman instruments have a less focussed laser so may well be better suited to the application, and in turn could give promising results. Further investigation into the application of Raman for bud fruitfulness prediction is warranted.

Bud Fruitfulness prediction using NIR scanning

An MPA benchtop NIR and Ocean Optics Jaz portable device were compared in predicting fruitfulness in the laboratory using excised buds of Pinot Noir and Chardonnay.

Figure 1 demonstrates typical raw spectra obtained from the Bruker MPA instrument and Figure 2 shows Error Mean Square Correction spectra obtained from the same instrument.

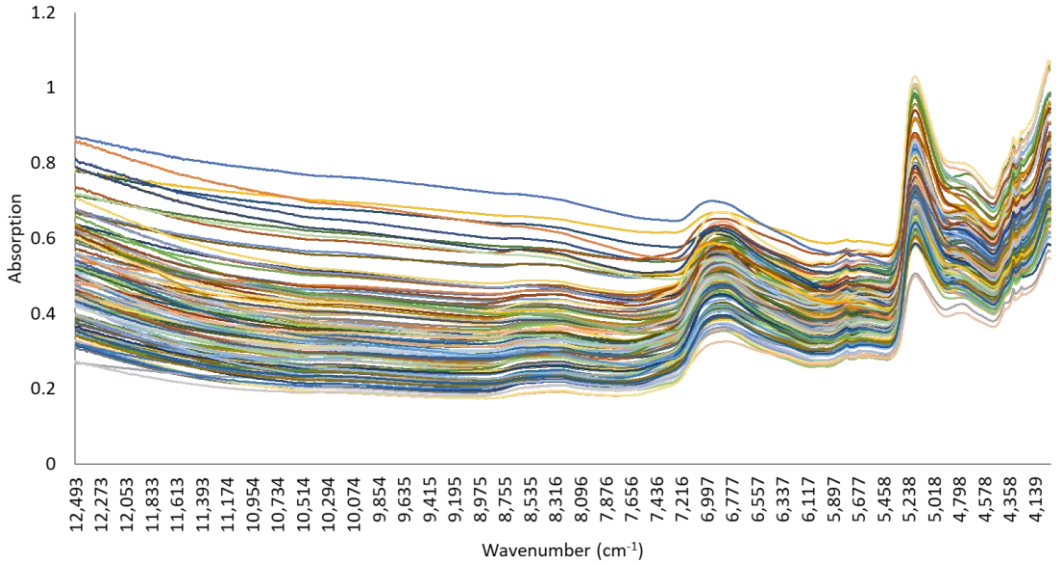


Fig 1: Typical raw spectra of buds obtained using the Bruker MPA instrument.

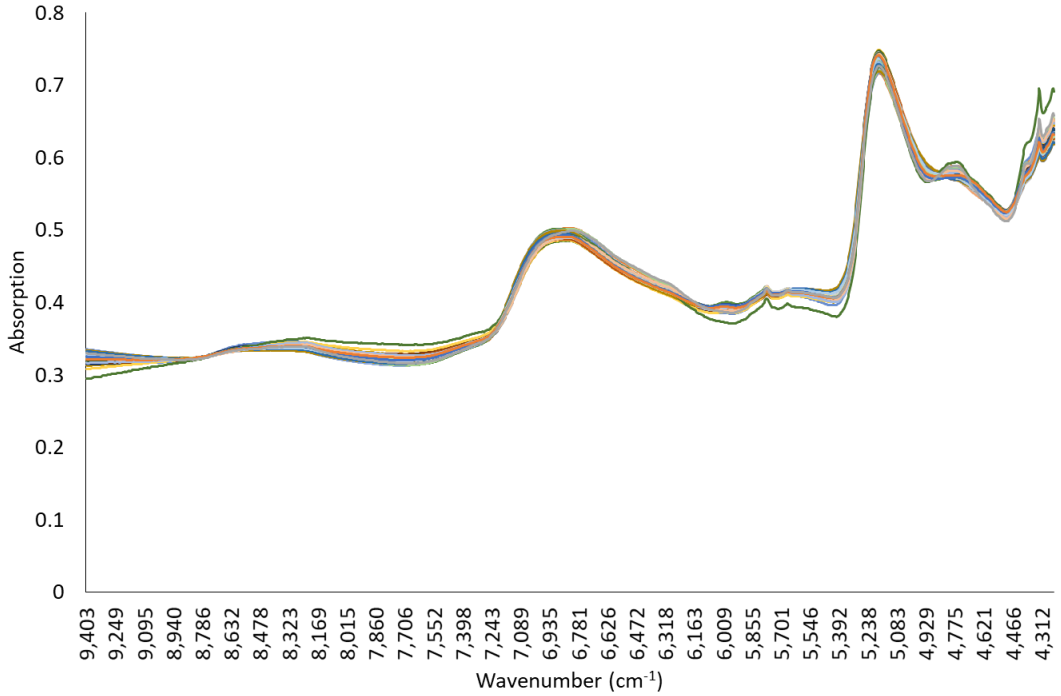


Fig 2: Typical EMSC spectra of buds obtained using the Bruker MPA instrument.

Spectra were used to build the model and then to predict accuracy. When using the Bruker MPA scans, separating variety did not improve the accuracy of the model. The greatest driver appeared to be vintage variation. The accuracy of prediction using the Bruker MPA instrument for the four seasons of analysis of excised buds and ground truthing against actual bud fruitfulness using bud dissection are presented in Tables 1 a-d.

Table 1: Confusion matrix for Bruker MPA benchtop instrument optimised at 20 principle components a) 2016 Pinot Noir and Chardonnay data, demonstrating an accuracy of 79.50% b) 2017 Pinot Noir and Chardonnay data, demonstrating an accuracy of 66.37% c) 2018 Pinot Noir and Chardonnay data, demonstrating an accuracy of 66.87% d) 2019 Pinot Noir and Chardonnay data, demonstrating an accuracy of 97.32%

a)

	2016-20PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	54	5	2	
	2	3	97	25	
	3	9	13	70	
	Accuracy	81.82%	84.35%	72.16%	79.50%

b)

	2017-20PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	63	27	24	
	2	9	94	12	
	3	6	34	64	
	Accuracy	80.77%	60.65%	64.00%	66.37%

c)

	2018-20PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	56	27	17	
	2	9	99	20	
	3	27	10	67	
	Accuracy	60.87%	72.79%	64.42%	66.87%

d)

	2019-20PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	43	0	0	
	2	0	36	1	
	3	2	0	30	
	Accuracy	95.56%	100.00%	96.77%	97.32%

When employed in the laboratory setting using excised Pinot Noir and Chardonnay buds the Ocean Optics Jaz instrument produced spectra such as that shown in Figure 3.

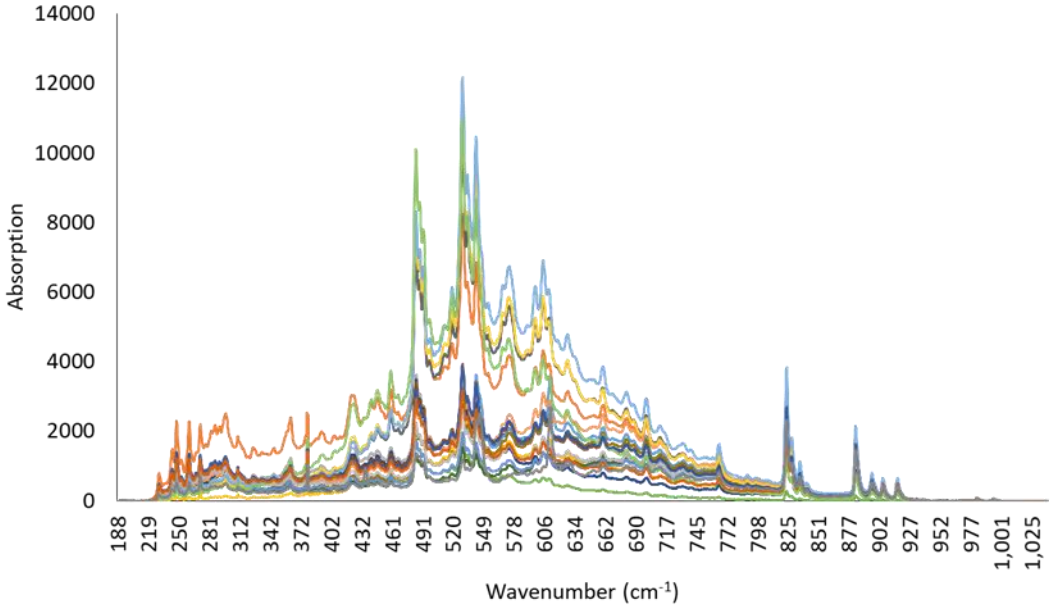


Fig 3: Typical raw spectra of buds obtained using the Ocean Optics Jaz instrument in the laboratory using excised buds.

Jaz spectra were used to build the model and the accuracy for predicting the bud fruitfulness reported. The accuracy of prediction using the Ocean Optics Jaz instrument for the three seasons of analysis of excised buds and ground truthing against actual bud fruitfulness using bud dissection are presented in Tables 2 a-c. 2016 scans are not included as a different Jaz instrument was used and the spectral data is not compatible with the following 3 years.

Table 2: Confusion matrix for Ocean Optics Jaz instrument a) 2017 Pinot Noir and Chardonnay data combined, optimised at 15 principal components demonstrating an accuracy of 60.7% b) 2018 Pinot Noir and Chardonnay data, optimised at 12 principal components demonstrating an accuracy of 53.2% c) 2019 Pinot Noir and Chardonnay data, optimised at 10 principal components demonstrating an accuracy of 53.6%

a)

	15PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	32	5	1	
	2	26	43	0	
	3	18	16	27	
	Accuracy	42.1%	67.2%	96.4%	60.7%

b)

	12PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	68	24	11	
	2	39	54	14	
	3	31	37	55	
	Accuracy	49.3%	47.0%	68.8%	53.2%

c)

	10PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	19	2	0	
	2	17	23	4	
	3	19	10	18	
	Accuracy	34.5%	65.7%	81.1%	53.6%

In 2017 the Ocean Optics Jaz instrument was used in the field to scan Chardonnay bud fruitfulness. The typical raw spectra obtained from the Ocean Optics Jaz NIR instrument in the field was the same as shown in figure 3.

When the Ocean Optics Jaz instrument was used in the field, the spectra obtained were used to build a model and the accuracy for predicting the bud fruitfulness reported. Confusion matrices showing the accuracy of prediction using the Ocean Optics Jaz instrument for analysis of buds in the field and ground truthing against actual bud fruitfulness recorded at flowering the following December are presented in Tables 3 a & b.

Table 3: Confusion matrix for Ocean Optics Jaz instrument a) 2017 Chardonnay data, optimised at 8 principle components demonstrating an accuracy of 75% b) 2018 Pinot Noir data, optimized at 6 principal components, demonstrating an accuracy of 68%

a)

	2017-8PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	12	2	0	
	2	2	10	0	
	3	2	6	14	
	Accuracy	75%	56%	100%	75%

b)

	2018-6PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	8	0	0	
	2	3	0	8	
	3	1	0	9	
	Accuracy	67%	100%	53%	68%

With the Ocean optics Jaz instrument the UV wavelengths were not used to avoid interference from surface effects and only the more penetrating short visible and NIR wavelengths were used. The Bruker MPA uses longer wavelength NIR which are more penetrating. The Bruker has the advantage that it is a Fourier Transformed instrument, resulting in a high spectral resolution and high signal to noise spectra.

In 2018 the ARCoptics Rocket portable FT-NIR was also used in the field. Figure 5 demonstrates typical raw spectra obtained from the ARCoptics Rocket portable NIR instrument and Figure 6 shows Error Mean Square Correction (EMSC) spectra obtained from the same instrument.

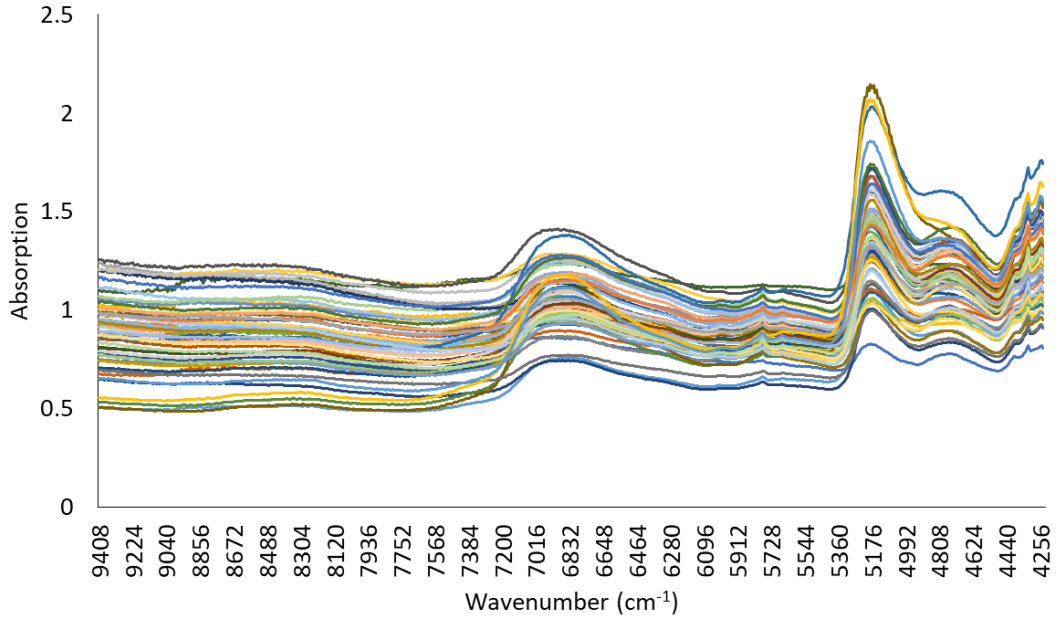


Fig 5: Typical raw spectra of buds obtained using the ARCoptics Rocket portable instrument

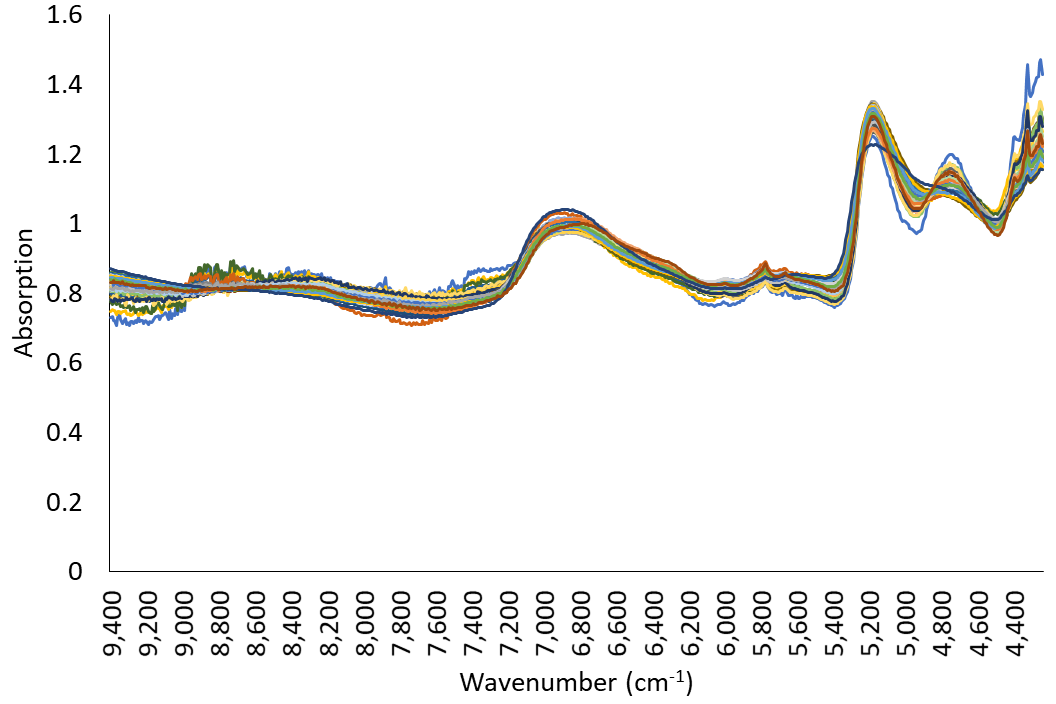


Fig 6: Typical EMSC spectra of buds obtained using the ARCoptics Rocket portable instrument.

The confusion matrix showing the accuracy of prediction using the ARCoptics Rocket portable instrument for analysis of buds in the field and ground truthing against actual bud fruitfulness at flowering the following December are presented in Tables 4 a & b.

Table 4: Confusion matrix for ARCoptics Rocket portable instrument a) 2018 Pinot Noir data only, optimised at 10 principle components demonstrating an accuracy of 100% b) 2019 Pinot Noir and Chardonnay data combined, optimized at 19 principle components, demonstrating an accuracy of 79.65%

a)

	2018-10PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	15	0	0	
	2	0	12	0	
	3	0	0	23	
	Accuracy	100.00%	100.00%	100.00%	100.00%

b)

	2019-19PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	72	1	0	
	2	2	45	0	
	3	31	1	20	
	Accuracy	68.57%	95.74%	100.00%	79.65%

In 2018 when Pinot Noir buds were analysed in the field it became apparent that particular care needed to be taken when scanning buds due to the frequent occurrence of double compound buds. The number of proximal nodes bearing double buds is reported to be cultivar-dependent with Pinot noir having the most, followed by Cabernet sauvignon, Syrah, Merlot and Chardonnay (only occasionally) (Sanchez et al, 2009). Usually the prophyll subtending each compound bud grows sufficiently to cover most of each bud, but in some cases the prophyll from the larger bud may almost completely cover both buds making the entire structure appear as one normal bud (Sanchez et al, 2009). It is possible that some of the error of prediction in modelling could have been caused by the presence of double compound buds, particularly when scanning buds in the field.

When using the Ocean Optics Jaz instrument, it became apparent through the PCA loadings that only a small number of NIR wavelength were required to achieve an optimal model. Further modelling using just 12 wavelengths showed improved accuracy of prediction in most cases. Confusion matrix for the models using just twelve wavelengths are shown in Table 5.

Table 5: Confusion matrix for the Ocean optics Jaz instrument using 12 wavelengths a) 2017 Chardonnay data, optimised at 12 principal components demonstrating an accuracy of 87.5% b) 2018 Chardonnay data, optimised at 9 principal components demonstrating an accuracy of 92% c) 2019 Chardonnay data, optimized at 10 principal components, demonstrating an accuracy of 79.3%

a)

	12PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	15	3	0	
	2	0	13	0	
	3	1	2	14	
	Accuracy	94%	72%	100%	87.5%

b)

	9PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	12	0	2	
	2	0	15	0	
	3	0	1	15	
	Accuracy	100%	94%	88%	92%

c)

	10PCs	Actual			
	Category	1	2	3	Overall
Predicted	1	32	1	0	
	2	22	18	0	
	3	0	0	11	
	Accuracy	59%	95%	100%	73%

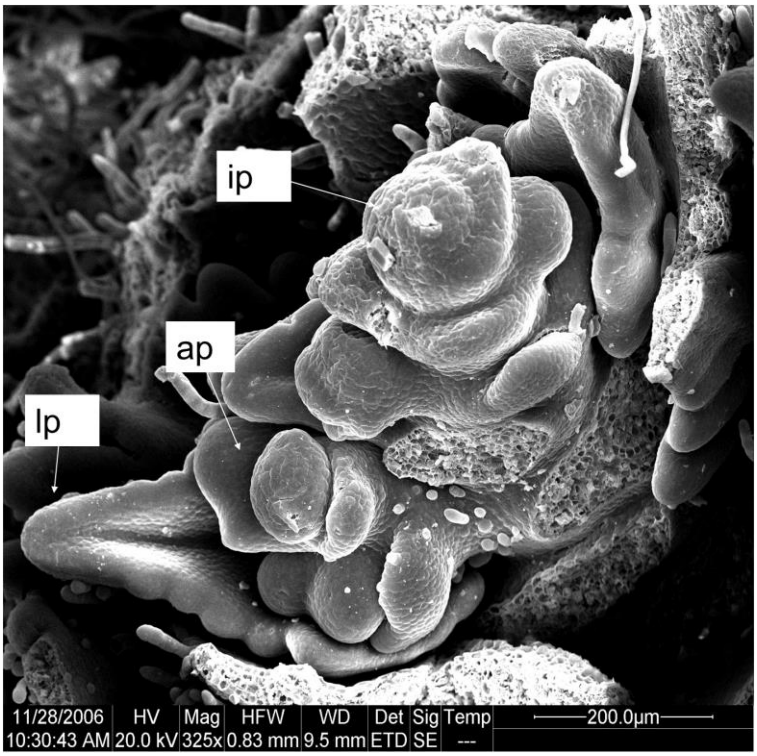
The success of using a small number of wavelengths opens the possibility for a cheap custom-built device based on LED's to provide the critical wavelengths. Analysis of spectral processing methods indicated that second-derivative or scatter correction processing was not required, validating the use of raw spectra and making the processing less complex.

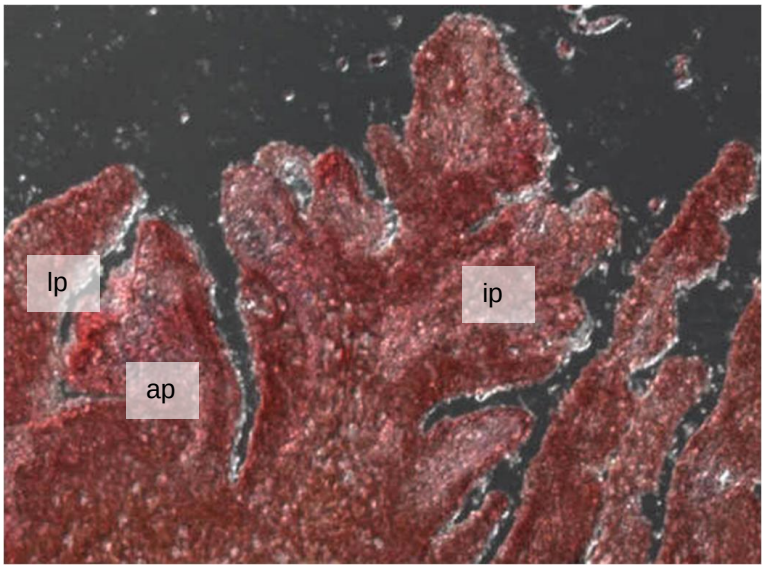
Discriminate Analysis (DA) provided the highest level of accuracy of prediction, using PCA scores to reduce the spectra data to a small number of orthogonal components that best described spectral variance. Non-linear discriminant analysis and kernel-fitting algorithms such as Support Vector Machines using PCA scores, rather than whole spectra, were successful. Partial Least Squares (PLS) calibrations to predict numerical size were unsuccessful, most likely due to a large degree of non-linearity.

In nearly all cases the majority of errors in prediction of fruitfulness were in an adjacent category (for example the model incorrectly predicted a high level of fruitfulness when the actual fruitfulness was medium). Part of the problem may be that the diameter of the excitation beam is too small to span a whole inflorescence and/or may also sometimes miss the inflorescence.

The highest degree of error across all years was in the low fruitfulness category. It may be that the signal arising from the shoot apex inside the bud is not adequately compensated for in the model. When dissecting buds microscopically it can be seen that small inflorescences and the shoot apex can be a similar size, and careful consideration is required to distinguish between them in some cases. The location of various structures is shown in Plate 10 a & b.

Plate 10 a) Inflorescence primordium, shoot apex and leaf primordia present in a bud. b) Apical section of a shoot primordium, showing shoot apex (ap), inflorescence primordium (ip) and leaf primordium (lp) (mag 10x)





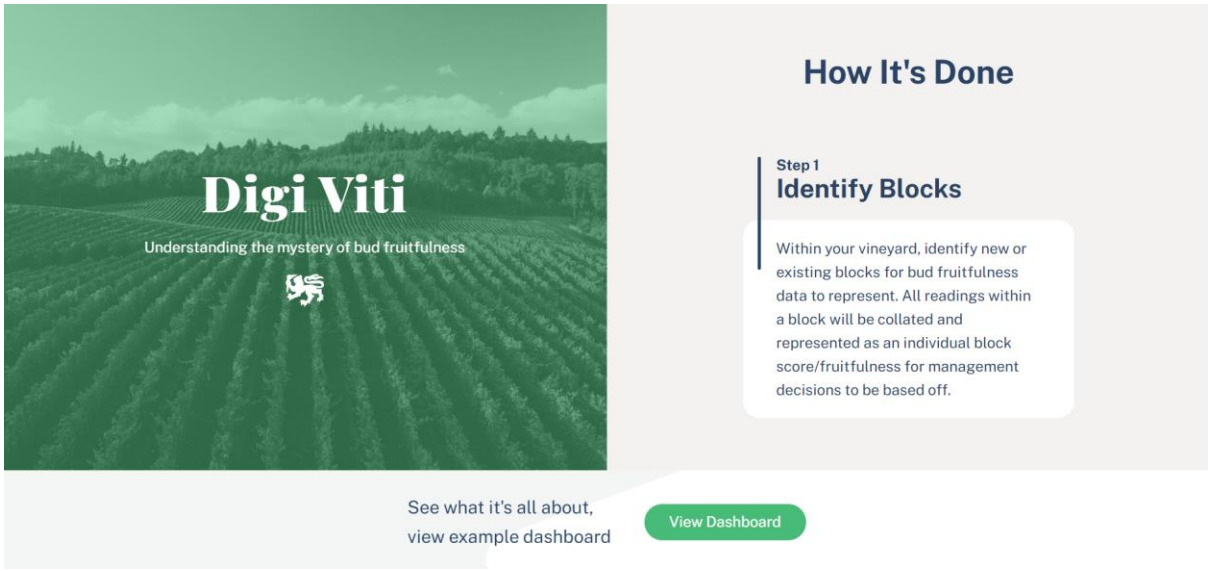
In the first two sampling years there were not enough unfruitful buds (ie zero inflorescences) to create their own category of fruitfulness. In 2018 there were sufficient empty buds to create a category of their own and when calibrations were prepared using ‘yes’ or ‘no’ for presence of inflorescences the prediction rate was 80% correct, suggesting that although predicting size may be difficult, detecting the presence of an inflorescence is more accurate. Size prediction may be more accurate with a larger, custom-built probe.

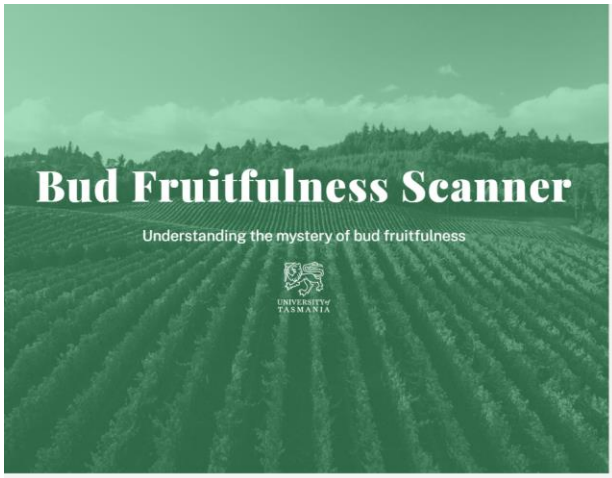
Development of Software package for forecasting in the field

A web-based platform has been developed to demonstrate to industry how a commercialized bud prediction tool could be utilised. The site can be found at https://digiviti.indicium.cloud/
This platform is designed to be used either as a website from a laptop or desktop in the vineyard office, or alternatively via a smartphone.

The opening page introduces the tool to a potential user and provides a basic 8 step process for using the tool in their business. Sponsors and funders are clearly displayed at the bottom of this landing page. If the potential user is interested to read more, they can click on the ‘view dashboard’ tab. This part of the website provides mock data to demonstrate how the process would be used in a business for decision making. This is all modelled around the Tolpuddle vineyard site, but in the final commercialized product would be personalized site information.

Plate 11 Various screen shots of the website which demonstrates the tool.





Step 5

Load Data to Cloud

Once all assessments are complete, the data can be uploaded to the website/app when the instrument has internet access. The program will automatically calculate the predicted fruitfulness and represent it both graphically and numerically in a traffic-light 'low, medium or high' scale on the website map and dashboard dropdown list respectively.



See what it's all about, view example dashboard

View Dashboard

See what it's all about, view example dashboard

View Dashboard

tia Tasmanian Institute of Agriculture

University of Tasmania | Tasmanian Government

TIA is a joint venture of the University of Tasmania and the Tasmanian Government

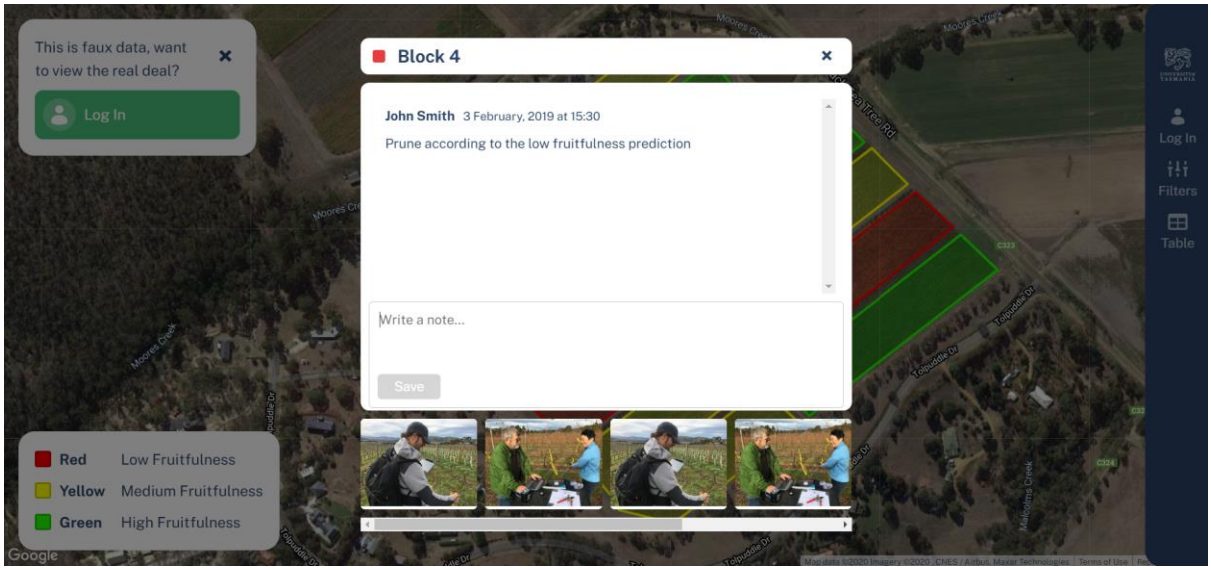
CSL Central Science Laboratory

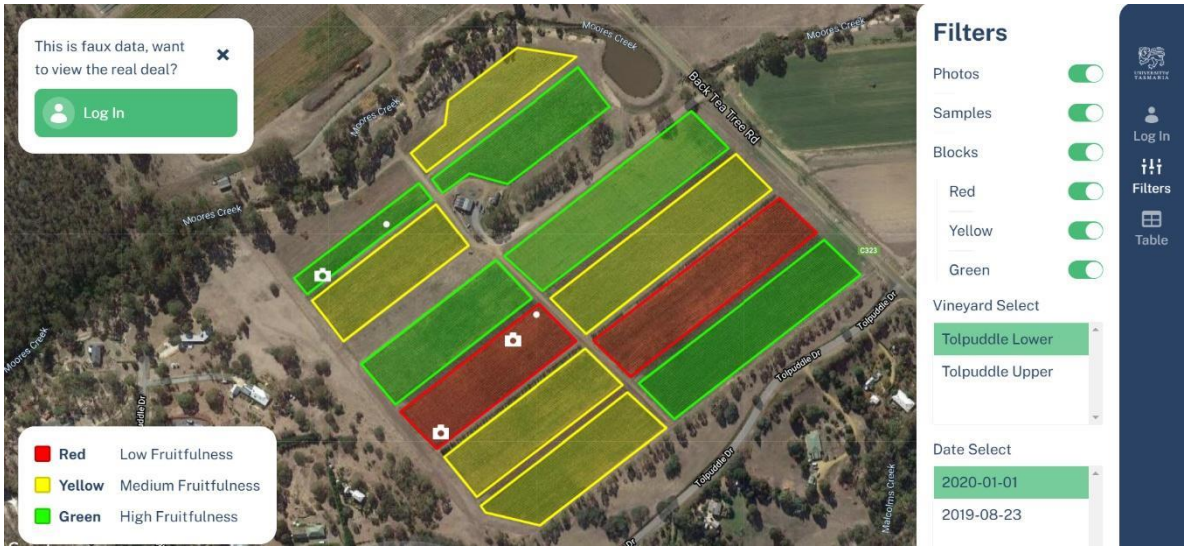
Lastek Photonics Technology Solutions

Shaw + Smith

Wine Australia

wineTQ





To accompany this software a YouTube clip has been created to allow concise grower-friendly communication of the research outcomes and the proof of concept software development. The YouTube clip can be accessed at https://www.youtube.com/watch?v=https://www.youtube.com/watch?v=fAa1MnR26yY

Neither the webpage nor the YouTube link have been approved by University of Tasmania nor the Department of Agriculture, Water and Environment, so are not yet ready for public sharing. Approval from the two organisations could be obtained as soon as Wine Australia agrees.

6.0 Outcome / Conclusion

The primary research objective of this study, 'to provide a proof of concept for the identification of bud fruitfulness by spectral analysis', was achieved. Modelling of NIR spectral fingerprint information of buds demonstrated that it was possible to predict the fruitfulness of buds at an acceptable level of accuracy.

Three different NIR instruments were trialled and all were able to predict bud fruitfulness, without modification of the buds. This was based on modelled spectral scans obtained from excised buds compared against actual bud fruitfulness measured by a microscopic bud dissection technique.

In the vineyard, a model utilising spectral scans from the off-the-shelf portable ARCoptics Rocket and the Ocean optics Jaz instruments were able to predict fruitfulness of buds. This represents achievement of the second aim of this study which was to 'Demonstrate the feasibility of prediction of bud fruitfulness prior to pruning through the use of a portable hand-held device'. The current data was produced within various patches of a particular vineyard trial site in the Coal River Valley. Further work is warranted to produce global models that incorporate data from additional sites and vintages.

The success of using a small number of wavelengths in the modelling process opens the possibility for the development of a low-cost, custom-built device based on LED's that can provide the critical wavelengths. Confirmation that spectral processing was not required, and that the use of raw spectra was effective for modelling, also suggests that a simple NIR tool for predicting bud fruitfulness is an option. It is anticipated that the results of this project can inform a final investigation aimed at commercialisation and the custom manufacture of device available to industry at an affordable cost. There may be other applications in the vineyard or winery for a portable NIR instrument. NIR spectroscopy can predict vine starch reserves (Jones et al, 2020), berry pH and Brix (Larrain et al 2008) and volumic mass and reducing sugars in white wine (Fernandez-Novales et al, 2008). The likelihood of multi-use application improves the attractiveness of the purchase of such an instrument by wine business.

The ability to predict bud fruitfulness early in the season is a high priority for the Australian wine industry and appears to be achievable based on this research. This represents achievement of our third research aim which was to 'Encourage avoidance of a blanket approach to pruning'. If our findings can be commercialised, a blanket approach to pruning could be avoided via decision support tool that would lead to a reduction in late season bunch removal for achieving target yields, and in turn greater fruit quality and industry profitability. The development of the web-based tool realises the achievement of our final research aim which was to 'provide useful decision support which would lead to a reduction in late season bunch removal for achieving target yields'.

This research has provided a proof of concept of non-destructive and rapid prediction of bud fruitfulness, as well as the development of a tool to allow the provision of pruning decision support to vineyard managers. The ultimate outcome could be the alleviation of the negative impacts of excessively high and excessively low yielding years.

7.0 Recommendations

The key recommendations arising from this study are:

- Further investment to enable commercialization of the bud fruitfulness prediction tool to enable industry uptake and the realization of benefits to industry
- Further research into the application of the tool to other varieties (note that there is no reason why the model would not be effectively when applied to other grapevine varieties).
- Further work in other sites is required to prepare robust prediction models, including deliberate modelling to improve accuracy for varieties with frequent occurrence of double compound buds.
- To date a global mode of prediction of sufficient accuracy has not been possible, and new models have been developed for each season. Ongoing work is necessary to build a sufficient data base that will support the development of a global model that can overcome the effects of seasonal variability. Indeed this may be more easily achieved in warmer viticultural sites where the effects of vintage are not as extreme.

8.0 Appendix 1: Communication

8A: Communication with industry

1. **Taking yield forecasting into the digital age, Wine Australia, June 2017.**

https://www.wineaustralia.com/news/articles/taking-yield-forecasting-into-the-digital-age?utm_source=Wine+Australia+RD%26E+News&utm_campaign=12cd8c5636-RD_E_News_June_2017&utm_medium=email&utm_term=0_440931c1c7-12cd8c5636-210379605

1. **Alderton, M. (2018). Vine of the Times: Winemakers Discover a New Taste for Tech. *PM Network, 32*(5), 56–63.**

2. **Wine and Viticulture Journal, Spring 2018**

VITICULTURE | CROP PREDICTION

Taking yield forecasting into the digital age



Thomas Rodemann trials a new portable NIR device to scan Pinot Noir buds at Shaw and Smith's Tolpuddle vineyard, in Tasmania's Coal River Valley. Devices such as these are easily carried in a backpack and can be controlled with a tablet mounted on the user's chest.

The regulation of grapevine yield is a common goal for growers, viticulturists, winemakers, and sales teams alike. In addition to informing the regulation of yield, the inability to accurately forecast yield has substantial economic consequences relating to pre-harvest crop reduction, harvest planning, price negotiations, intake scheduling, tank space allocation, capital investment and the development of marketing strategies.

For the past 15 years Dr Joanna Jones, from the Tasmanian Institute of Agriculture, has been working with Tasmanian grapegrowers at pruning time, using her expertise in reproductive biology and knowledge of bud fertility to help them make informed pruning decisions. Many producers send bud samples off to dissection services each year to receive information about bud fruitfulness to allow them to plan the coming vintage.

Developing a method to predict bud fruitfulness without the need to remove buds, dissect them and inspect under the microscope was the goal. The launch of Wine Australia's Digital Viticulture Rural R&D for Profit Program last year means those plans are now a reality. While success is not a given, the early results are encouraging.

The aim is to use near infra-red (NIR) technology to determine bud fruitfulness and then to create a simple tool growers can use to store and translate data. It's a complex project that requires a team of researchers.

Dr Jones, who is part of the Grape and Wine Science Group at the Tasmanian Institute of Agriculture, is working closely with Dr Thomas Rodemann, who is a specialist in spectroscopy, and Dr Bob Dambergs, who has extensive knowledge in the application of spectroscopy to novel applications.

NIR technology has been used for a variety of applications in the fruit industry including sorting machines to sort fruit for ripeness through the skin. It has also been used in the wine industry, for example to measure alcohol, or a more specialised application for grapes, to measure Brix and anthocyanin concentration. The technology had not been applied to measure bud fruitfulness inside woody canes in the vineyard before.

The first stage of the project, which began in August 2016, was to validate that the scanning technology could find the right mass of tissue and give a reading. Buds are protected by a woody scale on the outside and there is also a lot of developing leaf tissue and an enormous number of protective hairs in the way.

"We were looking at different techniques of pulling scales off, leaving scales on, to make sure we are picking up the right mass inside the bud," Jones said. "We then ground truth that with actual bud dissections under the microscope, as you would traditionally do them". The early trials showed promise.

"We then needed to look at all sorts of other parameters that can affect bud





Bob Dambergs and Joanna Jones scan Chardonnay buds which will be returned to after budburst to record actual inflorescence number and size.

fruitfulness; for example, can we only detect the number of bunches or would we be able to detect approximate size? We needed to see if these parameters can strengthen the model, or just complicated it."

One of the challenges is that to create a tool that is applicable and valuable to industry, the team needs to do a year's worth of work crammed into pruning time. "It gives us a short window each year to collect data and then play around with that for the rest of the year. In the true style of agricultural research, we are confined by seasons."

Subsequent seasons have seen the team test different devices, ranging from a MPA Bruker bench-top device through to portable devices able to be used in the vineyard.

"Each winter we sample hundreds of buds of Pinot Noir and Chardonnay, scan them with the different NIR devices and then dissect the buds and record the number and size of the inflorescences. We also record information like bud necrosis or damage. When sampling the buds, we hope we are getting a variety of fruitfulness levels, ranging from no inflorescences through to highly fruitful buds. The data is incorporated into the model and discriminate analysis is performed."

> "For us, the highlight is in hopefully finding a way to help growers deal with the year-to-year fluctuations in bunch numbers that is a real problem."

This winter the team is expanding their field trial, where they are tagging buds on the vines, scanning them, then returning towards the end of the year to record actual inflorescence number and size.

"We are hoping the model holds up for this part of the trial which is non-destructive and has huge potential as a method for growers to use".

"For us, the highlight is in hopefully finding a way to help growers deal with the year-to-year fluctuations in bunch numbers that is a real problem."

"It puts pressure not only on their bottom line in terms of the yields that they can achieve, but also down the chain in intake scheduling in the winery, and even marketing and sales," Jones said. "Being able to more accurately predict the yield that is coming their way can only have massive advantages."

This project is supported by The University of Tasmania, through funding from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit program and Wine Australia.

3. Precision Ag News, Winter 2019, Issue 4 pages 12 and 13

Tool cuts destructive pruning

Rebecca Thyer



Researcher Thomas Rodemann uses a portable device as part of Tasmanian research to help wine producers make more informed pruning decisions.

Vineyard pruning decisions could soon be made with NIR technology, moving away from an often costly and destructive process.

By bringing together researchers with skills in physics, biology and agronomy, a team in Tasmania is building a non-destructive and time saving vineyard tool to determine potential yield.

Team leader Dr Joanna Jones from the Tasmanian Institute of Agriculture (TIA) has worked with Tasmanian Pinot Noir and Chardonnay grape growers for more than 15 years helping them to make more informed pruning decisions to manage yields. Her latest work aims to improve that process through technology.

Fruitful techniques

Selective vineyard pruning is a technique undertaken to manage vine growth and is based on estimating bud fruitfulness. To measure this attribute, grape growers remove buds from vines and either dissect and count them themselves using a microscope or send them to a service provider.

The aim is to count how many potential bunches (the number of inflorescence primordia; IP) are in each bud. There can be up to three viable IP, but in some cases none, if the IP are dead (necrotic). The number of viable IP per bud is a measure of the vine's fruitfulness for that season.

This information is useful for estimating the potential yield at harvest. Research shows that the number of bunches per vine accounts for about 60% of seasonal yield variation.

Grape growers use this information to manage the coming yield by selectively pruning vineyards. "Based on the bud count a grower may decide to leave 12 buds per vine, for example, as they know this gives a potential yield of 10 tonnes to the hectare'," Dr Jones says.

However, the process of bud counting is usually costly, destructive and requires microscope skills and some growers choose not to make the effort.

"The number of bunches per vine accounts for 60% of seasonal yield variation."

Novel NIR use

Near-infrared reflectance (NIR) measures wavelengths in the near infrared region of the electromagnetic spectrum that are scattered off and through a sample. The readings are compared to a reference database and allow a material's properties to be quickly determined without altering or destroying the sample. This technique is widely used in laboratories to measure fodder and grain quality.

Dr Jones is using NIR spectroscopy as part of her research with the TIA's Grape and Wine Science Group. She works with spectroscopy specialists Dr Thomas Rodemann and Dr Bob Dambergs. TIA's carbohydrate ecophysiology expert Associate Professor Dugald Close also contributes to the project.

The team is using NIR spectroscopy to measure the vibration from organic material. These unique spectral outputs are compared to the known vibration patterns for potential bunches of grapes and converted to bunch number.

Dr Jones explains: "The vibration of hydrogen atoms attached to oxygen, nitrogen or carbon, produces a signal when you scan an organic material. Using this information, a graph is produced that our model interprets to give a simple output on bud fruitfulness."

The end product will give growers a number that would predict how many bunches, on average, are expected on grape vines across the particular vineyard.

Once this tool is commercially available, as a hand-held or vehicle-mounted device, it will have the advantage of being non-destructive, quicker and less costly than existing dissection methods. It will also give growers useful information about the performance of blocks within their vineyard.

"In a well-managed, uniform vineyard, there are not many management variables," Dr Jones says. "However, you may notice differences in IP number due to variation in seasonal growing conditions, or differences in sections due to waterlogging or wind. You may also detect fruitfulness issues associated with bud mites or necrosis. This is where our tool could be very helpful. By collecting data on those variables and recording it spatially, growers can start to make

other management changes at other spatial levels, to address these issues."

The main goal – to improve pruning decisions in order to manage yield expectations - is also in itself very valuable. "Growers will be able to make more informed decisions with contract winemakers or with others in the industry. For example, they will be able to more accurately predict whether they are likely to expect high or low yields that season and act accordingly ahead of time."

Validation

The team began working on the project in August 2016. The first stage was to validate that the scanning technology could find the right tissue mass and give a reading.

Dr Jones says this step was important because of protective woody scales on the outside of vine buds. There is also developing leaf tissue and a large number of protective hairs to contend with. "So it was uncertain that scanning technology would accurately pick up the correct tissue."

To address that, the team looked at different techniques – pulling scales off and leaving scales on – to make sure scanning would pick up the right mass inside the bud. "We are confident we can leave bud scales on, thereby making the tool easy for growers to use."

Ground truthing followed. Thousands of spectral scans were compared with actual bud dissections. Dr Jones says the early trials showed promise. The next phase considered whether other parameters that affect bud fruitfulness, such as bunch size, could be included. Dr Jones says the results were positive and bunch size was detectable via NIR scanning.

The team tested different devices across the seasons, ranging from a FT-NIR MPA Bruker bench-top device to portable devices that are capable of being used in the vineyard. (A Jaz Ocean Optics Spectrophotometer and FT-NIR ARCoptix Rocket portable device were assessed).

Fieldwork is always ongoing during the short winter vine-dormancy period each year. Last winter (2018) the team expanded its field trial, tagging buds on vines, scanning them, then returning towards the end of the year to record actual bunch number and size.



Dr Bob Dambergs and Dr Jones using the Jaz spectrophotometer as part of their research into detecting bud fruitfulness

"We have taken thousands and thousands of samples and have confidence in what we are seeing and predicting. Now it is a matter of turning that into a tool.

"After another year of field trials, we will turn the model into something growers can use by working with a software and commercialisation group."

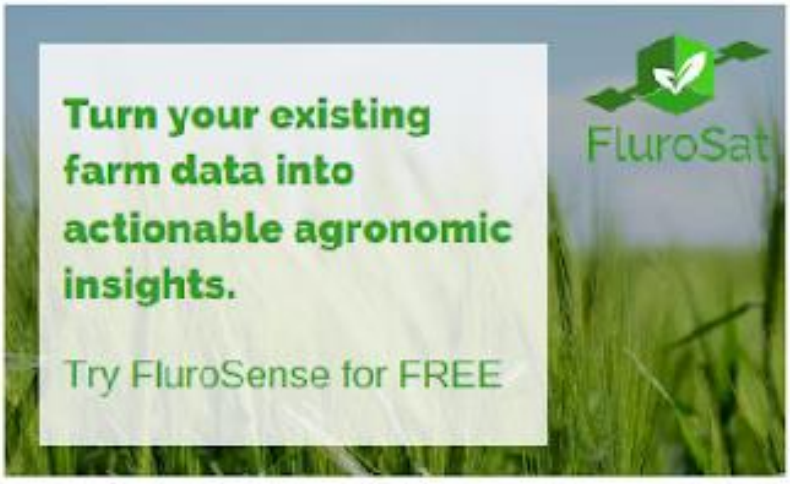
In the future Dr Jones would like to expand the tool to incorporate other varieties and regions. "We are working with two varieties in a cool climate. Our fruitfulness is lower than regions such as the Barossa Valley (South Australia), but the model should be able to be expanded to suit those regions as well. It could also be used internationally or by other grape growers, like sultana producers."

This project is supported by The University of Tasmania, through funding from the Australian Government Department of Agriculture and Water Resources as part of its Rural R&D for Profit program and Wine Australia.

Biography

Dr Joanna Jones is a lecturer and researcher at the Tasmanian Institute of Agriculture (TIA).

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4. **936 ABC Hobart, Thursday August 22, 2019**

https://mms.tveyes.com/ProgramSummaryView.aspx?ProgramSummaryItemID=f3f1528d-2fd7-4ab9-8085-dc959ce34e19

5. **Weekly Times: Tasmanian Country, August 23, 2019**

Full page feature: Page 28

Way to grape expectations

CUPPA TIA

A TINY piece of tech could make a big difference to the bottom line of vineyards across Australia.

In a world first, researchers at the Tasmanian Institute of Agriculture have discovered a new way to use existing infrared technology for rapid in-field prediction of grape yield.

This could mark the end of the time-consuming and expensive manual bud dissection currently required for growers to plan their vineyard and winemaking operations, particularly pruning.

A large vineyard can spend up to $150,000 a year on manual bud dissection to inform decisions on pruning and predict yield.

TIA senior research scientist Joanna Jones said a key advantage of the technology was the speed and non-destructive nature of measurement.

"Manual bud dissection is a time-consuming operation that requires skilled labour with only a small window of opportunity when buds are suitable," Dr Jones said.

"With many vineyards now selling their grapes under contract, an accurate yield forecast will allow growers to make pruning and planning decisions informed by predicted fruitfulness, a win-win for grower and winemaker.

"This is financially powerful information as it flows across all subsequent grape-growing operations and through to the winery. This can range from the number of bins needed for harvest to tank space allocation in the winery."



QUICK READ: TIA researcher Joanna Jones is studying using infrared technology to predict yields from wine grapes.

Dr Jones says while the technology is not new, the application in crop forecasting is.

"The bud scanner uses Near Infrared Reflectance to emit wavelengths invisible to the human eye that make the organic material in the bud vibrate, bouncing back a unique wave pattern to the detector.

"The clever science is the computer modelling matching this wave pattern to the number of flowers in the bud."

The research team was able to adjust the accuracy of the tool after a long process of manual testing.

"Over the last three seasons, we NIR-scanned and then manually dissected thousands of grape buds to ground truth what a dormant grape bunch looks like as a spectral fingerprint," Dr Jones said.

The inspiration for testing the technology came from a serendipitous moment when Dr Jones was hand dissecting buds in the laboratory alongside wine spectral specialist Bob Dambergs.

Dr Dambergs' suggestion that this technology could potentially be used in the field was a lightbulb moment.

They partnered with University of Tasmania spectral chemist Thomas Rodemann, Shaw and Smith's Tolpuddle vineyard and Lastek technology solutions to test the idea.

"Our next goal is to take this one step further to see if we can also detect bunch size, and the results looking very promising," Dr Jones said.

"We anticipate that the bud scanner will be made commercially available as a hand-held device."

Dr Jones said the bud scanner could offer growers useful information about the performance of individual blocks within their vineyard.

"You may see differences in sections of a block due to waterlogging or wind. You may also detect fruitfulness issues associated with bud mites or disease. By collecting this data growers can start to make targeted management changes to address these issues", she said.

The project is supported by UTAS through federal research funding and Wine Australia.

6. **VINEX**

https://en.vinex.market/articles/2018/08/13/australian_researchers_develop_technology_to_forecast_yields_without_having_to_take_samples

8B: Communication with scientific community

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9.0 Appendix 2: Intellectual Property

This project has the potential to generate considerable intellectual property. The current research team would like to enter into discussions with Wine Australia to ascertain the appetite for further work to progress commercialisation of the research and development of a tool ready for use by industry.

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