Horticulture Innovation Australia

Final Report

Determining and establishing quality parameters for Australian Walnuts

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Australian Walnut Industry Association

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WN11001

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Summary

The rapidly increasing Australian walnut crop will provide some interesting marketing challenges as production will greatly exceed the Australian domestic market demand.

Locally produced Walnuts have always had an edge on quality over most of the imported nuts. It will be important to maintain and improve this facet of the Australian crop to meet the forthcoming market competition on both the domestic and export markets.

Much of what affects Walnut flavour and quality is determined by the timing of the harvest and the subsequent drying and storage conditions. Timing, temperature and humidity are three vital factors affecting the eventual conditions of the kernel. Each of these factors will have a vital affect on the eventual nature of the oils in the kernel and the flavour either developed or destroyed.

The objective of this project was to "maintain and improve the quality of Australian walnuts to meet market competition in both the export and domestic markets" through the development of agreed quality parameters, test them with a group of growers through participatory research and then transfer the information to the broader group of growers within the Australian walnut industry

Participatory Research was the major phase of the project. The Tasmanian Institute of Agriculture (TIA) researchers designed the methods in consultation with participants from Walnuts Australia, and the AWIA. In liaison with an AWIA appointed technical communications officer, the participants coordinated the day-to-day activities, and collected the data and information which was collated by the AWIA technical officer. Raw data was then sent to the TIA researchers, who were available for clarification on methodology, for analysis continuously throughout the investigation.

From the Participatory Research a set of agreed quality parameters and a range of „tools" to measure and record relevant information were developed. The publication "Quality Parameters for Australian Walnuts" is a collation of the quality parameters, methodology and templates for recording relevant information to measure the parameters.

The final part of the project was dissemination of the information and the materials developed to Australian walnut growers. Training sessions were conducted for some 35 growers where they were introduced to the Quality Parameters components and the documentation prepared including associated templates and colour plates.

As part of the ongoing role of the AWIA Technical Communications Officer all grower members will be introduced to the Australian Walnut Industry Quality Parameters and encouraged to utilise them as part of the 2015 harvest and beyond.

Introduction

The rapidly increasing Australian walnut crop provides some marketing challenges as production is forecast to exceed Australian domestic market demand.

Locally produced walnuts have always had an edge on quality over most of the imported nuts. It will be important to maintain and improve this facet of the Australian crop to meet the forthcoming market competition on both the domestic and export markets.

Much of what affects Walnut flavour and quality is determined by the timing of the harvest and the subsequent drying and storage conditions. Timing, temperature and humidity are three vital factors affecting the eventual conditions of the kernel. Each of these factors will have a vital affect on the eventual nature of the oils in the kernel and the flavour either developed or destroyed.

The monitoring and recording of these factors is required to be undertaken to assist the Australian walnut industry. Part of the work will be the periodic assessment of changes in the lipid characteristics of the kernel and how this is affected by different treatments and accurate recording of data loggers of temperature and humidity during drying and storage.

Methodology

1. Project Management and Consultation

   A project team comprising Colin Jack (Chair), Norm Wilkinson, Michael Burston, Kathy Evans (Tasmanian Institute of Agriculture TIA, & David McNeil TIA was established to define the parameters of the work to be undertaken, with Trevor Ranford and Mac MacArthur acting as Secretary/co-ordinator respectively.

   A grower working group of Norm Wilkinson, Colin Jack, Michael Burston, Alan Kubeil and Derek Goullet (Walnuts Australia) was also established.

2. Literature Review

   A literature review of walnut quality parameters was undertaken by Professor David McNeil and Dr Kathy Evans from TIA. The material was presented to the AWIA for review by the project team who collated the relevant material into the publication "Improved Management of Walnut Quality Factors under Grower Control" in 2014.

   The document was disseminated to all AWIA members during November 2014.

   The review findings were also published in the symposium proceedings of the VIIth International Walnut Symposium (held in China 20 -23 July, 2013) following a presentation by research scientist Harold Adem from the Victorian DPI"s Tatura Research Institute.

3. Sampling kernels to establish maturity and quality parameters

   Kernels were collected at the 2013 harvested and placed into storage on property and at an independent laboratory. Sampling of kernels were conducted by the grower panel at the point of harvest and then after 3, 6 and 9 months of storage.

   Project participants forwarded 300 g of kernel from the 2013 harvest to the Symbio-Alliance laboratory for free fatty acid and peroxide value analyses. Further samples were sent from the central storage samples from each orchard at 3, 6 and 9 months from harvest.

   The results of these tests have been reported by TIA in their final report to the AWIA, attached as an Appendix.

4. Documenting quality

   Grower workshop sessions were held to develop the collection and collation of appropriate data, and AWIA held a number of grower workshops throughout the life of the project at which the aspect of quality and quality parameters were discussed, reviewed, implemented and reviewed again.

   A draft methodology for assessing Australian Walnut Quality Parameters was approved for use by the grower working group in May 2013. Training sessions of the grower working group were held at the Victorian DPI Research Centre at Tatura during 2012. Draft documentation developed by TIA including a workbook and methodology for assessing quality were trialled and after several revisions were used during the 2012/13 season.

5. Participatory Research - involving a group of selected walnut growers in basic research

   Six walnut orchards in Victoria, New South Wales and Tasmania were involved in the participatory research which was managed by Kathy Evans and David McNeil from TIA. This is described fully in the report from TIA, attached as an Appendix.

6. Fatty Acid and Peroxide

   Determining an acceptable level was an important objective of the research, and a literature review was undertaken to establish a baseline. Samples of walnuts from the six participating growers were then analysed by Symbio-Alliance for Free Fatty Acid and Peroxide.

7. Postharvest assessment of hedonistic quality

   A recommendation from TIA following the participatory research was for participating growers to conduct a hedonistic quality assessment 6 -12 months after harvest of walnuts in central storage and on-farm. TIA undertook the data analysis and chemical testing to support the results. Samples from all six orchards were tasted and the analysis by TIA is attached as an Appendix.

Outputs

1. The AWIA reported on the status of the project at regular intervals during the life of the project including the:-

   a) Walnut Symposium held on Saturday 18th August 2012.

   b) Walnut Symposium held on Friday 23rd August 2013

   c) Walnut Symposium held on Saturday 23rd August 2014

2. Presentations were given by Professor David McNeil and/or Dr Kathy Evans from the Tasmanian Institute of Agriculture at each of the Symposiums. The relevant project presentations have been made available to walnut growers through the AWIA website, www.walnut.net.au.

3. Summaries of the progress with this project and the key outcomes were published in the AWIA monthly newsletter *The Kernel* circulated to around 100 AWIA members and other walnut growers and industry people. (Ref. „Update on the Walnut Quality Parameters Project" published in *The Kernel* March 2013 Vol.1 Issue 12). A further update will be published in the May 2015 e-bulletin of *The Kernel.*

4. "Improved management of walnut quality factors under grower control" – an industry booklet was collated from the literature review undertaken by Professor David McNeil and Dr Kathy Evans and has been distributed to members of the AWIA.

5. "Quality Parameters for Australia Walnuts" - a document was collated from the workbooks developed as part of the project and distributed to members of the AWIA. A full range of colour plates, record keeping templates and other associated forms have been prepared and are available for downloading and use by growers. The relevant colour plates have been formatted, printed, laminated and distributed with the Parameters document.

Outcomes

The major outcome from conducting this research is that growers have now have resources available for monitoring quality that are based on sound scientific principals.

Establishing Quality Parameters

At the outset of the project the parameters currently being monitored by growers which have an impact on quality were identified as moisture at harvest and after drying, colour, oil content, oil oxidization, flavour (bitterness), kernel shrivel and/or damage, shell cleanliness, and size

Additional factors that growers felt were essential to be considered in the project included:

a. Microbiological tests to ensure food safety - industry does not have established limits for these tests (E.coli, salmonella & listeria) and/or regulated (aflatoxins).

b. Other microbiological tests that do not present a food safety risk, but are indicative of quality.

c. Chemical residue tests should be performed on growers crops. As a very minimum there should be tests for residues for any chemicals applied to the crop.

d. Other Chemical parameters - Free fatty acid and Peroxide value are measured as indicators for rancidity, however there is evidence that walnuts can taste rancid and still have an acceptable peroxide value. Peroxide development appears to be related to storage temperature. Growers indicated that “the challenge for the industry was to build some relevant detail around these parameters that then can be used to assist growers at harvest, during drying and throughout the storage process”.

A range of other parameters were also considered essential but growers were not sure how they would be measured by growers in the field. These included the surrounding shuck/hull colour and split (colour will change from green to yellow), nut size, nutmeat moisture, internal nutmeat size, internal nutmeat colour (Extra Light, Light, Light Amber and Amber), internal nutmeat texture, internal nut membrane colour (should be brown colour rather than light coloured), rancidity or oily appearance, lipid levels, lipid characteristics.

Participatory Research

Refer to attached report from TIA for detailed information relating to the outcomes from this research.

Fatty Acid and Peroxide

The results for the Free Fatty Acid and Peroxide testing of six industry samples, tested by Symbio-Alliance are included as Table 1 below.

As found in the literature review, the fatty acid profile of walnuts can also be highly variable by cultivar; for example, the range in linolenic acid contents in walnuts from a study in New Zealand was 8.0-13.8% (Zwarts et al., 1999) whereas in an Italian study it was 12.8-15.3% (Ruggeri et al., 1996). Walnut kernels generally contain about 60% oil but this can vary from 52 to 70% depending on the cultivar, location grown and irrigation rate (Greve et al., 1992). A full analysis of walnuts is given by Robbins et al. (2011), McNeil (2012) and in a summarised form in Nuttab (2010).

Using Robbins as a reference, for example English walnut in their study has 67 g total lipid/100 g. The oleic acid (18:1) content was 17% of that, which we calculate to be 11.39 g/100 g or 0.1139 g/g to put it in the same units as the Symbio-Alliance report.

Table 1: Free Fatty Acid & Peroxide Values from stored samples

SAMPLE DESCRIPTION TEST	METHOD CODE	UNIT	SAMPLE	SAMPLE	SAMPLE	SAMPLE	SAMPLE	SAMPLE
			255721-1	255722-1	255723-1	255726-1	255727-1	255728-1
Variety			Chandler	Chandler	Howard	Chandler	Chandler	Franquet
Free Fatty Acid	CF018.3	%w/w as Oleic	0.08	0.17	0.19	0.12	0.1	0.11
Peroxide Value	CF025.3	mEq/kg	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

Table 2: Mean values from the Oleic Acid (Free Fatty Acid) content from the literature review

Source	Chandler %	Howard %	Franquette %	Total Range
This paper Aust	12	19	11	8 – 19
Range ex Aust	6 - 17	7 - 23	18 - 27	6 – 28
Eur. J. Lipid Sci. Technol. 2008, 110, 1183–1189 Argentina	16.1	23.2	-	16 -25
Journal of the American Oil Chemists‟ Society 1999, Volume 76, Issue 9, pp 1059-1063	-	-	-	13 - 21
NZ Oil & Fat Industries February 1929, Volume 6, Issue 2, pp 21-23	-	-	(18)	18
USA Int J Food Sci Nutr. 1999 May; 50(3):189-94.	-	-	-	14 - 26
NZ Grasas y Aceites 328 Vol. 56. Fasc. 4 (2005), 328-331	-	-	-	23 -27
Anatolia J. AMER. SOC. HORT. SCI. 117(3):518-522. 1992.USA	6	7	-	6 - 12
Iran. J. Chem. Chem. Eng. Vol. 28, No. 1, 2009 Turkey	-	-	-	13.4
JAOCS, Vol. 83, no. 9 (2006). Argentina	17		27	16 - 28

In conclusion from the results in table 1 and comparing with the information from the literature review as detailed in table 2, results for Free Fatty Acid were "within the expected range".

There appeared to be no issues with peroxide value - an indicator, or variable associated with rancidity. David McNeil from TIA reported that Savage & McNeil 1999 found fresh walnut oil had peroxide values of between 0.15 - 0.4 mEq/kg peroxide values and that the grower samples showed *"the peroxide values as being excellent well below any level where they would be an issue".*

Postharvest assessment of hedonistic quality

Nuts from the 6 participating orchards including 6 months centrally stored and on farm stored were tasted and sent to Kathy Evans for analysis.

The analyses for the taste tests were compared to the values observed by Symbio-Alliance.

Results of the taste tests are detailed in the Appendix.

Evaluation and Discussion

While Project WN11001 has gone through a number of extensions and variations this has been important to ensure that the best possible results were achieved from the project.

The development and establishment of an agreed set of Quality Parameters for the Australian Walnut Industry was a real challenge for the industry but the end results are testament to the researchers and growers involved in the project.

The interaction of a small grower group with the researchers through the life of this project was a major benefit to the project and a major learning from the project. Researchers learnt from the growers and the growers learnt from the researchers resulting in a set of grower „tools" that are practical, robust and „grower friendly" but are still supported by a rigorous and sound scientific background and structure.

The ***"Participatory Research"*** , designed by TIA researchers in consultation with Walnuts Australia and AWIA participants and involving grower participants worked well, and the two documents produced

a. Improved management of walnut quality factors under grower control, and

b. Quality Parameters for Australia Walnuts

will become two of the more significant documents produced for Australian walnut growers.

Overall, while the project has required some amendments along the journey, the end result for the Australian walnut industry has been highly beneficial and gives the AWIA a significant foundation to support the development and expansion of high quality Australian walnut production well into the future.

Recommendations

The Project Team has made the following recommendations:

1. That all material produced from this project be made available on the AWIA website for reference and use by grower members.

2. That all material produced from the project be regularly reviewed and where necessary be updated.

3. That the material produced be used at each future technical meetings organised by the AWIA to ensure the maximum utilisation by the growers.

4. Walnut quality parameters are selected, or developed further, to establish minimum (threshold) values for each quality parameter according to what each producer aspires to supply and what each customer is willing to buy. The methods booklet can be translated into a series of workflows and flow charts to suit the needs of individuals responsible for implementing the methods and/or collecting data in the future.

5. Selected walnut quality parameters are monitored throughout the supply chain, from storage on-farm through to receipt by one or more customers. Each sector in the supply chain is described in relation to the conditions and duration of storage. Such a study would reveal specific supply-chain sectors and/or durations of storage leading to large and/or unacceptable declines in walnut quality.

6. A logical framework for future research and development on walnut quality is developed. Such a framework would involve all potential collaborators to develop a common purpose and desired outcomes. It will also describe the objectives of the work to be conducted, who is best placed to conduct each activity and how diverse participants will interact to achieve the desired results, to manage risk and to maximise innovation across the Australian industry.

7. AWIA develops and supplies relevant and timely information to customers, including advertising material, to support the quality of Australian walnuts throughout the value chain.

8. AWIA continues to build a community of practice for sharing and managing knowledge about factors influencing walnut quality, including forums that promote co-learning through safe, open and honest discussion.

Scientific Refereed Publications

N/A

Intellectual Property/Commercialisation

No commercial IP generated

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    - Mr N Wilkinson,
    - Mr M Burston,
    - Mr A Kubeil,
    - Ms J Whitney, and
    - Ms J Sulcs;
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Appendix

- Report on Participatory Research, Tasmanian Institute of Agriculture

Australian Walnut Industry Association
HAL project: WN11001

Determining and establishing quality parameters for Australian walnuts

RESULTS OF PARTICIPATORY RESEARCH

A report prepared by the Tasmanian Institute of Agriculture for the Australian Walnut Industry Association (AWIA).
This report is a component of AWIA's final report to HAL project WN11001.

8 April, 2014.

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Dr M Lang and Mr D Goullet, Walnuts Australia.
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Executive summary

The purpose of this work was to involve members from the Australian Walnut Industry Association in determining and establishing quality parameters for Australian walnuts. The current investigation was limited to factors directly within the grower's control and which have the potential to affect walnut quality. Management of walnut quality starts in the orchard and then proceeds through harvest (timing, method), processing (cleaning, drying conditions), storage (type, length) and transport.

Data were collected by grower participants from six walnut orchard blocks in Victoria, New South Wales and Tasmania during the 2012/13 growing season. Participants recorded in-season crop and weather conditions and were trained to assess and record kernel and hull maturity. After harvest and processing, 15 kg in-shell walnuts from each block were stored on-farm or transported to a central storage facility at Tatura, Victoria. Processing operations were documented and the following qualities measured post drying: nut size, shell discolouration and disfigurement, kernel weights, suture strength, kernel disfigurement and colour. Participants were trained to conduct tests of the hedonistic qualities of kernels (taste, texture, aftertaste, rancidity), which were assessed approximately 3, 6 and 9 months after harvest. Within this 9-month period, kernels were sent at various times to an accredited commercial laboratory for tests of peroxide value and free fatty acids (FFA).

Heat accumulation varied significantly among sites, with 3,342–4,571 growing degree days (T_{base} = 0^oC) accumulated between October 1 and April 30. Production challenges included extreme heat, sunburn and localised soil moisture deficits. Multiple assessments of kernel and hull maturity at three sites revealed asynchrony between kernel and hull maturity. The nature of harvesting, hulling, cleaning and drying operations varied. Subsequent measures of shell and kernel quality provided each grower participant with values to compare with their desired target value and to reference back to documented production conditions.

Mean hedonistic scores averaged across taster, storage location, duration of storage or orchard location indicated that that all scores were approximately two or less, indicating that walnut quality was still good to very good after 9 months in storage. There was a reduction in the quality of walnuts after 9 months storage compared with 3 and 6 months across all treatments. There was a consistent significant difference among the tasters indicating the need to balance the tasters across experiments of this type. There was no storage location effect. All peroxide values were below 2 and all FFA values below 0.2 indicating that nuts had not deteriorated from being high quality.

The report concludes with five recommendations, including the development of a logical framework for future research and development on walnut quality, application of the information generated in this investigation, and approaches that will build the capacity of this group to operate effectively as a community of practice. The participatory approach helped the group to understand the current situation and to learn how to work together for generating, sharing and managing knowledge.

Individual site reports and various data files are listed in and attached to this report.

1 Background and scope

Australia's share of the global market depends on maintaining the quality of locally produced walnuts or improving it to the quality desired by consumers. The quality of Australian walnuts is presumed to be superior to those that have been imported; however, quality in relation to consumer needs is ill-defined and quality parameters have not been standardised. The purpose of this preliminary study was to involve members from the Australian Walnut Industry Association in establishing quality parameters for Australian walnuts.

The current investigation was limited to factors directly within the grower's control and which have the potential to affect walnut quality. These factors were derived from the review of the literature by McNeil and Evans (2012) and through consultation with a core group of AWIA members who would later collect relevant data. The basic premise of this work was that management of walnut quality starts in the orchard and then proceeds through harvest (timing, method), processing (cleaning, drying conditions), storage (type, length) and transport.

2 Definitions

Budburst

Budburst was defined as the date when 5% of the terminal buds had lengthened and the exterior of the basal leaves were distinguishable; that is, stage Cf 2 as illustrated in Figure 3.1.

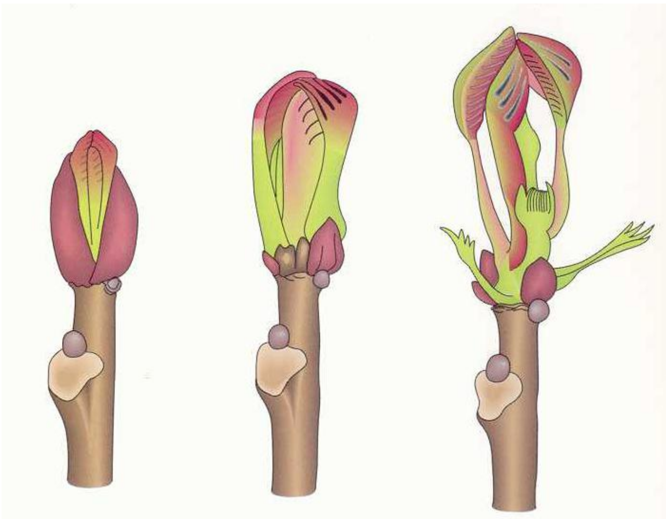


Figure 3. 1. Stages of budburst. Stage Cf 2 is known colloquially as the "prayer stage". Illustration sourced and adapted from Germain *et al.* (1999).

Growing degree days

Daily values of growing degree days (GDD) were calculated using the daily maximum temperature (T_{max}), daily minimum temperature (T_{min}), and a base temperature (T_{base}) of 0^oC.

$$GDD = (T_{max} + T_{min})/2 - T_{base} \quad (\text{where } T_{base} = 0\,^oC)$$

Daily values of GDD were accumulated between two selected dates to determine heat summation at a particular site and to allow comparison to another site.

Kernel and hull maturity
Walnut harvest requires both the kernel and the hull, the outer layer of the fruit, to be mature. Kernels are mature and lightest in colour when the packing tissue surrounding the kernel is brown in colour. This packing tissue is also called the inner membrane. The crop stage known as *packing tissue brown* (PTB) indicates that ≥ 90% fruits are at PTB. The splitting and separation of the hull from the nut is known as *hull dehiscence*. When there is cracking and separation of ≥ 95% of the hull from the shell, then the hull is mature. Determining the number of fruit with mature hulls in a sample enables calculation of the *percentage of hullable fruits.*

Cultivar and climatic differences influence the timing and rate at which kernels and hulls mature. Figure 3.2 shows two situations where kernel maturity and hull maturity are asynchronous. Harvest time may vary significantly among sites in relation to maturation of kernels and hulls. Therefore, comparison of walnut quality at harvest among sites for a particular cultivar requires that the harvest date is referenced in terms of the date of PTB and the percentage of hullable fruits. Storage of walnuts, whether it be on the tree, on the ground after nut fall, or in the shed prior to hulling, commences once the crop has reached the date when ≥ 90% fruits are at PTB.

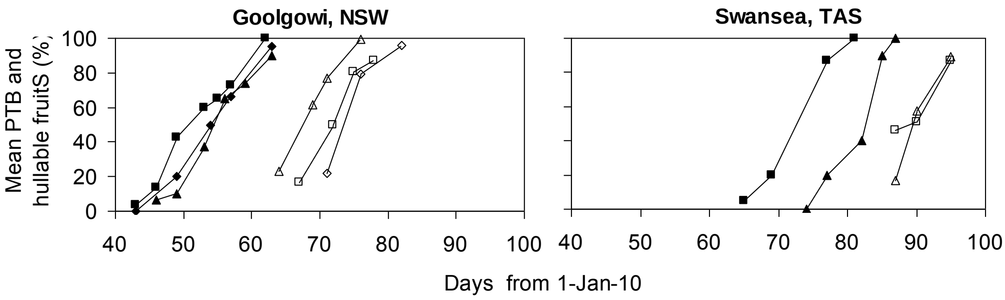


Figure 3.2 Progression of kernel maturity (PTB) (closed symbols) and hullable fruits (open symbols) on Howard (diamonds), Lara (squares) and Vina (triangles) fruits at Goolgowi, NSW, and Swansea, TAS. Reproduced from Lang, MD and Evans, KJ (2010) Advancing hull split to maximize yield and quality of walnuts, Final Report to Horticulture Australia Limited, WN09000.

Harvest Date
In an ideal world, harvest would occur soon after the crop has reached the date when ≥ 90% fruits are at packing tissue brown. Harvest date has been defined here as the date on which walnuts were removed from the orchard and transported to the next operation (e.g. hulling, storage).

3 Methods

3.1 Participants and participatory design process
Six walnut orchards managed by AWIA members were selected for this investigation (Table 4.1). Data were collected during the 2012/13 growing season, with the final assessment of walnut quality occurring in December, 2013.

Table 4.1 Participants and orchards.

Site	Participant	Orchard	Nearest town	Latitude; longitude	Walnut variety
1	Alan Kubeil	Glenvale	Violet Town, Victoria	-36.645249; 145.802388	Chandler on *J. hindsii* rootstock
2	Colin Jack	Somerset Park Walnuts	Strathfieldsaye, Victoria	-36.803523, 144.381806	Chandler on black nigra and Paradox rootstock
3	Norm Wilkinson	The Junction	Dargo, Victoria	S 37^{o} 31.885 E 147^{o} 15.626	Franquette on nigra + (Royal hybrid)
4	Mike Burston	King Valley Walnuts	Myrrhee, Victoria	S 36.43.16 E 146.18.02	Howard on nigra, hindsii or Paradox
5	Jen Whitney, Michael Lang	Goolgowi, Walnuts Australia	Goolgowi, New South Wales	34°3'59'' S, 145°42'41'' E	Chandler on Paradox RS or Californian Black
6	Julie Sulcs, Michael Lang	Cranbrook, Walnuts Australia	Swansea, Tasmania.	-42.065523, 148.049928	Chandler on black walnut

Kathy Evans and David McNeil from the Tasmanian Institute of Agriculture (TIA) drafted a list of variables to be measured, along with suggestions for the collection of information relating to orchard management, local climate and processing methods and conditions. This list was discussed with the grower participants and the study methods developed through an iterative process. The result was extensive documentation of methods (Section 8) for collecting the required data and information about site-specific walnut production and processing. Actions required by grower participants were described in a step-by-step, instructional manner, and modified throughout the study based on feedback from participants. Grower participants were also provided with two workbooks (Section 8) to assist recording of the required information.

McNeil and Evans conducted a training workshop for participants to improve their understanding of the methods, to facilitate the group to organise themselves to collect the information, and to coach the group on hedonistic (taste) testing. Methods were modified again based on how the group worked together in practice, and to account for differences in availability of participant and/or orchard location and operations.

A key principle was that methods could be implemented within the course of normal orchard operations; participants had the opportunity to indicate the degree of data collection they expected they could undertake in practice. The assumption was that the AWIA-appointed project officer was available to coordinate the group activity.

The following methods are a summary of those presented in Appendix A. Ideally, all participating growers would have collected the full set of data as described below. Missing data and/or variation among participants in how the methods were implemented are documented in the individual site reports and in the results below.

3.2 Timeframes for data collection
There were seven periods during the 2012-13 growing season and post-harvest period in which data were collected:

1. Budburst to 2-3 weeks before harvest (pre-harvest).
2. Pre-harvest to the start harvest.
3. Harvest to the start of hulling and cleaning.
4. Hulling/cleaning to the end of drying (0 months).
5. Three months after drying.
6. Six months after drying.
7. Nine months after drying.

3.3 Budburst to pre-harvest
Each grower participant recorded relevant site and crop details such as location, layout, variety, date of budburst and general information about crop inputs.

Monthly weather records were collected from the nearest A-grade Bureau of Meteorology (BOM) station and/or from on-site environmental sensors. Data from the latter were considered indicative only because details about sensor calibration, positioning and maintenance, the factors contributing to data quality, were unknown. These data were then used to describe seasonal conditions associated with a particular orchard site, such as growing degree days accumulated during the season (heat summation), number of days exceeding 38^{o}C and significant weather events such as extended drought or significant rain events. The two periods of interest for environmental conditions in the orchard were the season-long conditions (budburst to harvest) and conditions from kernel maturity (100% PTB) to removal of nuts from the orchard.

Growers were also instructed to record any abiotic or biotic stresses that they felt might have impacted significantly on walnut production; for example, frost, disease and/or drought.

As budburst approached, 10 trees per orchard block were selected arbitrarily. The degree of budburst per tree on any particular date was determined by selecting 20 terminal buds on one side of the tree and 20 terminal buds on the other side of the tree. The number of terminal buds that were at stages Cf or earlier, stage Cf 2 and stages Df or later were counted (Figure 3.1). The percentage budburst for all 10 trees was then calculated from data combined for all ten trees.

3.4 Pre-harvest to harvest
Kernel maturity was determined by selecting one row in the orchard block. A sample of 20 nuts was selected arbitrarily from either side of the row and from the interior of the canopy to avoid nuts that were fully exposed to the sun. Each walnut was split open to assess whether or not the packing tissue surrounding the kernel was brown in colour. The percentage of the 20 fruit at PTB was calculated. This method was repeated with two more samples of 20 nuts. Assessment of kernel maturity commenced 2-3 weeks before the expected harvest date was repeated until the assessment revealed ≥ 90% PTB.

The first assessment of percentage of hullable fruits was done as the crop was approaching ≥ 90% PTB. If ≥ 90% PTB occurred well before harvest day, then percentage hullable fruits was assessed at harvest, if not before. Percentage of hullable fruits was determined by sampling 20 nuts arbitrarily from either side of a single row and from the interior and exterior of the canopy. Each walnut was rolled by hand, with gentle downward pressure, on a steel grating mesh platform for 5 seconds to see if ≥ 95% of the hull surrounding the shell was removed (Figure 4.4.1). This method was repeated with two more samples of 20 nuts, and the whole method repeated every 3-5 days until harvest.

If percentage of hullable fruits was assessed on the day of harvest, then the assessment procedure was modified. Fruit were shaken from each of a minimum of three trees in the orchard block. For each tree, a garden rake was used to pull fruit out into mid-row area. One 'pull' by the rake was done for each side of the tree; further raking on each side of the tree was done until there were at least 50 fruit (in total per tree) sampled. These fruit, comprising a minimum of 50 nuts per tree, were used to estimate percentage of hullable fruits as per the method above.

Figure 4.4.1 Michael Lang from Walnuts Australia assessing percentage hullable fruits.

3.5 Harvest to the start of hulling and cleaning.

Participants were given a template to record the sequence of harvest operations, the date on which each operation took place, the equipment used, and the time each operation commenced or finished. Operations included tree shaking, sweeping, storage of nuts on the ground (if done), collection of nuts from the ground, and transport of nuts to a shed for storage of green nuts (if done) or for transfer of nuts to the hulling/cleaning line.

Environmental conditions were monitored once nuts were moved from the orchard to areas for storage and/or processing.

Temperature in storage bins

Temperature was monitored within piles of nuts stored in bins or cardboard containers pre- or post-drying. An ibutton® DS1921G Thermochron sensor (https://www.thermodata.com.au/) was mounted in an ibutton fob, connected to a piece of brightly coloured string or bailer twine, and lowered into the centre of the pile of nuts to a depth of 50 cm. The sensor was located well away from the sides of the bin and was set to record at an interval of 60 minutes.

The DS1921G Thermochron sensors operate in the range -40 to +85°C and their accuracy is reported to be ± 0.5°C.

Contaminating and adhering material

Harvested nuts in three separate bins were sampled to determine the amount of contaminating and adhering material. Using digital kitchen scales with 1 g or smaller increments, a sample of 1 kg of walnuts was taken from each bin before nuts were dried. Each sample was then separated into nuts and other materials (stones, sticks, insects, leaf, hulls, etc) labelled 'trash'. Nuts and 'trash' were weighed and the percentage contaminating material was calculated as:

% contaminating material = 100*(trash weight)/(trash weight + nut weight)

The number of nuts with and without adhering material was then counted. Adhering material was defined as husk affecting > 10% of the shell surface, or frass/dirt strongly attached affecting > 5% of the shell surface. The percentage of nuts with adhering material was then calculated.

3.6 Hulling/cleaning to the end of drying.

Participants were given a template to record the sequence of hulling, cleaning and drying operations, the date on which each operation took place, the equipment used, and the time each operation commenced or finished. Operations included hulling and cleaning (one or two operations), storage of hulled nuts prior to drying (if done), and drying.

Moisture content of walnuts before and after drying

Three samples of 20 nuts were collected from each storage bin. Each sample of 20 nuts was weighed with the digital kitchen scales and the 'initial weight' recorded. A domestic oven was pre-heated to 105^{o}C. If the oven's thermostat was unreliable, then the temperature was set to 80^{o}C to reduce the chance that the temperature spiked above 105^{o}C.

In-shell nuts were kept whole or 'smashed' to create a wider surface area for more rapid oven drying.

The 3 x 20 nut samples were placed on trays in the pre-warmed oven for 3 hours. The samples were weighed again and returned to the oven. After 1 hour, the nuts were weighed again. If the weight was different to that measured after 3 hours of drying, then the nuts were returned to the oven. This procedure was repeated until the weight of nuts remained unchanged for two measures 1 hour apart. This weight was recorded as the 'final weight'. The moisture content for each sample of 20 nuts was calculated as:

Moisture content (percentage water) = 100 – (Final weight/Initial weight)*100

Environmental conditions in dryer

Temperature and relative humidity was monitored in the dryer or drying area using an ibutton® DS1923 Hygrochron sensor (https://www.thermodata.com.au/) mounted in an ibutton fob. The recording interval was 60 minutes.

The DS1923 sensors operate in the range -40 to +85°C and 0 to 100% relative humidity, and their accuracy is reported to be ± 0.5°C and ±5% relative humidity.

3.7 Storage and tests post drying

Once in-shell walnuts had been dried, two samples of 15 kg were collected. One of the 15 kg samples was shipped to a central storage facility at the Department of Primary Industries and Environment, Tatura, Victoria, where the samples were placed in a cool room with a relatively constant temperature of 6^{o}C. Bulk samples of nuts from each grower participant arriving at the central storage facility had different qualities; however, the common storage location provided an opportunity for participants to monitor any changes in nut quality under these common, constant storage conditions.

The other 15 kg sample was stored 'on farm' at ambient temperature and in an area designated by the grower participant. This process provided the opportunity for each grower participant to detect any differences in the quality of their walnuts over time from the different storage locations. Kernel quality was assessed 0, 3, 6 and 9 months after drying using tests for colour, hedonistic qualities, and assays for peroxide value and free fatty acids, as described below. These tests were done after a one-off assessment of nut size, shell discolouration, shell disfigurement and kernel weights as described in the next section.

Environmental conditions in storage containers were monitored using ibutton® DS1923 Hygrochron or DS1921G Thermochron sensors as described previously.

3.8 Nut size, shell discolouration, shell disfigurement and kernel weights

Immediately after drying, three samples of 50 nuts were sampled arbitrarily. The width of each in-shell nut at its widest point was measured using digital callipers. Using these raw measurements, nuts were grouped into the following size categories:

MAMMOTH	- nuts that will not pass through 38 mm holes.
JUMBO	- nuts which will pass through a 38 mm hole but not a 32 mm hole.
LARGE	- nuts that will pass through a 32 mm hole but not a 29 mm hole.
STANDARD	- nuts that will pass through a 29 mm hole but not a 25 mm hole.
BABY	- all nuts that pass through a 25 mm hole.

For each 50-nut sample, numbers of nuts that were uniformly discoloured or highly discoloured (Figure 4.8.1) were counted.

Figure 4.8.1 Example of discoloured shells (left) and relatively clean shells (right).

The numbers of nuts that in each of the following categories were also counted.

Category	Description
Shell staining	Abnormal colour which covers >10% of the surface of the shell of an individual nut and which is of a brown, reddish brown, grey or other colour in pronounced contrast with the colour of the rest of the shell or the majority of shells in the lot.
Mechanical damage	Tip breakdown, non suture crack or significant visible damage caused by hulling.
Mould or decay	Mould filaments visible to the naked eye. Significant decomposition caused by the action of micro-organisms.
Insect damage	Insect holes visible or significant chewing scars.
No disfigurement	Nuts that do not fit into any of the categories above.

Kernel removed from the same sample of 3 x 50 nuts and kernel and shell weights determined using the digital kitchen scales. Two types of crackout percentage were calculated for each sample of 50 nuts as follows:

1. The total weight of shells and kernels from 50 nuts = a
2. The number of empty walnuts (blanks) = b
3. The weight of shells and kernels of all non-blanks = c

   In-shell nut weight = c/ (50-b)

4. Total kernel weight = d

   Mean kernel weight = d/ (50-b)

5. Crackout % (1) = (d x 100)/a
6. Crackout % (2) = (d x 100)/c

4.9 Suture strength and kernel disfigurement

Suture strength

Another sample of 3 x 50 nuts with kernels (non-blanks) was selected. Suture strength was determined by dropping each walnut from a height of 1.5 m onto a concrete paver and then manually squeezing the shell to test whether the walnut seal opened. Each walnut was given a score of one if the walnut was not firmly intact. The individual scores were then summed for each sample of 50 nuts.

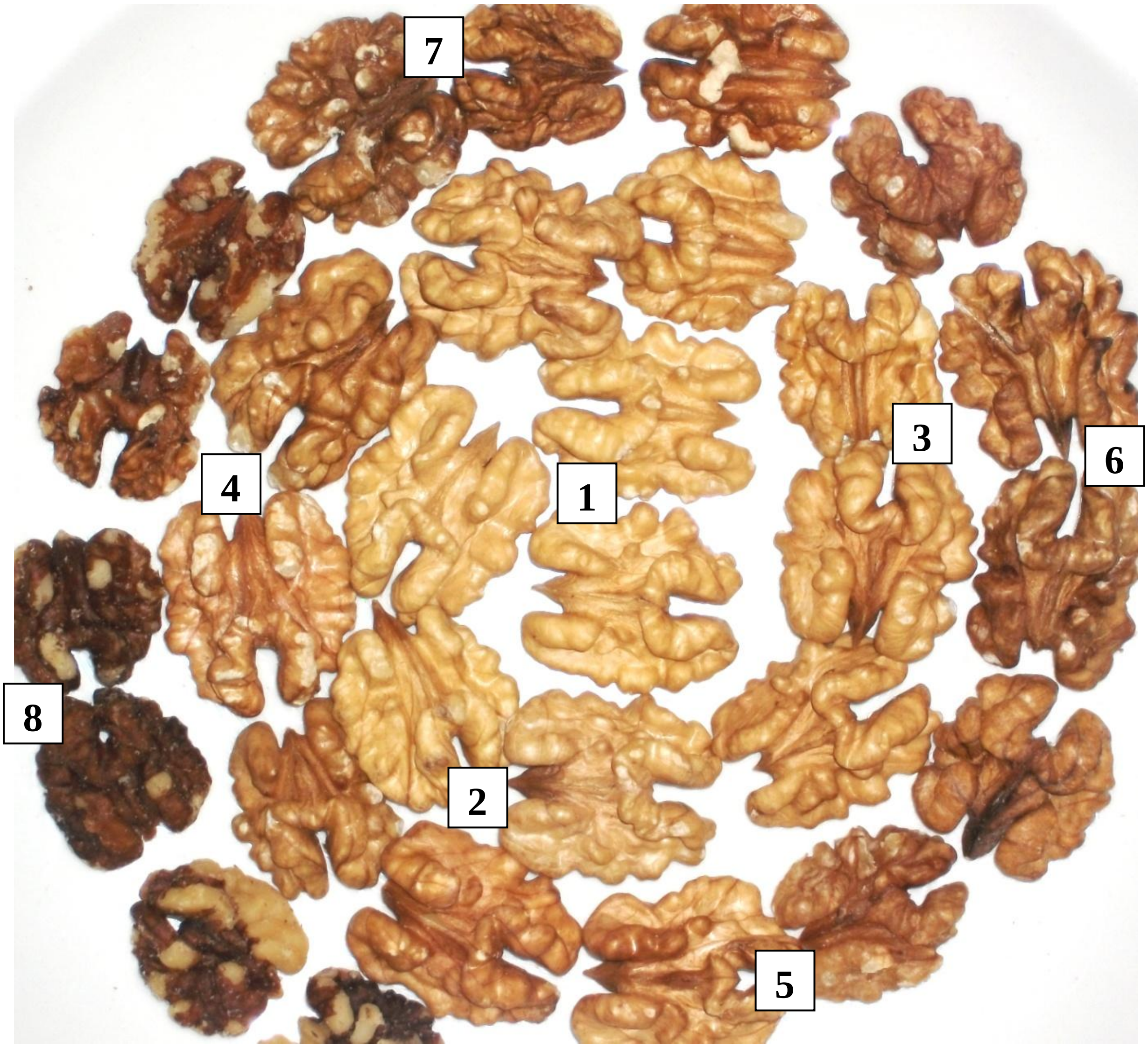
Kernel disfigurement

Each of the nuts in the 3 x 50-nut samples was cracked across the seal with a manual nut cracker and the kernels removed from the shell. The kernels from one walnut were kept together. The number of walnuts that had kernels in each of the following categories was counted:

Category	Description
Tip shrivel	Distal end of kernel shrivelled and often dark.
Yellowing/staining	Kernel showing areas >20% of a distinct yellow or stained colour different from the rest of the kernel.
Shrivelled kernel	Whole kernel shrivelled and often dark and leathery.
Fungal discolouration	Kernel plump(ish) but dark rotten and may show mould or bacterial lesions. Mould filaments visible to the naked eye. Significant decomposition caused by the action of micro-organisms.
Insect infestation	Visible damage caused by insects or other animal parasites or the presence of dead insects or insect debris.
Undried kernels	Kernels soft and pliable, high moisture content.
No disfigurement (sound kernels)	All kernels from a nut which do not fit into any of the categories above.

4.10 Kernel colour

All remaining sound half kernels (no disfigurement) from the test for kernel disfigurement (3 x 50-nut samples) were scored with the aid of the following colour chart. All grower participants were given a high-quality colour chart printed from on the same paper and from the same printer. The mean colour score for each 50-nut sample was calculated along with the number of kernels scoring < 4.



Colour scoring was also done 3, 6 and 9 months after drying by sampling 3 x 50 nuts from the bulk samples stored on-farm or in the central storage facility.

4.11 Hedonistic qualities

The first date on which taste testing was conducted was done as a group exercise (Figure 4.11.1). Three grower participants were selected to be the tasters on this date and for all subsequent assessment dates.

Each person tasting the nuts was blindfolded. Six walnuts sampled from the bulk sample from each site and storage location were then placed in each of three bowls that was labelled to indicate the sample origin. An assistant to the taster, wearing surgical gloves, selected six nuts from one of the bowls and removed the kernels. Six sound half kernels were selected and a piece was then broken off each half kernel such that all six pieces together constituted approximately one walnut half. This mix of walnut pieces was the sample used for tasting. The assistant handed the taster the mix of nut pieces and recorded their response to different aspects of hedonistic quality, as described below. The taster then rinsed their mouth with water to allow any aftertaste to dissipate. The assistant selected another bowl of nuts from another site and location and repeated the tasting process.

Figure 4.11.1 Participants assess the hedonistic qualities of walnuts at Tatura.

This tasting process was adopted because there is a limit on the number and amount of walnut kernels that one person can taste reliably and there may be differences among kernels in a batch. Therefore it was necessary to taste a mix of a number of different kernels. It was assumed that each taster provided consistent assessment of relative taste among assessment dates.

Definition of hedonistic quality

Quality	Definition
Texture	This is the mouth feel of the nuts. Generally the very crisp value would be perceived from the highly dried nuts.
Taste	The enjoyment achieved from eating the nuts.
Rancidity*	A sharp, bitter and unpleasant taste associated with rotten oils.
After taste	The taste remaining 15 seconds after the nut has been chewed and eaten.

*It can be difficult to separate rancidity from poor taste.

Hedonistic scale

	1	**2**	**3**	**4**	**5**
Texture	Very crisp, snaps when bitten	crunchy	Firm	Soft and chewy	Soft and pliable
Taste	Highly flavoursome and sweet	Tasty	Acceptable but bland taste	Poor	Bad
Rancidity	None	Hint of off taste	Clear rancid overtones	Not a pleasurable experience to eat but possible	Inedible
Aftertaste	None or continuing flavoursome	Some residual taste hinting at walnut	Some taste remaining, not benefitting experience	Some taste remaining suggesting rancidity	Unpleasant and rancid

Assessment of the hedonistic qualities of walnut kernels did not commence until approximately 3 months after drying, when grower participants were able to meet in the one location. Given that walnuts were harvested at different times among the participating orchards, the following tests were conducted approximately 3, 6 and 9 months after drying. The exact number of days after drying for walnuts from a particular site is presented in the results section.

Data analyses for hedonistic qualities

Factorial analyses of variance (ANOVA) were conducted for each hedonistic quality and for mean hedonistic score averaged across texture, taste, rancidity and aftertaste. Three tasters provided three sets of tastings per orchard site and storage location, with the variance associated with taster partitioned in ANOVA. Variance was also partitioned for storage location (on-farm, central storage), duration of storage (3, 6 or 9 months) and orchard location as well as all 2 factor interactions.

4.12 Peroxide value and free fatty acids

Up to three samples of 100 g of shelled nuts from the bulk sample of nuts on any given sampling date were placed in 'ziplocked' polythene bags and sent by express post to a NATA accredited laboratory (Symbio Alliance, Brisbane, QLD) for analyses of peroxide value and free fatty acids.

Methods for these tests can be obtained from https://aocs.personifycloud.com/PersonifyEbusiness/Store/AOCSStore.aspx

1. AOCS Official Method Cd 8b-90 provides the milliequivalents of peroxide per 1000 grams of test sample that oxidize potassium iodide under the conditions of the test. The substances are generally assumed to be peroxides or other similar products of fat oxidation.

2. AOCS Official Method Ca 5a-40 determines free fatty acids, %w/w as oleic acid equivalent.

Walnuts were considered to be of high quality if mean peroxide values were < 2 mEq/kg and free fatty acids were below 0.2 %w/w oleic acid equivalent (Mitcham *et al.* 2004).

Data analyses for chemical analyses
Analyses of variance (ANOVA) were conducted for the main effects of storage location (on-farm, central storage), duration of storage (3, 6 or 9 months) and orchard location.

4 Results

All data collected by grower participants are summarised in individual site reports (six attachments). Raw data have been provided directly to AWIA, including compilation of environmental data collected from ibutton sensors. Details of environmental data available are listed in each site report.

Given the variation in operations conducted at each site, the environmental data provides each participant with a record of their particular storage conditions. Similarly, descriptions of harvest and hulling operations, which varied significantly among businesses, can be found in the individual site reports.

The following results are a synthesis of the data from the individual site reports to illustrate the magnitude of and variation among values for each variable measured or recorded during this investigation. Sections 5.1 to 5.4 provide a series of self-explanatory tables about production challenges, crop phenology, orchard environments, and shell and kernel quality. Kernel quality is described further in sections 5.5 and 5.6, where the results of taste tests for hedonistic qualities and chemical analyses are presented, analysed and interpreted.

5.1 Production challenges

Site Report	Orchard	Production challenges
WN11001_1	**Glenvale**	Very dry from September to December. Sunburn from extreme heat 5-6/1/13.
WN11001_2	**Somerset**	Extreme heat during Dec/Jan/Feb. Significant sunburn on western side of trees. Large flocks of cockatoos during and after harvest – removal of nuts.
WN11001_3	**Dargo**	Participant was absent from orchard for prolonged periods due to circumstances beyond their control; consequently, there were gaps in data collection.
WN11001_4	**King Valley**	Little rain after mid-November. Hot conditions and localised lack of irrigation may have contributed to smaller than average nut size. Edi Upper weather station recorded significant rainfall events in February and March.
WN11001_5	**Goolgowi**	Extreme heat resulting in some sunburn.
WN11001_6	**Swansea**	No particular challenges. Average temperatures were above normal in January and February. The highest recorded temperature in February was 46°C.

5.2 Crop phenology

Site report:	WN11001_1	WN11001_2	WN11001_3	WN11001_4	WN11001_5	WN11001_6
Locality	**Glenvale**	**Somerset**	**Dargo**	**King Valley**	**Goolgowi**	**Swansea**
Cultivar	Chandler	Chandler	Franquette	Howard	Chandler	Chandler
Variable						
Budburst 100%	30/9/12	26/9/12	no data	< 29/9/12	24/9/12	1/10/12
PTB	23/3/13	8/4/13	no data	≤ 20/3/13*	27/3/13*	70% PTB on 25/3/13
Harvest	24/4/13	8–25/4/13	1–30/4/13	29–30/3/13	15–18/4/13	30/4/13–1/5/13
Hullable fruit at 100% PTB (%)	5–15	62–70	no data	no data	98% 8 days after 100% PTB	no data
Hullable fruit at harvest (%)	95–100	62–70 (start of harvest)	no data	≥ 90	98	no data

*Only one assessment reported, so it is not known if the crop had been close to 100% PTB on a previous date.

Asynchrony between kernel and hull maturity was evident at orchards where there was sufficient data to reveal a time series (Figures 5.2.1 and 5.2.2). Notably, increases in PTB and hullable fruit percentages appeared to occur in parallel at a particular site; however, the delay in reaching a hullable fruit percentage equivalent to the same PTB percentage was about 20 days for Glenvale orchard (Figure 5.2.1) and about 6 days for Somerset Part (Figure 5.2.2). It is postulated that the change in PTB percentage is influenced by temperature, whereas hullable fruit percentage is influenced by rainfall after 100% PTB, and/or changes in relative humidity as influenced by diurnal fluctuations in temperature (M. Lang, Walnuts Australia, personal communication).

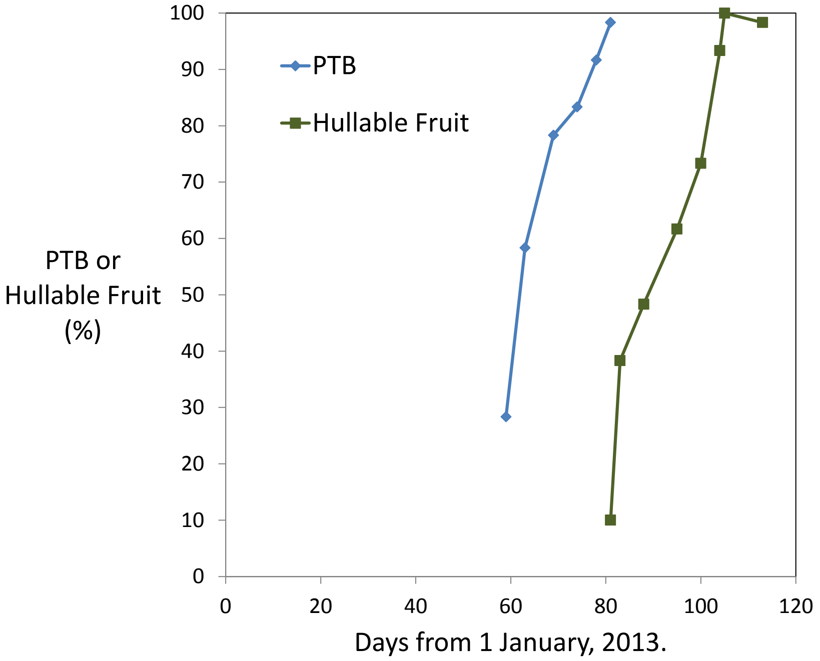


Figure 5.2.1. Packing tissue brown (PTB) and hullable fruit percentages for Chandler walnuts at Glenvale orchard in 2013.

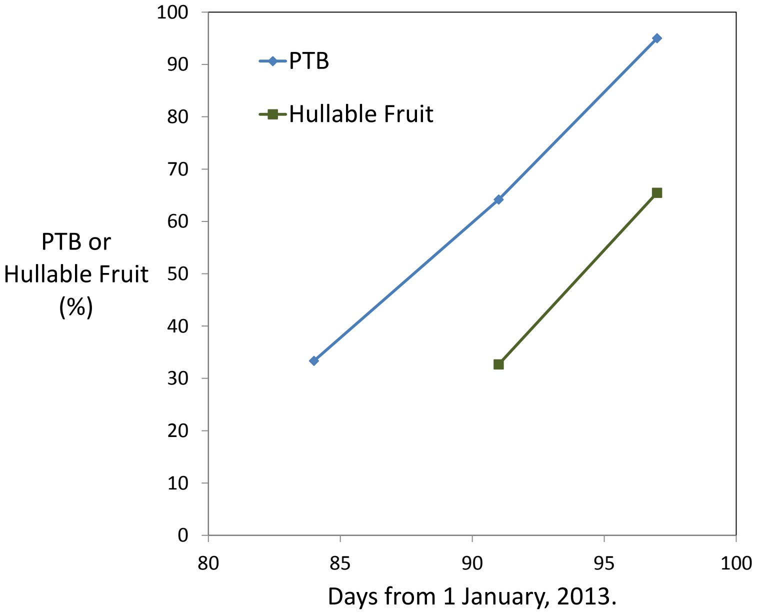


Figure 5.2.2. Packing tissue brown (PTB) and hullable fruit percentages for Chandler walnuts at Somerset Park in 2013. For the purpose of graph preparation, the value of PTB at 91 days after January 1 was calculated as the average of the observations 84 and 97 days after January 1.

5.3 Orchard environments

Site report:	WN110011	WN110012	WN110013	WN110014	WN110015	WN110016
Locality	**Glenvale**	**Somerset**	**Dargo**	**King Valley**	**Goolgowi**	**Swansea**
Cultivar	Chandler	Chandler	Franquette	Howard	Chandler	Chandler
Nearest weather station[a]	Benalla Airport ID 082170	Bendigo Airport ID 081123	Bairnsdale Airport[b] ID 085279	Edi Upper ID 083083	Griffith Airport ID 075041	Swansea ID 092148
Variable						
Number of days from budburst to harvest	207	≥ 195	no data	> 183	≥ 204	213
Number of days exceeding 38^{0}C	9	6	3	5	17	1
Growing degree days with T_{base} = 0^{o}C; budburst to harvest	4094	≥ 3816	no data	gaps in data	4571	3342
Growing degree days with T_{base} = 0^{o}C; 1/10/12 to 30/4/13.	4174	4095	3723	gaps in data	4672	3342
Total in-season rainfall (mm) 1/10/12 to 30/4/13	225	157	371	≥ 298	202	229
Total rainfall (mm) from 100% PTB to removal of nuts from orchard	21	5	no data	93	25	≤ 43

[b]Bureau of Meteorology weather station.
[b]Closest weather station; however, it does not represent the orchard site well.

5.4 Nut size, crackout, shell and kernel quality

Site report:	WN110011	WN110012	WN110013	WN110014	WN110015	WN110016
Locality	**Glenvale**	**Somerset**	**Dargo**	**King Valley**	**Goolgowi**	**Swansea**
Cultivar	Chandler	Chandler	Franquette	Howard	Chandler	Chandler
Variable						
Moisture content (%) before drying	no data	no data	no data	no data	machine output	no data
Moisture content (%) after drying	8.4–8.7	no data	no data	6.5–11.2	7–9	9
Walnuts exceeding 29 mm width (%)	100	100	92–96	80	100	86
Walnuts with no shell disfigurement (%)	76	96	72	95	95	78
Walnuts with shell discoloured or highly discoloured (%)	24	0	2	3	0.4	19
Suture strength score	no data	2/50	1/150	7–13/50	4–9/50	15–27/50
Crackout (%) including blank nuts	49	52	44	47	45	52
Walnuts with sound kernels (no disfigurement) (%)	69	88	96	89	13*	no data
Walnuts with kernels scoring < 4 for colour (%)	61	100	97	88	85	no data

*48% of walnuts had kernels had tip shrivel and 32% of walnuts had kernels with yellowing/staining.

5.5 Hedonistic qualities

The overall mean score across the four hedonistic criteria (texture, taste, rancidity and aftertaste) was considered the best overall test of quality as it was less variable and included all the criteria with equal weight. Values of this mean score for each orchard and storage location ranged from 1.3 to 2.6 (Figure 4.5.1).

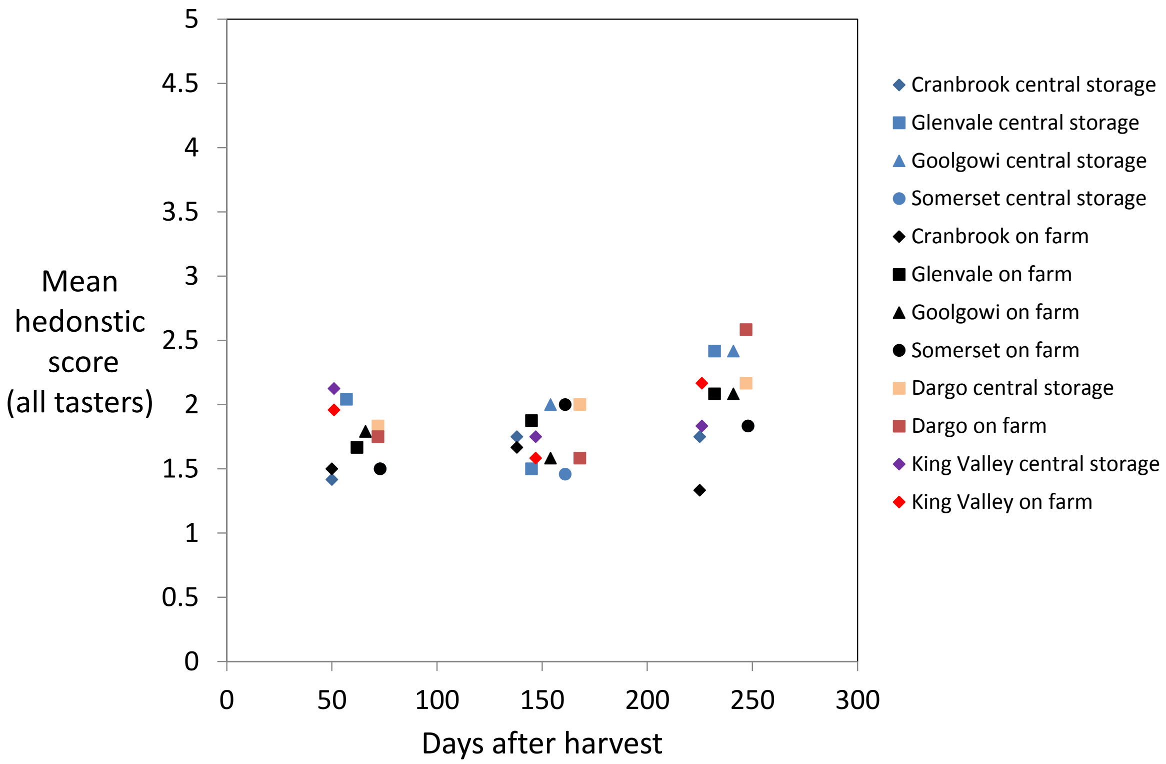


Figure 5.5.1. Mean hedonistic score averaged across texture, taste, rancidity and aftertaste, and averaged across the three tasters. Samples were from on-farm or central storage.

When mean hedonistic score was averaged according to the main effects of taster, storage location, duration of storage or orchard location (Table 5.5.1), the results indicated that

1. All scores were approximately 2 or less indicating that the quality was still good to very good after 9 months in storage.
2. There were no significant interactions among factors (Table 5.5.2). For example, if the two factors investigated for hedonistic score were storage time and storage location, then storage location did not affect how the hedonistic score changed over time.
3. Mean scores for Cranbrook were (statistically) lower than all sites, except Somerset.
4. There was no storage location effect indicating on farm and centrally stored nuts were performing well.
5. There was a consistent significant difference among the tasters indicating the need to balance the tasters across experiments of this type.
6. The important, significant effect was the reduction in quality of walnuts after 9 months storage compared with 3 and 6 months across all treatments. While still falling into the high quality range (~2) it indicates a need to pay attention to time of storage.

Table 5.5.1. Mean hedonistic score averaged across texture, taste, rancidity and aftertaste. Within a group, mean scores followed by the same letter are not significantly different at the 5% level. More information about the results of analysis of variance is presented in Table 5.5.2.

Taster	**Mean**	**Std Error**	**LSD Sig at<5%**
One	1.479	.072	a
Two	2.215	.072	b
Three	1.816	.072	c
Storage	**Mean**		
central	1.866	.059	a
on farm	1.808	.059	a
Age_months	**Mean**		
3	1.740	.072	a
6	1.729	.072	a
9	2.042	.072	b
Location	**Mean**		
Cranbrook	1.569	.101	a
Glenvale	1.931	.101	b
Goolgowi	1.944	.101	b
King Valley	1.903	.101	b
Dargo	1.986	.101	b
Somerset	1.688	.101	ab

Table 5.5.2. Results of Analysis of Variance (ANOVA) for mean hedonistic score averaged across texture, taste, rancidity and aftertaste. P values in **bold** text indicate significant effects because $P < 0.05$. 'Location' refers to the orchard site. 'Storage' refers to the storage location (on farm or central storage).

Tests of Between-Subjects Effects

Dependent Variable: Mean

Source	Type III Sum of Squares	df	Mean Square	F	P value
Corrected Model	20.022[a]	43	.466	2.511	**.000**
Intercept	364.376	1	364.376	1965.041	**.000**
Age_months	2.268	2	1.134	6.116	**.004**
Location	2.534	5	.507	2.733	**.027**
Storage	.090	1	.090	.488	.488
Taster	9.777	2	4.888	26.363	**.000**
Age_months * Location	1.985	10	.199	1.071	.398
Age_months * Storage	.018	2	.009	.048	.954
Age_months * Taster	.913	4	.228	1.231	.307
Location * Storage	.483	5	.097	.521	.759
Location * Taster	1.732	10	.173	.934	.509
Storage * Taster	.221	2	.110	.595	.554
Error	11.867	64	.185		
Total	396.266	108			
Corrected Total	31.889	107			

[a] R Squared = .628 (Adjusted R Squared = .378)

When the hedonistic characters were analysed individually (Table 5.5.3), essentially the same results occurred. Taste testers noted that the taste of rancidity and aftertaste were sometimes confused; however, the effect of duration of storage was significant for rancidity and taste, but not for aftertaste and texture. The effect of production location (orchard site) was significant for taste, but not significant for the other three hedonistic characters. Storage location was not significant for any character, only 2 of 24 interactions were significant, while taster was significant for all characters.

Table 5.5.3. Results of Analysis of Variance (ANOVA) for the four components of the mean hedonistic scores. P values in **bold** text indicate significant effects because P < 0.05. 'Location' refers to the orchard site. 'Storage' refers to the storage location (on farm or central storage).

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	P value
Corrected Model	Texture	52.780[a]	43	1.227	2.449	**.001**
	Taste	54.931[b]	43	1.277	2.252	**.002**
	Rancidity	9.593[c]	43	.223	1.640	**.036**
	After_taste	35.634[d]	43	.829	1.622	**.039**
Intercept	Texture	458.391	1	458.391	914.533	**.000**
	Taste	551.259	1	551.259	971.645	**.000**
	Rancidity	151.704	1	151.704	1115.506	**.000**
	After_taste	366.676	1	366.676	717.877	**.000**
Age_months * Location	Texture	6.940	10	.694	1.385	.208
	Taste	2.606	10	.261	.459	.910
	Rancidity	2.259	10	.226	1.661	.110
	After_taste	5.801	10	.580	1.136	.351
Age_months * Storage	Texture	.810	2	.405	.808	.450
	Taste	1.097	2	.549	.967	.386
	Rancidity	2.074	2	1.037	7.626	**.001**
	After_taste	1.421	2	.711	1.391	.256
Age_months * Taster	Texture	10.148	4	2.537	5.062	**.001**
	Taste	1.523	4	.381	.671	.614
	Rancidity	.704	4	.176	1.294	.282
	After_taste	4.676	4	1.169	2.289	.069
Location * Storage	Texture	.762	5	.152	.304	.909
	Taste	2.444	5	.489	.862	.512
	Rancidity	.296	5	.059	.436	.822
	After_taste	.546	5	.109	.214	.955
Location * Taster	Texture	3.898	10	.390	.778	.650
	Taste	3.801	10	.380	.670	.748
	Rancidity	.704	10	.070	.517	.872
	After_taste	5.426	10	.543	1.062	.404
Storage * Taster	Texture	.907	2	.454	.905	.410
	Taste	.875	2	.438	.771	.467
	Rancidity	.296	2	.148	1.089	.343
	After_taste	.130	2	.065	.127	.881
Age_months	Texture	1.699	2	.850	1.695	.192
	Taste	9.310	2	4.655	8.205	**.001**
	Rancidity	1.185	2	.593	4.357	**.017**
	After_taste	.616	2	.308	.603	.550
Location	Texture	4.428	5	.886	1.767	.132
	Taste	11.657	5	2.331	4.109	**.003**

	Rancidity	.519	5	.104	.763	.580
	After_taste	4.907	5	.981	1.922	.103
Storage	Texture	.280	1	.280	.559	.457
	Taste	.750	1	.750	1.322	.255
	Rancidity	.148	1	.148	1.089	.301
	After_taste	.037	1	.037	.073	.789
Taster	Texture	22.907	2	11.454	22.851	**.000**
	Taste	20.866	2	10.433	18.389	**.000**
	Rancidity	1.407	2	.704	5.174	**.008**
	After_taste	12.074	2	6.037	11.819	**.000**
Error	Texture	32.079	64	.501		
	Taste	36.310	64	.567		
	Rancidity	8.704	64	.136		
	After_taste	32.690	64	.511		
Total	Texture	543.250	108			
	Taste	642.500	108			
	Rancidity	170.000	108			
	After_taste	435.000	108			
Corrected Total	Texture	84.859	107			
	Taste	91.241	107			
	Rancidity	18.296	107			
	After_taste	68.324	107			

a. R Squared = .622 (Adjusted R Squared = .368)

b. R Squared = .602 (Adjusted R Squared = .335)

c. R Squared = .524 (Adjusted R Squared = .205)

d. R Squared = .522 (Adjusted R Squared = .200)

5.6 Free fatty acids and peroxide values.

Table 5.6.1 Results of laboratory analyses for peroxide value and free fatty acids from samples of approximately 100 g kernels. It is assumed samples arrived at the Symbio Alliance laboratories up to four days after the sample date. Samples were tested between the date Symbio received the samples and the date shown on their report.

Orchard	Sample date	Storage location	Days after harvest	Sample	Free Fatty Acid %w/w oleic acid equivalent[a]	Peroxide Value mEq/kg[b]
Glenvale	6/05/2013	on farm	12	1	0.08	1.00
Glenvale	6/05/2013	on farm	12	2	0.49	0.30
Glenvale	6/05/2013	on farm	12	3	0.07	0.60
Glenvale	16/09/201	on farm	145	1	0.15	0.30
Glenvale	3/10/2013	central	162	1	0.12	0.10
Somerset	9/05/2013	on farm	31	1	0.07	0.10
Somerset	3/10/2013	central	178	1	0.17	0.10
Dargo	22/05/2013	on farm	43	1	0.08	1.00
Dargo	12/09/2013	on farm	156	1	0.13	0.40
Dargo	3/10/2013	central	177	1	0.11	0.10
King Valley	4/06/2013	on farm	35	1	0.11	1.00
King Valley	4/06/2013	on farm	35	2	0.11	0.70
King Valley	4/06/2013	on farm	35	3	0.12	1.00
King Valley	16/09/2013	on farm	139	1	0.12	0.40
King Valley	8/10/2013	central	161	1	0.19	0.10
Goolgowi	20/05/2013	on farm	35	1	0.07	0.60
Goolgowi	27/09/2013	on farm	165	1	0.13	0.10
Goolgowi	27/09/2013	on farm	165	2	0.11	0.10
Goolgowi	27/09/2013	on farm	165	3	0.11	0.10
Goolgowi	3/10/2013	central	171	1	0.10	0.10
Swansea	20/05/2013	on farm	19	1	0.07	0.40
Swansea	27/09/2013	on farm	149	1	0.09	0.10
Swansea	27/09/2013	on farm	149	2	0.10	0.10
Swansea	27/09/2013	on farm	149	3	0.06	0.10
Swansea	3/10/2013	central	155	1	0.08	0.10

[a]Symbio method code CF018.3
[b]Symbio method code CF025.3

Table 5.6.2. Main effects for peroxide and free fatty acids (FFA). Values followed by the same letter are not significantly different at P < 5%.

Dependent Variable	Orchard	Mean	Std. Error	LSD Sig <5%
FFA %w/w oleic equivalent	Cranbrook	.092	.016	a
	Goolgowi	.102	.016	ab
	Dargo	.118	.016	abc
	Somerset	.135	.017	abc
	King	.138	.016	bc
	Glenvale	.154	.016	c
Peroxide mEq/kg	Goolgowi	.426	.187	a
	Somerset	.591	.206	ab
	King	.646	.187	ab
	Cranbrook	.686	.187	ab
	Dargo	.946	.187	ab
	Glenvale	1.032	.187	b

Dependent Variable	Store_site	Mean	Std. Error	LSD Sig <5%
FFA %w/w oleic equiv	central	.125	.011	a
	on farm	.122	.008	a
Peroxide mEq/kg	central	.545	.137	a
	on farm	.897	.100	b*

*P=0.054 (marginally significant)

Dependent Variable	Months	Mean	Std. Error	LSD Sig <5%
FFA %w/w oleic equiv	3.0	.103	.016	a
	6.0	.126	.010	ab
	9.0	.142	.010	b
Peroxide mEq/kg	3.0	.429	.188	a
	6.0	.177	.125	a
	9.0	1.558	.118	b

Table 5.6.3. Significance table for the chemical analyses main effects only across months of storage, location of production and storage site. FFA = free fatty acid; Perox = peroxide value.

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	FFA	.020[a]	8	.003	2.163	.077
	Perox	13.452[b]	8	1.682	10.070	**.000**
Intercept	FFA	.363	1	.363	310.599	**.000**
	Perox	12.410	1	12.410	74.312	**.000**
Farm	FFA	.014	5	.003	2.334	.080
	Perox	1.272	5	.254	1.523	.227
Store_site	FFA	4.518E-005	1	4.518E-005	.039	.846
	Perox	.701	1	.701	4.201	**.054**
Months	FFA	.005	2	.003	2.259	.130
	Perox	11.839	2	5.919	35.448	**.000**
Error	FFA	.023	20	.001		
	Perox	3.340	20	.167		
Total	FFA	.511	29			
	Perox	37.037	29			
Corrected Total	FFA	.044	28			
	Perox	16.792	28			

a. R Squared = .464 (Adjusted R Squared = .249)
b. R Squared = .801 (Adjusted R Squared = .722)

Tables 5.6.2 and 5.6.3 indicate the effects of storage, source and time on the chemical composition of the walnuts. With all peroxide values below 2 and all FFA values below 0.2 there was no indication that any of the nuts have deteriorated from being high quality. However, the results indicated some deterioration at 9 months, even if slight, consistent with the hedonistic tests. There may also be a marginal increase in peroxide values with on-farm storage compared to central storage. While differences do exist among the orchards they are marginal.

5 Evaluation of participatory research

Participatory research is the co-construction of research through partnerships between researchers and people affected by and/or responsible for action on the issues under study. In this investigation, TIA researchers designed the methods in consultation with Dr Michael Lang and Mr Derek Goullet, Walnuts Australia, and the AWIA participants. It was then the responsibility of the participants, in liaison with an AWIA appointed technical communications officer, to coordinate the day-to-day activity of the group effort, and to collect the data and information. The AWIA technical officer collated some of the data; however, most raw data was sent directly to the TIA researchers at various times during the investigation. TIA researchers were available for clarification of the methods throughout the investigation; however, the grower group was largely responsible for developing their own workflows to collect the data and to adjust activities to suit the local conditions.

Benefits of this approach
The benefits of participatory research centre on the active involvement of people in a mutual learning process. The current approach enabled participants to ask the researchers questions, and to have answers given, or to initiate exploration on a new topic. An important learning element of this work was a practical understanding and observation of asynchrony in kernel and hull maturity. The participants are now equipped to measure these variables and to ascertain their impact on walnut quality. Participation also raised awareness of all the possible variables that might impact on walnut quality, and, critically, the development of practical methods to measure them on-farm.

The participatory approach provided the researchers with a deeper understanding of operations being conducted in practice. It also identified and revealed implicit knowledge held by the participants, and enabled activities to be designed and prioritised within the context of the desired outcomes articulated by the group.

When information and results were shared, it was discussed in the whole-orchard and value-chain context, which will help the group identify a common purpose and the most important issues to address in future work. Participants soon realise that no single producer gets everything right all of the time. However, if we do not measure what we do, then we cannot manage it.

Limitations of this approach
Every effort was made to describe the methods so that they could be followed readily, a bit like a recipe to prepare food. In this context, the researchers were analogous to experienced cooks and the grower participants were, more or less, learning how to cook for themselves. Researchers are well equipped to interpret experimental protocols and to adjust them as needed. In an ideal world, the lead researcher works closely with a technician to fine tune the collection of data to suit how the technician operates and their degree of understanding of the method. The result is a workflow suited to the individual technician. In this investigation, the grower participant needed to develop their own workflow for data collection. An inappropriate workflow can lead to gaps in the data and/or inappropriate data collection. More time could have been spent of training participants to install and access environmental data from the data loggers. Otherwise, there were few instances of inappropriate data collection during this investigation; however, replication was often omitted, thus reducing the potential to report rigorous results to the wider community of researchers and industry proponents.

Significant gaps in the data were evident. Participants expressed frustration at not being able to collect necessary data at various times. Gaps in data collection may have been the consequence of the workload being higher than expected, a participant not knowing how to collect the data or not knowing how to collect it efficiently within the context of their operations. Participants indicated that data collection did not occur if other, business-related activities took higher priority, and/or if life circumstances prevented involvement. Clearly, grower participants do not have the capacity to manage the risks associated with data collection when research activity is additional to those tasks conducted during the normal course of their business.

Learnings
This initial joint effort between TIA and AWIA to conduct walnut quality research was like any first-time partnership. The group was ambitious in terms of the amount of work to be undertaken, but there is now a greater appreciation of what procedures worked well to produced meaningful results; for example, the hedonistic testing worked very well, not only in terms of its power to discriminate differences in walnut quality, but also in the way it brought the group together to achieve a common goal. The group can now focus on the activities they do well together and make those the core group activity.

Gaps in consistency of the approach to data collection were expected and of relatively minor importance given that the purpose of this interaction was beyond finding answers to a specific question. The role of TIA in this partnership was to provide the group with some training on how to build their capacity to understand their current situation and the consequence of their actions as a basis to formulate and prioritise research questions. Identification of factors limiting desired walnut quality is an outcome of this capacity-building process.

The interaction also provided the opportunity for one participant to note the actions of another as a basis for open and honest discussion about how that person achieved what they did. Outcomes can be significant when this type of learning is fostered.

Building on the joint effort
This participatory research serves as a catalyst for the group to further develop their community of practice (Wenger *et al.* 2002) to enable honest and open exchanges of data, information, knowledge and wisdom. The way the group works together will evolve so that research questions emerge organically from a common purpose. Gaps in data collection and consistency will lessen as better protocols and priorities emerge. The group will develop a better understanding of how researchers can add value to their work by recruiting appropriate expertise and negotiating participants’ roles to best meet project needs. This work will continue if the group sees clear value from acting collectively, including better risk management and improved profitability of individual businesses.

6 Conclusions

The variable nature of walnut production and processing among orchards, plus inadequate replication of tests at some orchard sites, prevented systematic and statistically valid comparisons of nut size, crackout percentage, shell and kernel quality. Nevertheless, results from a particular site can be assessed by the grower participant in relation to the desired target value for a particular variable. If the value for any particular quality is deemed suboptimal, then contributing factors during production can be explored. The results suggest sub-optimal values for nut size, crackout percentage, shell discolouration, kernel disfigurement and/or colour scores at one or more sites. Indeed, one participant noted that localised deficiencies in soil moisture may have contributed to smaller than average nut size.

Given variation among sites in the nature of walnut production, tracking the progression of packing tissue brown (PTB) and hullable fruit percentage over many growing seasons can provide growers with information to understand the consequences of weather conditions after 100% PTB on the time-course of hullable fruit percentage. This information can then be used to support decisions about harvest logistics. Moreover, adequate recording of crop phenology, crop inputs and weather conditions provides the means to explore retrospectively the cause of suboptimal walnut quality.

Over the course of 9 months, all walnuts stored in shell retained high quality according hedonistic and chemical tests, both on-farm and at the central storage facility. However, some decline in quality was evident by 9 months, suggesting that storage beyond that period may become an issue. Further research to understand differences in walnut quality for nuts stored for 9-12 months after harvest, relative to those stored for 3-6 months. Storage up to 6 months appears to have no adverse effect on walnut quality if the nuts remain in-shell.

Hedonistic and chemical tests revealed small differences in quality and at a level that is, presumably, well below that noticeable by most consumers. This means that any issues can be detected before they become a problem. Participants now have some baseline information from which to develop benchmarks for the quality of Australian walnuts and a basis from which to further develop and establish walnut quality parameters.

The participatory approach to this investigation allowed the results to be framed and discussed in the whole-orchard and value-chain context. Even though there was diversity in walnut production, processing methods and seasonal conditions, differences in walnut quality among the different businesses were relatively small. Producers should now consider what happens to walnut quality once it enters storage and/or transport conditions beyond their direct control. If so, the participants, and AWIA members more broadly, have further work to identify and consolidate a common purpose and desired outcomes.

7 Recommendations

The following recommendations are based on the results of this investigation and the learnings during implementation of participatory research:

1. Participants complete a 12-month (or later) post-harvest assessment of hedonistic quality using remaining walnuts in central storage and on-farm. The group have committed to undertaking this assessment in late May, 2014, after the current season harvest. TIA will undertake extra data analyses as an 'in kind' contribution to the project. Chemical testing could also be undertaken at this time to support results of hedonistic testing

2. An article is prepared by AWIA for the *Australian Nutgrower* to share the results of this work with the wider nut industry.

3. Walnut quality parameters are selected, or developed further, to establish minimum (threshold) values for each quality parameter according to what each producer aspires to supply and what each customer is willing to buy. The methods booklet can be translated into a series of workflows and flow charts to suit the needs of individuals responsible for implementing the methods and/or collecting data in the future.

4. Selected walnut quality parameters are monitored throughout the supply chain, from storage on-farm through to receipt by one or more customers. Each sector in the supply chain is described in relation to the conditions and duration of storage. Such a study would reveal specific supply-chain sectors and/or durations of storage leading to large and/or unacceptable declines in walnut quality.

5. A logical framework for future research and development on walnut quality is developed. Such a framework would involve all potential collaborators to develop a common purpose and desired outcomes. It will also describe the objectives of the work to be conducted, who is best placed to conduct each activity and how diverse participants will interact to achieve the desired results, to manage risk and to maximise innovation across the Australian industry.

6. AWIA develops and supplies relevant and timely information to customers, including advertising material, to support the quality of Australian walnuts throughout the value chain.

7. AWIA continues to build a community of practice for sharing and managing knowledge about factors influencing walnut quality, including forums that promote co-learning through safe, open and honest discussion.

8 References

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