Rootstock Improvement for the Australian Avocado Industry - Phase 3

Dr Anthony Whiley
Sunshine Horticultural Services Pty Ltd

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Rootstock Improvement for the Australian Avocado Industry Phase III

A.W. Whiley *et al.*

FINAL REPORT

Sunshine Horticultural Services, NAMBOUR QLD 4560

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Project Leader: Dr Anthony W. Whiley AM, Sunshine Horticultural Services Pty Ltd, 287 Dulong Road, Nambour 4560. Phone (07) 544154412; Fax ((07) 54412292; Mob. 0427411541; email whileys@bigpond.com

Project Personnel: Dr Lindy Coates, Senior Principal Plant Pathologist, Horticulture and Forestry Science, Department of Agriculture, Fisheries and Forestry (DAFF) Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102. Phone 07 3255 4353 email Lindy.Coates@daff.qld.gov.au
Dr Peter Hofman, Senior Principal Horticulturist, Department of Agriculture, Fisheries and Forestry (DAFF) Queensland, PO Box 5083 SCMC, Nambour 4560. Phone (07) 5453 5968; Mob. 0407 173 608; email Peter.Hofman@daff.qld.gov.au
Dr Elizabeth Dann, Principal Plant Pathologist, Queensland Alliance for Agriculture & Food Innovation, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park QLD 4102; email Elizabeth.Dann@daff.qld.gov.au
Dr Ken Pegg AM, Post-retirement Associate, DAFF, Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102.
Dr Roberto Marques, Research Horticulturist, Department of Agriculture, Fisheries and Forestry (DAFF) Q, PO Box 5083 SCMC, Nambour 4560; email Jose.Marques@daff.qld.gov.au
Ms Jan Dean, Senior Laboratory Technician, DAFF, Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102.
Ms Louise Shuey, Laboratory Technician, DAFF, Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102.
Mr Luke Smith, Laboratory Technician, DAFF, Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102.
Mr Tony Cooke, Senior Experimentalist, DAFF, Queensland, Ecosciences Precinct, 2C West, 41 Boggo Road, Dutton Park, QLD 4102.
Mrs Barbara Stubbings, Senior Technician, Department of Agriculture, Fisheries and Forestry (DAFF) Q, PO Box 5083 SCMC, Nambour 4560; retired.
Jonathan Smith, Technician, Department of Agriculture, Fisheries and Forestry (DAFF) Q, PO Box 5083 SCMC, Nambour 4560; Johnson.Smith@daff.qld.gov.au
Mrs Dorothy G. Whiley, Secretary/Technical assistant, Sunshine Horticultural Services Pty Ltd. Nambour 4560; email whileys@bigpond.com

The "Rootstock Improvement for the Australian Avocado Industry" has run for approximately 10 years and has embraced propagation research, the study of rootstock agronomy and its impact on postharvest fruit quality. This document is the final project report and covers results from the last four years of the R&D program. It includes details on long-term rootstock performance, research on rootstocks with Phytophthora root rot resistance and postharvest fruit quality from production sites across Australia.

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Dr Tony Whiley AM

Contents

1. MEDIA SUMMARY 7

2. TECHNICAL SUMMARY 8

3. EXECUTIVE SUMMARY 10

3.1 Agronomic Performance of Rootstocks 10
3.1.1 Effect of rootstock race on yield 11
3.1.2 Seedling vs cloned rootstocks 11
3.2 High-yielding Rootstocks Identified from Experimental Sites 12
3.3 Phytophthora Tolerance, Tree Growth and Yield Data from the "Elite" Rootstock Recovery Program 12
3.4 Evaluation of Overseas (Spanish) Rootstocks 13
3.5 Affect of Rootstocks on Postharvest Performance of Fruit 13
3.5.1 Growing location 13
3.5.2 Seasonal variation 14
3.5.3 Seedling vs. clonal rootstocks 14
3.5.4 Rootstock race 14
3.5.5 The effect of rootstock on fruit skin nutrients 14
3.5.6 The effect of rootstock on fruit biochemical's potentially involved in disease resistance 15
3.5.7 Relationship between yield and postharvest fruit quality 15
3.6 Intellectual property 15
3.7 Technology Transfer 15

4. INTRODUCTION 16

5. AGRONOMIC PERFORMANCE OF ROOTSTOCKS 20

5.1 Introduction 20
5.2 Materials and Methods 20
5.3 Results and Discussion 22
5.3.1 Experiment 1 (Pemberton, WA) 22
5.3.2 Experiment 2 (Carabooda, WA) 27
5.3.3 Experiment 3 (Duranbah, NSW) 28
5.3.4 Experiment 4 (Hampton, Qld) 29
5.3.5 Experiment 5 (Childers, Qld) 33
5.4 Conclusions 48

6. HIGH-YIELDING ROOTSTOCKS IDENTIFIED FROM EXPERIMENTAL SITES 51

6.1 Introduction 51
6.2 Materials and Methods 51
6.3 Results and Discussion 51

7. PHYTOPHTHORA TOLERANCE, TREE GROWTH AND YIELD DATA FROM THE "ELITE" ROOTSTOCK RECOVERY PROGRAM 55

7.1 Introduction 55
7.2 Materials and Methods 55

8. EVALUATION OF OVERSEAS (SPANISH) ROOTSTOCKS 57

8.1 Introduction 57
8.2 Materials and Methods 57

8.3 Results and Discussion 57
9. RIVERLAND ROOTSTOCK EXPERIMENT 59
9.1 Introduction 59
9.2 Materials and methods 59
10. AFFECT OF ROOTSTOCKS ON POSTHARVEST PERFORMANCE OF FRUIT 60
10.1 Introduction 60
10.2 Materials and methods 60
10.3 Results 64
10.3.1 Childers QLD ('Hass') 2008 64
10.3.2 Childers QLD ('Hass') 2009 69
10.3.3 Childers QLD ('Hass') 2010 73
10.3.4 Hampton QLD ('Hass') 2008 77
10.3.5 Hampton QLD (Hass) 2009 81
10.3.6 Hampton QLD (Hass) 2010 85
10.3.7 Pemberton WA (Hass) 2008 89
10.3.8 Pemberton WA (Hass) 2010 93
10.3.9 Pemberton WA (Hass) 2012 97
10.3.10 Walkamin QLD (Hass) 2010 101
10.3.11 Walkamin QLD (Hass) 2011 105
10.3.12 Walkamin QLD (Hass) 2012 109
10.3.13 Walkamin QLD ('Shepard') 2009 113
10.3.14 Walkamin QLD ('Shepard') 2010 117
10.3.15 Walkamin QLD ('Shepard') 2011 121
10.3.16 Tree to tree variability in fruit quality and fruit minerals between seedling and clonal rootstocks 126
10.4 Discussion 129
11. INTELLECTUAL PROPERTY 132
11.1 'SHSR-04' 132
11.2 'SHSR-07' 132
11.3 'SHSR-08' 133
12. TECHNOLOGY TRANSFER 134
12.1 Conferences, Field days and Publications 134
13. REFERENCES 135
14. APPENDIX I 139
14.1 Site Plans of Rootstock Experiments 139
15. APPENDIX II 150
15.1 Field assessment of avocado rootstock selections for resistance to Phytophthora root rot 150

Key Recommendations

The “Rootstock Improvement for the Australian Avocado Industry” project has recently completed ten years of funding support. During this time regional rootstock experiments were established in Western Australia, New South Wales, Queensland and more recently South Australia. These experiments have been monitored for annual production and fruit quality (postharvest storage and disease potential) characteristics. Additionally, rootstocks with potential Phytophthora root rot resistance have been recovered from existing orchards, clonally propagated, grafted to ‘Hass’ and planted out and assessed. Key recommendations from this research are tabulated below:

- Cloned rootstock did not give a consistent productivity advantage over seedling rootstocks. Hence for orchards planted with no or low Phytophthora root rot pressure it is recommended that the Australian avocado industry continue to use well-credentialed seedling rootstocks that are responsive to phosphonate treatment, e.g. ‘A10’, ‘SHSR-02’ and ‘Velvick’.
- The top yielding rootstocks were from the Guatemalan and West Indian races, e.g. ‘A8’, ‘Nabal’, ‘Plowman’, ‘Reed’, ‘SHSR-02’, ‘V1’ and ‘Velvick’.
- ‘SHSR-04’ has high Phytophthora root rot resistance and should be commercialised for use by the Australian avocado industry.
- The project identified consistently high yielding trees and the rootstocks from these should be recovered, propagated and further assessed for high production using ‘Velvick[D]’ as the standard for comparison.
- The Guatemalan rootstocks ‘A10’ and ‘SHSR-03’, and the West Indian x Guatemalan rootstock ‘Velvick’, in general had a positive influence on ripe fruit quality (i.e. reduced disease and physiological disorders) in both ‘non-stored’ and ‘stored’ ‘Hass’ fruit, and in ‘non-stored’ ‘Shepard’ fruit, and should be used in new orchard establishment.
- Mexican rootstocks such as ‘Barr Duke’, ‘Duke 7’ and ‘Thomas’ should be avoided as they regularly caused negative quality issues in both ‘non-stored’ and ‘stored’ ‘Hass’ and/or ‘Shepard’ avocado fruit.
- Nitrogen (N) and calcium (Ca) concentrations (as well as N/Ca balances) in the skin of unripe avocado fruit at harvest appear to be one of the best indicators we have of fruit quality in ripe ‘Hass’ and ‘Shepard’ avocado fruit. The potential to use these parameters as pre-harvest predictors of fruit quality for industry should be further explored.
- Given the vast amount of fruit quality data generated in these rootstock experiments over the past five years, it is strongly recommended that further, more detailed statistical analysis of data be undertaken in order to maximize the amount of information extracted from the experiments. This should include further analysis of seedling versus clonally propagated rootstocks and tree yield versus fruit quality.
- Detailed molecular analyses should be undertaken to characterise the genetic parentage of rootstocks currently used, or under selection, in Australia. This has never been undertaken for Australian rootstock or scion material, much of which is unique to the Australian industry.

1. Media Summary

The "Rootstock Improvement for the Australian Avocado Industry" project was developed to address a number of key issues important to the long-term sustainability of avocado production in Australia. Namely these were to identify: 1) if clonally propagated rootstocks are superior (higher yields and improved fruit quality) to seedling rootstocks which have been historically used by the Australian industry; 2) do rootstocks from different horticultural races impact differently on crop performance when grafted to either 'Hass' or 'Shepard'; 3) will rootstocks perform differently across the range of environments where avocados are grown in Australia; and 4) can significant Phytophthora root rot resistance be located in rootstocks used by the Australian avocado industry. To address these issues rootstock experiments using both cloned and seedling material grafted to 'Hass' and 'Shepard' were planted in each significant production region in the country and their agronomic and postharvest fruit performance monitored for 3-6 years. Additionally, rootstocks identified with potential Phytophthora root rot resistance were cloned and evaluated in soils providing intense disease pressure.

The funding of this research had an immediate impact on the Australian avocado industry through creating grower-awareness of the importance of the selection of rootstocks when establishing a new orchard. Empowerment through knowledge led to a significant improvement in rootstock choices from the nursery's servicing the avocado industry.

From both agronomic and postharvest perspectives cloned rootstocks in general did not improve orchard or postharvest fruit performance with seedling rootstocks largely being equal to or in some cases better than their cloned genetic pair. Regarding productivity there was no single rootstock that had superiority across all production regions. However, the highest yielding rootstocks overwhelmingly came from the Guatemalan and West Indian horticultural races, e.g. 'A8', 'Nabal', 'Plowman', 'Reed', 'SHSR-02', 'V1' and 'Velvick'. Hybrids with Mexican and Guatemalan race genes were in the second most successful group, e.g. 'A10', 'Shepard', 'SHSR-03' and 'Zutano', whilst Mexican race rootstocks were overall the least represented group in the high performance echelon, viz. 'Barr Duke', 'Parida' and 'Thomas'. Although the influence of rootstocks on fruit quality varied according to growing location and year of assessment, a number of trends could be identified. In some experiments there were no significant effects of rootstock on fruit quality, but in other trials there were a number of differences. Some rootstocks (e.g. 'A10', ' SHSR-03', and 'Velvick') frequently had a positive influence on 'Hass' and 'Shepard' fruit quality (i.e. reduced flesh disorders after storage and the incidence of postharvest rots) compared to others (e.g. 'Barr Duke' and 'Duke 7' in 'Hass', or 'Thomas' and 'Duke 7' in 'Shepard'). Fruit with the highest postharvest quality often had the lowest N and highest Ca skin concentrations. This was supported by positive correlations between fruit quality and skin nutrient ratios of N/Ca, and negative correlations between fruit quality and skin nutrient ratios of Ca+Mg/K. These may be a useful diagnostic tool for predicting postharvest fruit performance.

The project also developed a new rootstock ('SHSR-04') with high Phytophthora root rot resistance, although some strategic chemical support will still be required to maintain good tree health under high disease pressure with trees in heavy crop.

2. Technical Summary

Avocado (*Persea americana* Mill.) has significant genetic diversity within the species. The three horticultural races that make up the species (*Persea americana* var. *drymifolia*; *Persea americana* var. *guatemalensis*; and *Persea americana* var. *americana*) are commonly designated the Mexican, Guatemalan and West Indian races after their perceived evolutionary centres (Whiley *et al*., 2002). Varieties within each race largely conform to specific common traits within the grouping, but hybridisation readily occurs between the races that are also "horticulturally" graft compatible. The majority of the world's avocado orchards are still growing on seedling rootstock, which results in genetic variability within and between orchards. Such variability reduces the effectiveness of orchard management and results in under performance.

Exploitation of useful genetic traits within each race to improve rootstock performance has only occurred on a limited scale. Examples are found in Israeli, where the industry has selected predominantly West Indian race rootstocks to combat saline water and calcareous soils while the Californian industry is largely based on Mexican race rootstocks to combat cold winter temperatures. More recently, Australian research has demonstrated opportunities to improve crop performance and reduce the incidence of fruit rots through rootstock selection (Thomas, 1997; Willingham *et al*., 2001). To capitalise on superior rootstocks, genetic uniformity through clonal propagation may be required. To date this technology has only been commercially developed for Mexican race material, which is the easiest group to clonally propagate (Reuveni and Raviv, 1981). However, at least subtropical Australia current indications are that beneficial rootstocks are more likely to be found in the more recalcitrant Guatemalan and West Indian gene pools. The broad objectives of this project were: 1) to compare clonally propagated with seedling rootstocks; and 2) to evaluate a genetically diverse group of rootstocks across the major production regions of Australia measuring agronomic and postharvest fruit performance. The studies were conducted with 'Hass' and 'Shepard as the scion varieties, with experiments planted at Walkamin (QLD), Childers (QLD), Hampton (QLD), Duranbah (NSW), Pemberton (WA) and Carabooda (WA). Additionally, the project identified and assessed rootstocks with potential Phytophthora root rot resistance. Results from clonal propagation research were reported in AV01007 and AV04007.

To compare the agronomic performance of cloned vs. seedling rootstocks five experiments (four grafted to 'Hass' and one to "Shepard') with clonal and seedling propagated rootstocks of the same variety (a total of 26 matched pairs across the five experimental sites) were studied. When assessing cumulative yield over the duration of the project (5-6 years yield data depending on site) there were no significant differences measured between 16 of the paired rootstocks. There were significant differences ($P \leq 0.05$) for cumulative yield between 10 of the rootstock pairs but of these seven pairs favoured the seedling rootstock and three pairs favoured the cloned rootstock. When rootstock yield variance was analysed between the seedling/cloned pairs in most cases there was no significant difference thereby challenging the preconceived concept that cloned rootstocks would increase uniformity between trees. Hence, the results from this project across the rootstocks selected for research, strongly favour seedling superiority with respect to yield performance over the longer term.

Rootstocks with the highest yields overwhelmingly came from the Guatemalan and West Indian horticultural races, e.g. 'A8', 'Nabal', 'Plowman', 'Reed', 'SHSR-02', 'V1' and 'Velvick'. Hybrids with Mexican and Guatemalan race genes were in the second most successful group, e.g. 'A10', 'Shepard', 'SHSR-03' and 'Zutano', whilst Mexican race rootstocks were overall the least represented group in the high performance echelon, viz. 'Barr Duke', 'Parida' and 'Thomas'. With respect to individual rootstock performance across all sites, 'Velvick' had the greatest consistency for high yield followed by 'Zutano' and 'V1'. However, other rootstocks performed highly at individual locations, e.g. the cumulative yield from cloned 'SHSR-03' grafted to 'Hass' and grown at Hampton was exceptional compared with other rootstocks (both seedling and cloned) and seedling 'Reed' has outperformed the other seedling rootstocks when grown in a disease-free site (until 2011) near 'Childers' (Table 35).

In 2004, 'SHSR-04' was identified as an escape tree in an orchard infested with *Phytophthora cinnamomi* at South Kolan, QLD. Subsequent field evaluation of a population of 'Hass' trees propagated to cloned 'SHSR-04' rootstock demonstrated genetic resistance to Phytophthora root rot. It is recommended that this rootstock be commercialised for use by the Australian avocado industry.

Fruit for postharvest assessment were either road transported or flown from remote sites to the laboratory for assessment within 24 hours after harvest. Fruit were either ripened at 23°C ('non-stored' fruit) or cold-stored for four weeks at 5°C and then ripened at 20°C ('stored' fruit). At the eating ripe stage (based on fruit softness), 'non-stored' fruit was assessed for flesh diseases, while 'stored' fruit evaluations included both external (e.g. skin colour and skin chilling injury) and internal (e.g. flesh diseases and physiological disorders) quality.

While the influence of rootstock on fruit quality did vary considerably according to growing location and year of assessment, a number of trends could be identified. In some experiments there were no statistically significant effects of rootstock on fruit quality, but in other experiments there were a number of differences. Both 'non-stored' and 'stored' 'Hass' fruit from trees on the Guatemalan rootstocks 'A10' and 'SHSR-03', and the West Indian rootstock 'Velvick', frequently had better fruit quality at eating ripe (i.e. reduced flesh diseases and physiological disorders) than fruit from trees on the Mexican rootstocks 'Barr Duke' or 'Duke 7'. 'Non-stored' 'Shepard' fruit from trees on 'A10' and 'SHSR-03' rootstocks often had less flesh disease than fruit from trees on the Mexican rootstocks 'Thomas' and 'Duke 7', whereas for 'cold-stored' 'Shepard' fruit there was little difference between rootstocks in external or internal quality in two out of three years.

At each of the four sites x three seasons evaluated in this project, fruit samples were taken at harvest from the rootstock/scion combinations selected and analysed for the major nutrients N, Ca, Mg and K concentrations as well as concentrations of biochemical's potentially involved in resistance of avocado to postharvest disease (phenolics and reactive oxygen species (ROS) enzymes - peroxidase and catalase). Although there was some variation in results, both 'non-stored' and 'stored' fruit from rootstock/scion combinations with the best fruit quality (in terms of disease and physiological storage disorders) often had the lowest skin N and highest skin Ca concentrations. This was supported by correlation analyses which showed positive correlations between fruit quality parameters and skin N/skin N/Ca ratios and negative correlations between fruit quality parameters and skin Ca/skin Ca+Mg/K ratios. Correlations between fruit biochemical's (skin phenolics and flesh ROS enzymes) and fruit quality were not as strong or consistent as nutrient correlations. Total tree yield and/or yield efficiency often correlated negatively with postharvest quality of both 'non-stored' and 'stored' fruit (i.e. fruit from high yielding trees tended to have lower levels of disease and physiological disorders than those from low yielding trees), although these correlations were generally not as strong as the correlations between nutrients (N and Ca) and disease. Based upon the results obtained in this project, N/Ca ratios in the skin of unripe avocado fruit at harvest time currently constitute one the best indicators we have to predict fruit quality in ripe fruit.

3. Executive Summary

The "Rootstock Improvement for the Australian Avocado Industry" project was developed to address a number of key issues important to the long-term sustainability of avocado production in Australia. Namely these were to identify: 1) if clonally propagated rootstocks are superior (higher yields and improved fruit quality) to seedling rootstocks which have been historically used by the Australian industry; 2) do rootstocks from different horticultural races impact differently on crop performance when grafted to either 'Hass' or 'Shepard'; 3) will rootstocks perform differently across the range of environments where avocados are grown in Australia; and 4) can significant Phytophthora root rot resistance be located in rootstocks used by the Australian avocado industry.

Genetically diverse lines exist in horticultural races found within the *Persea americana* Mill. species but exploitation of this diversity has only occurred on a limited scale. Examples are found in Israeli, where the industry has selected predominantly West Indian race rootstocks to combat saline water and calcareous soils while the Californian industry is largely based on Mexican race rootstocks to combat cold winter temperatures. More recently, Australian research has demonstrated opportunities to improve crop performance and reduce the incidence of fruit rots through rootstock selection (Thomas, 1997; Willingham *et al*., 2001). To capitalise on superior rootstocks, genetic uniformity through clonal propagation may be required. To date this technology has only been commercially developed for Mexican race material, which is the easiest group to clonally propagate (Reuveni and Raviv, 1981). However, at least in subtropical Australia current indications are that beneficial rootstocks are more likely to be found in the more recalcitrant Guatemalan and West Indian gene pools.

To address the issues numerated above, experiments using both cloned and seedling rootstock material from the three horticultural races that make up the species (*Persea americana* var. *Drymifolia*, Mexican; *Persea americana* var. *Guatemalensis*, Guatemalan; and *Persea americana* var. *Americana*, West Indian), were grafted to 'Hass' and 'Shepard' and planted in each significant production region in the country and their agronomic and postharvest fruit performance monitored for 3-6 years. Additionally, rootstocks identified with potential Phytophthora root rot resistance were cloned and evaluated in soils providing intense disease pressure.

The Executive Summary documents key results achieved from research carried out in this project which is detailed in Chapters 5 to 10.

3.1 Agronomic Performance of Rootstocks

Avocados were introduced into Australia during the mid-1800 aboard sailing ships that crossed the Pacific Ocean carrying miners to the gold fields. This traffic brought a rich genetic diversity of avocados from the Central American countries that included representatives from the three horticultural races. Seed planted along the New South Wales and Queensland coastlines matured into bearing trees which in many cases hybridized with nearby neighbours further amplifying genetic variability. As interest in commercial production of avocados developed in Australia seeds from this population of trees were gathered for propagation and hence became the foundation of rootstocks used by the industry. As a consequence the Australian avocado industry was planted on the most genetically diverse population of rootstocks when compared with other avocado-growing countries. Due to the lack of investment into rootstock research by the Australian industry prior to 2002 our knowledge in this area was very limited with a high potential for improvement.

The agronomic component of the project was designed to answer several questions on rootstocks for Australian avocado growers which are summarised as:

1. Is there any specific genetic group (horticultural race) with enhanced compatibility when grafted to 'Hass' or 'Shepard' that will consistently improve yield?
2. Will different rootstocks be more suited for each production region across the country considering significant differences in environmental (both soils and climate) conditions?
3. Will the use of cloned rootstocks enhance production over the seedling rootstocks currently used through providing greater genetic uniformity?

3.1.1 Effect of rootstock race on yield

In answering the three points above the top yielding rootstocks overwhelmingly come from the Guatemalan and West Indian horticultural races, e.g. 'A8', 'Nabal', 'Plowman', 'Reed', 'SHSR-02', 'V1' and 'Velvick'. Hybrids with Mexican and Guatemalan race genes were in the second most successful group, e.g. 'A10', 'Shepard', 'SHSR-03' and 'Zutano' whilst Mexican race rootstocks were overall the least represented group in the high performance echelon, viz. 'Barr Duke', 'Duke 7', 'Parida' and 'Thomas'. Based on numerical ranking of performance across all sites 'Velvick' (3.35) has led the field followed by 'Zutano' (2.92) and 'V1' (2.5). However, this doesn't mean that only these three rootstocks should be considered for planting in Australia. For example, the cumulative yield from cloned 'SHSR-03' grafted to 'Hass' and grown at Hampton was exceptional when compared with other rootstocks (both seedling and cloned) at this site and seedling 'Reed' has outperformed the other seedling rootstocks when grown in a disease-free site (until 2011) near 'Childers'.

3.1.2 Seedling vs cloned rootstocks

Many highly improved tree and vine fruit crops, e.g. apples, citrus, table grapes have developed genetically uniform rootstocks that are vegetatively propagated for their production systems. Providing the rootstocks chosen enhance crop production it is logical that genetic uniformity should improve total production measured as tonnes produced per hectare of planted land. It was with this expectation that seedling vs. cloned avocado rootstocks studies were set up in this project. Five experiments compared seedling rootstocks with clonally propagated rootstocks of the same variety and a total of 26 pairs were matched across the experimental sites. When comparing cumulative yield over the duration of the project (5-6 years yield data depending on site) there were no significant differences measured between 16 of the paired rootstocks. There were significant differences ($P \leq 0.05$) for cumulative yield between 10 of the rootstock pairs but of these seven pairs favoured the seedling rootstock and three pairs favoured the cloned rootstock. When rootstock yield variance was analysed between the seedling/cloned pairs in most cases there was no significant difference thereby challenging the preconceived concept that cloned rootstocks would increase uniformity between trees. Hence, the results from this project across the rootstocks chosen for research, strongly favour seedling superiority with respect to yield performance over the longer term. Selection of seed for this study was rigorous with material being sourced from maternal trees that were unlikely to be out-crossed with other varieties thus limiting genetic diversity to that contained in the parent tree. The potential for out-crossing to change seedling performance is demonstrated in the results of Smith *et al*. (2011) who found when 'Hass' was grafted to two 'Velvick' seedling lines where the maternal trees had difference out-crossing opportunities yield was significantly different. The significance of this result should be checked with molecular studies to determine the extent of genetic variance among seedling lines of the same variety from sources with different out-crossing opportunities since this may significantly change the management of seed production for nursery use. For example, it may demonstrate that there are significant commercial benefits to be gained from producing seed for nursery use in isolation from out-crossing during flowering.

Despite the overall under-performance of cloned rootstocks there were four exceptions where a cloned rootstock was the highest yielding (although not significantly different to all rootstocks) in the experimental pool of varieties (both seedling and cloned). At Pemberton the cloned 'Zutano' rootstock grafted to 'Hass' produced 36% more fruit over the five year cropping cycle compared with cloned 'A10' which was the next highest yielding rootstock at this site but was not significantly different ($P \leq 0.05$). Cloned 'SHSR-03' grafted to 'Hass' was the highest yielding rootstock over the six-year cropping cycle at Hampton but was not significantly different to seedling 'A10', seedling 'Nabal', seedling and cloned 'Velvick' and seedling and cloned 'Zutano'. At Childers, cloned 'V1' grafted to 'Hass' was the highest yielding rootstock (499.5 $kg.tree^{-1}$) at this site but was not significantly different to seedling 'Velvick' (456.4 $kg.tree^{-1}$). 'V1' is a seedling selection of 'Velvick' which has not been offered for sale hence it would be eligible for Plant Breeders Rights however, it was not exceptional as a seedling and is quite difficult to commercially clone although with further propagation research this may be overcome.

3.2 High-yielding Rootstocks Identified from Experimental Sites

In a commercial orchard at Hampton, Thomas (1997) identified a small number of avocado trees grafted to seedling rootstocks that consistently yielded higher than the other trees in the block over a 6-year period. This project has provided the opportunity to assess the productivity of 600 rootstocks over 5-6 years cropping when grown at various locations across Australia. Individual rootstocks were considered to crop higher than their peers when cumulative yield over the full period was at least 120% higher than the mean of the 10 replications of the genetic line and 170% of the mean yield of the total seedling rootstock population at the experimental site.

At Pemberton, two rootstocks were identified as potential elite yielding lines. These were 'A10' and 'Toro Canyon' seedlings. It is of interest that both rootstocks have Mexican race genes; 'A10' is thought to be a Guatemalan x Mexican race hybrid whilst 'Toro Canyon' is a straight Mexican race variety. 'Zutano' is a Mexican race variety and when propagated as a clone at this site was the highest producing rootstock compared with other cloned rootstocks in the experiment. Pemberton is the coldest experimental site in this program and Mexican race lines are known for their greater cold tolerance when compared to Guatemalan and West Indian race material. Hence it may not be coincidental that the highest yielding individuals at this site come from a gene pool of higher cold tolerance.

Using the selection criteria three potential high yielding lines were identified at Hampton: 'Nabal', 'Plowman' and 'Velvick'. Of these, 'Velvick' is of the greatest interest since this line has been amongst the highest yielding at other experimental sites across the project.

At the Childers site the 'V1' rootstock grafted to 'Hass' was identified as being potentially high yielding. As a cloned rootstock 'V1' produced the highest yield of all rootstocks at this site. Seedling 'Plowman' grafted to 'Shepard' growing at the Childers site also met the selection criteria for above average yielding rootstocks. 'Shepard' production overall at this site was less than a similar experiment at Walkamin which has a more favourable climate for this variety.

The 'Hass' experiment at Walkamin produced the largest number of rootstocks with potential for above average yields. During its establishment this site was affected by Cyclone Larry and kangaroo damage to trees which resulted in greater variability between trees that may have led to the larger population of out-performing rootstocks. Careful examination of individual trees should be undertaken before rootstock recovery attempts are made from this site. 'Shepard' grafted to seedlings resulted in six rootstocks with above average yield over the six years of data collection. Rootstocks in this group include 'A8', 'SHSR-02', 'Velvick' (x2), and 'V1' (x2). Individual 'SHSR-02' and 'Velvick' rootstocks have been identified at some of the other experimental sites suggesting that the gene pools of these seedlings may have a higher number of individuals with above average yield potential.

For the most part the identified "elite" trees have shown either a consistent increase in production or a mild alternate bearing trend over the 5-6 years of recorded data. This is in contrast to most other trees in the experimental population that have already developed a significant alternate bearing pattern despite all things being equal with respect to management at each site. This pattern supports the earlier data of Thomas (1997) that demonstrated that over a six-year period some individual 'Hass' trees grafted to a seedling rootstock population out-performed their peers by maintaining consistent high yields without reverting to alternate bearing. This suggests that in some trees there is a genetic influence on yield stronger than environmental and management factors.

3.3 Phytophthora Tolerance, Tree Growth and Yield Data from the "Elite" Rootstock Recovery Program

The "elite" rootstock component of this project has focussed on identifying, recovering and further evaluating rootstocks in the field that showed extraordinarily high levels of resistance to Phytophthora root rot (PRR) compared with the population of surrounding trees. Additionally, rootstocks selected for evaluation within the project and established in replant sites have also been evaluated for their resistance to PRR and where appropriate have been further tested. To date the only significant resistance to PRR has been identified in the 'SHSR-04' rootstock which was recovered from an orchard in South Kolan (near Bundaberg) and its PRR resistance in an infested soil has been well documented (Smith *et al*., 2010).

The rootstock trial at Walkamin was established in a Phytophthora-infested soil and the seedling rootstock 'SHSR-02' indicated an above average level of PRR resistance in the early years of growth. A population of 'SHSR-02' seedling rootstocks grafted to 'Hass' scions was planted in the PRR-infested site at Duranbah along with a population of 'A10'/'Velvick' seedling hybrid rootstocks and disease resistance monitored. Initially six rootstocks were selected from this population (five 'SHSR-02' seedlings and one 'A10/'Velvick' seedling) for recovery and further testing. After the extremely wet summer of 2011 this has been reduced to one 'SHSR-02' seedling know known as 'SHSR-07' and the 'A10'/'Velvick' seedling known as 'SHSR-08'. These two lines have been cloned and a population of 10 trees of each rootstock will be planted in May 2013 (post-project) at the Duranbah PRR-infested site where they will be compared to 'SHSR-04', 'SS3-1' (from Spain) and 'Dusa' (from South Africa).

3.4 Evaluation of Overseas (Spanish) Rootstocks

At the V World Avocado Congress held in Spain Ms Luisa Gallo-Llobert presented data on the *Phytophthora cinnamomi* resistance of three avocado rootstocks ('Gema', 'Maoz' and 'SS3-1') that had been evaluated in the Canary Islands. Subsequently these rootstocks were imported to Australia where they have been cloned, grafted to 'Hass' and evaluated at Tolga (North Queensland) in a replant site heavily infested with *Phytophthora cinnamomi*.

Results from this study showed Phytophthora root rot tolerance of 'Gema' and 'Maoz' documented in the Canary Islands did not compared favourably with the locally selected rootstock 'SHSR-04' when evaluated at Tolga, NQ. However 'SS3-1' has produced a credible result and is worthy of further research. It is intended to include 'SS3'-1 in a new evaluation trial to be planted in *Phytophthora cinnamomi* infested soils at Duranbah, northern NSW in May 2013 (post-project). The disappointing results from 'Gema' and 'Maoz' may be due to strong environmental differences between the Canary Islands (dry Mediterranean) compared with North Queensland (summer-wet subtropical) and further work on these two lines is not recommended.

3.5 Affect of Rootstocks on Postharvest Performance of Fruit

Given the wide variation in growing environments included in this study, combined with seasonal variation at individual sites, rootstock/scion, cultivar/race and propagation method, it is not surprising that there was a high degree of variation in results across the study. Despite this however, we have seen a number of trends emerge from the vast amount of data collected from 2008 to 2012. These trends are discussed below in relation to the principal variables studied in this evaluation:

3.5.1 Growing location

In this study a number of the rootstocks were evaluated at multiple sites, and in some instances at every site. Examples of the latter included clonal 'A10', 'Duke 7', 'Velvick' and 'Zutano'. Overall, fruit harvested from 'Hass' or 'Shepard' trees grafted to clonal 'A10' rootstock performed well at most sites in terms of fruit quality, both in relation to 'stored' and 'non-stored' fruit. Fruit from trees on clonal 'Velvick' also often performed well, but there were some instances where both fruit marketability ('non-stored' fruit) and % of sound fruit ('stored' fruit) were relatively low, such as at the Walkamin 'Hass' site in some years. Fruit from trees on clonal 'Zutano' generally performed well at the Pemberton site in relation to the percentage of sound (stored) fruit, but the rootstock was not a consistently good performer across all sites. Fruit quality was frequently poor in fruit from trees on clonal 'Duke 7' rootstock at all sites.

There were sites differences in postharvest performance of 'Hass' fruit from trees on clonal 'Reed' rootstock evaluated at Hampton, Pemberton and Walkamin. Fruit from trees on clonal 'Reed' at Hampton often had poor quality compared to fruit from trees on a number of other rootstocks (particularly non-stored fruit but also stored fruit), whereas equivalent fruit at Pemberton performed much better. Results for 'Reed' at Walkamin were less conclusive due to a general lack in significant differences between rootstocks, although the rootstock did perform well in 2012 in terms of the percentage of sound (stored) fruit.

As was the case for fruit from trees on clonal 'A10' rootstock, those on clonal 'SHSR-03' also tended to perform well in terms of fruit quality across several sites (although it was not evaluated at Pemberton).

3.5.2 Seasonal variation

While there was some variation in the performance of rootstocks from year to year at each site, generally trends could be seen in terms of the best and worst performing rootstocks. For example, at the Pemberton site, non-stored fruit from 'Hass' trees on clonal 'Barr Duke' were consistently the lowest quality in terms of postharvest disease in each of the three years in which evaluations were done, whereas equivalent fruit from trees on clonal 'A10' were always of comparatively high quality. Similarly at Hampton, non-stored fruit from 'Hass' trees on clonal 'Reed', 'Duke 7' and 'Hass' performed poorly across the three seasons compared to non-stored fruit from 'Hass' trees on clonal 'SHSR-03', 'A10' and 'Velvick' which performed consistently well. At Walkamin, non-stored fruit from 'Shepard' trees on clonal 'Thomas' rootstock were consistently of the lowest quality across the three seasons, whereas those on clonal and seedling 'A10', seedling 'SHSR-03' and 'Velvick' generally performed well in most evaluations. In all three locations, there were similar differences between rootstocks for 'stored' fruit in only one out of three seasons, with little significant differences in the other two seasons.

3.5.3 Seedling vs. clonal rootstocks

A comparison of seedling and clonally propagated rootstocks was undertaken at Childers on 'Hass' trees and at Walkamin on 'Shepard' trees. In terms of percentage marketable (non-stored) fruit and percentage sound (stored) fruit at the Childers or Walkamin sites, there was no indication that fruit from trees on either seedling or clonally propagated rootstocks performed better than the other.

There were also little differences in terms of the tree to tree variances between rootstocks of common origin for some key quality attributes and skin minerals in both locations over 2-3 seasons. Thus, the common belief that clonally propagated rootstocks would be less variable than seedling ones is not supported by the evidence provided by this research.

3.5.4 Rootstock race

Studies conducted prior to the commencement of this project (Willingham *et al*., 2001, 2006; Marques *et al*., 2003; Anderson *et al*., 2003) provided preliminary evidence that fruit quality parameters may be influenced by the "compatibility" of rootstock and scion race. In particular, fruit from 'Hass' trees grafted to Mexican race rootstocks such as 'Duke 6' and 'Parida' were shown to have higher levels of postharvest disease, particularly anthracnose, than those grafted to Guatemalan/West Indian race rootstocks. In this project fruit from 'Hass' (Guatemalan x Mexican hybrid) and 'Shepard' (Mexican x Guatemalan hybrid) trees grafted to a range of Guatemalan, West Indian and Mexican race rootstocks were evaluated for postharvest fruit quality. Results obtained in this project on 'Hass' fruit support these previous studies in the most part, in that we frequently found fruit from 'Hass' trees on Mexican race rootstocks such as 'Barr Duke' and 'Duke 7' performed poorly in terms of fruit quality compared to those from trees on predominantly Guatemalan (e.g. 'A10', 'SHSR-03') and 'West Indian' (e.g. 'Velvick') rootstocks. However, if race compatibility is a key factor, then one might expect that fruit from 'Shepard' (Mexican) trees would perform better when the scion is grafted to a Mexican rootstock, which was not necessarily what we found. Non-stored fruit from 'Shepard' trees grafted to the Mexican rootstock 'Thomas' were consistently of the lowest quality (in terms of postharvest disease), and those from trees on clonal or seedling 'Duke 7' (Mexican) had similar levels of poor quality in the third season of 'Shepard' trials (2011).

Detailed molecular analyses should be undertaken to characterise the genetic parentage of rootstocks currently used, or under selection, in Australia so that there is no error in the future interpretation of data.

3.5.5 The effect of rootstock on fruit skin nutrients

Previous studies (Willingham *et al*., 2001, 2006; Marques *et al*., 2003; Anderson *et al*., 2003) have indicated that nutrient levels (particularly N and Ca) in avocado fruit skin and leaves may be related to rootstock-mediated resistance to postharvest disease as well as other quality parameters. At each of the four sites evaluated in this project, and in each of the three seasons, fruit skin samples were taken at harvest for all of the rootstock x scion combinations evaluated and analysed for the major nutrients

N, Ca, Mg and K. Although there is variation in results, it was often found that fruit from rootstock x scion combinations with the best fruit quality (in terms of disease and physiological storage disorders) had the lowest skin N levels and highest skin Ca levels. This was supported by correlation analyses which showed positive correlations between fruit quality parameters and skin N levels/skin N/Ca ratios, and negative correlations between fruit quality parameters and skin Ca levels/skin Ca+Mg/K ratios. Based upon the results obtained in this project, N/Ca ratios in the skin of unripe avocado fruit at harvest time currently constitute one the best indicators we presently have of predicting fruit quality in ripe fruit.

3.5.6 The effect of rootstock on fruit biochemical's potentially involved in disease resistance

In the initial stages of the project, concentrations of total soluble phenolic compounds in the skin of fruit taken from all clonal rootstock x scion combinations were measured at harvest, and also in fruit starting to ripen ("sprung" fruit) and ripe fruit ("eating-ripe"). However in most cases there were no significant effects of rootstock on concentrations of phenolic compounds at the three different stages, and so future analyses were only done on fruit skin at harvest time. Throughout the project there continued to be little meaningful correlation between fruit skin phenolic concentration and postharvest fruit quality parameters. Similarly, the enzymes, catalase and peroxidase, have not to date been strong indicators of fruit disease resistance like fruit N and Ca have. Some correlations between these enzymes and disease have been found, but have not been strong or consistent.

3.5.7 Relationship between yield and postharvest fruit quality

Total tree yield and/or yield efficiency often correlated negatively with the incidence of postharvest disease and physiological disorders, i.e. fruit from high yielding trees tended to have lower disease and disorder levels. While these correlations tended to be weaker and less frequently observed than the correlations between N/Ca and disease, they still constitute an important finding of the study and confirm other studies (Cutting and Vorster, 1991; Hofman *et al*., 2002).

3.6 Intellectual property

Plant improvement research provides the opportunity to develop new genetic material that can be protected through Plant Breeder's Rights. This project has been continually recovering and testing genetic material that has the potential to improve avocado production both at the domestic and international level. Performance criteria being evaluated for rootstocks are high sustainable yields, anthracnose resistance imparted to fruit and Phytophthora root rot resistance. Success has been achieved in identifying rootstocks ('SHSR-04', 'SHSR-07' and SHSR-08') with commercial levels of Phytophthora root rot resistance. At the time of completing this report a decision had been made to proceed with the commercialisation of 'SHSR-04' whilst 'SHSR-07' and 'SHSR-08' will be further evaluated.

3.7 Technology Transfer

Throughout the duration of the project the Australian avocado industry was kept updated by all project participants on results as they became available via presentations at field days and national and international conferences. Additionally, papers were published in peer refereed journals. A series of articles with final results and recommendations to industry will be published in Talking Avocados during 2013 and 2014.

4. Introduction

Productivity of fruit tree crops is known to be intrinsically dependent on the choice of rootstock, whether it be either their ability to resist diseases or to impart higher production to the scion through the enhancement of physiological processes. The apple and citrus industries are clear examples where fruit production has been improved by rootstock selection that in many cases are specific to scion and soil type. It has also been shown that rootstocks can influence citrus fruit quality through the expression of rind thickness and pulp recovery.

In California, Webber (1926) commented "no factor of the avocado industry is more important than rootstocks, and there is no problem that we know less about, or which requires a longer time to solve." Since then a considerable body of knowledge has been accumulated on the effect of rootstocks on salinity and alkalinity tolerance, mineral nutrient uptake and Phytophthora root rot (PRR) tolerance (Gabor *et al*., 1990; Whiley *et al*., 1996; Kremer-Köhne and Duvenhage, 2000; Lahav and Whiley, 2002; Mickelbart, *et al.* 2007; Menge *et al.,* 2012; Lahav *et al.,* 2013). Additionally, publications have presented evidence of the effect of rootstocks on alternate bearing (Thomas, 1997; Mickelbart *et al*. 2007) which can be a production problem in many tree-fruit crops. However, despite the documented differences in environmental and edaphic responses between the botanical races of *P. americana*, with the exception of the Israeli rootstock program there has been little progress made on the selection and development of avocado rootstocks to improve productivity and fruit quality. Considerable effort has been expended on the search for *Phytophthora*-resistant rootstocks. The long-term investment into *Phytophthora*-resistant rootstocks has recently begun to pay dividends with the commercialisation of 'Dusa' from South Africa (Kremer-Köhne and Mukumo, 2003) and 'Zentmyer', 'Uzi' and 'Steddom' in California (Menge, 2012). However, while these rootstocks have a commercial level of *Phytophthora*-resistance they still require fungicidal support when grown under conditions of high disease pressure, viz. most eastern Australia production regions and the southern production regions of Western Australia. Biotechnology to develop inter-specific hybrids through protoplast fusion techniques has been researched in Florida (Pliego-Alfaro, 2001) but this line of investigation has been discontinued. In recent years biotechnology research has focussed on genetic transformation (Pliego-Alfaro *et* al., 2013) with Mitter *et al.* (2011) using embryogenic cells with hairpin RNA contructs aimed at *P. cinnamomi* essential genes. A transgenic line has been recovered and is undergoing multiplication before being challenged with *P. cinnamomi*.

The efficiency of commercial fruit growing is generally increased by selecting the best performing varieties for an area and reducing or eliminating the genetic variability between production units. For a chosen avocado variety this is relatively simple as scions are grafted onto rootstocks however, in Australia the latter are mostly of seedling origin with wide genetic diversity. The rootstock cloning technique of Frolich and Platt (1972) and the various modifications that have since developed (Ernst *et al*., 2013) have provided the technology to produce genetic uniformity in avocado orchards. This has mostly been exploited to retain levels of "*Phytophthora* root rot resistance" with trees grafted to cloned 'Duke 7' and more recently other elite rootstocks ('Dusa') that have been identified with resistance to this disease. Such trees have been widely planted in California and South Africa. A copy tree program has also been carried out in Israel where the rootstock and scion of high performance trees have been cloned and replanted in orchards. It is claimed that this program has been responsible for marked increases in avocado production in this country (Ben-Ya'acov and Michelson, 1995). Such a program has also been proposed for Australia by Thomas (1997) based on the identification of superior performing trees through perusal of orchard records.

There is no published data available from any country comparing the production from trees grown on cloned rootstocks to those on seedling rootstocks from the same maternal source although Köhne (unpublished data, Tzaneen, 2002) has stated that cloned rootstocks significantly out-yielded seedling rootstocks when evaluated in South Africa. Due to the high cost of cloning trees under Australia conditions, reliable comparative data on the performance of cloned and seedling rootstocks is required to validate which material is best used by industry.

There is increasing evidence of significant pre-harvest/postharvest interactions in horticultural products, as highlighted by several reviews (Arpaia, 1994; Hofman *et al*., 2002a) (Hofman and Smith, 1994; Hewett, 2006). The root system of trees (either own or rootstock) as well as the graft union between rootstock and scion, can significantly affect canopy and fruit performance. For example, fruit from declining 'Hass' trees (presumably because of PRR) can have less disease on the ripe fruit than on fruit from healthy tree (Witney *et al.*, 1990). Understanding the effects of tree constituents on fruit quality could indicate mechanisms whereby rootstocks may influence fruit quality.

Minerals concentrations have been implicated in several aspects of fruit quality. 'Hass' fruit with higher flesh calcium (Ca) concentrations at harvest often ripen more slowly (Cutting and Bower, 1990; Hofman *et al.*, 2002b) and have less disease in the ripe fruit (Hofman *et al.*, 2002b). There is also a general relationship between higher crop load (Hofman *et al.*, 2002b; Kruger *et al.*, 2004; Hofman and Mullen, 2005), less vigorous trees (Vorster *et al.*, 1989) and smaller fruit (Hofman *et al.*, 2002b), with less diseases. The relationship between high avocado fruit Ca concentration and reduced flesh disorders is also well established (Thorp *et al.*, 1997; Hofman *et al.*, 2002b; Willingham *et al.*, 2004). Potassium (K) and magnesium (Mg) have also been implicated in avocado fruit disorders, and often through ratios such as (Mg+K)/Ca or (Ca+Mg)/K (Witney *et al.*, 1990; Vuthapanich, 2001; Willingham *et al.*, 2006; Hofman *et al.*, 2007).

High avocado fruit nitrogen (N) is often associated with more flesh disorders and rots, and quicker ripening (Abou-Aziz *et al.*, 1975; Arpaia *et al.*, 1996). 'Pinkerton' fruit in South Africa obtained from trees grown in mesic areas, on fairly fertile soils with high organic matter content often had higher fruit N, and more flesh disorders after storage than those from trees grown on more stressful sandy soils in a slightly cooler climate (van Rooyen and Bower, 2005). Similar relations between higher fruit N concentrations and more rots and disorders have been observed in 'Hass' (Marques *et al.*, 2003; Willingham *et al.*, 2006). Higher N could affect fruit quality by increasing vegetative growth and competition with the fruit, thereby reducing fruit Ca concentrations (Shear and Faust, 1975) or carbohydrate reserves, or reducing cell wall thickness and increasing fruit softening during storage (van Rooyen and Bower, 2005).

The effects of crop load and tree vigour may also be through fruit size and fruit mineral concentrations (Hofman *et al.*, 2002b). Also, factors increasing tree vigour apart from N, such as reduced PRR pressure, can increase flesh diseases (Willingham *et al.*, 2004).

Plant growth regulators (PGRs) other than ethylene can influence ripening. Cultar® (paclobutrazol) application at flowering can delay ripening (Vuthapanich *et al.*, 1995), but this may be through delayed maturity or higher Ca concentrations in the fruit (Vuthapanich, 2001).

Other fruit constituents during fruit growth may influence postharvest performance. Anti-fungal dienes are natural fruit constituents that are in relatively high concentrations in non-ripe fruit but declined during fruit ripening in line with the increase susceptibility to disease development (Prusky and Keen, 1993). The 7 carbon (C7) sugars in the mesocarp may also be important. The double bond in mannoheptulose provides powerful water-soluble anti-oxidant properties, which may be a first line of defence against the negative effects of reactive oxygen species (ROS) associated with diene destruction (Tesfay *et al.*, 2010). It is possible that greater vegetative vigour reduces C7 sugar allocation to fruit, thus reducing anti-oxidant capacity and increasing susceptibility to flesh disorders. Hence, production conditions which optimize sugar reserves in fruit at harvest may reduce flesh quality loss during storage and ripening.

There is some evidence that physiological incompatibility at the inter-racial level may be affecting crop performance, particularly with respect to fruit quality. For instance, it is known that trees of the same variety grafted to Mexican or Guatemalan race rootstocks will have different mineral nutrient profiles (Haas, 1950; Whiley *et al.*, 1996; Bard, 1997; Lahav and Whiley, 2002; Mickelbart *et al.*, 2007). Similarly, different race rootstocks change the carbohydrate accumulation profile in trees of the same variety, which is known to drive productivity (Whiley, 1994).

Early research into the effects of irrigation on 'Hass' trees noted considerable variation in fruit quality between adjacent trees (Vuthapanich, 2001; Hofman *et al.*, 2002b). The trees were on apparently similar soils and with similar canopy characteristics, but on seedling rootstocks of unknown original. The most likely explanation for this tree-to-tree variation was a rootstock effect on scion fruit quality, which was later verified by specific trials comparing the quality of 'Hass' fruit on several known rootstocks (Willingham *et al.*, 2001; Hofman *et al.*, 2002b; Marques, 2003; Willingham *et al.*, 2006). The results have often shown that less disease develops in fruit from trees grafted to 'Velvick' (West Indian race) compared to fruit from trees grafted to 'Duke 6' (Mexican race), and that fruit Ca, K, Mg and N concentrations are often in agreement with the general relationships described above.

The earlier studies used a relatively narrow genetic base of material and this requires expansion before conclusive results can be obtained. Knowledge from such studies is important in the context of avocado production in Australia, which straddles a diverse range of soil types and environments. These range from the deep, red clay loams of the summer rainfall, subtropics through to the sands of the semi-arid, winter rainfall regions of Western Australia. With such diverse climate and soil conditions it is unlikely that one rootstock line will perform well in all situations. For example, 'Velvick' is a vigorous rootstock when used in subtropical Australia but when grown in California there are difficulties with establishment and growth of trees is slow (J. Menge, Riverside, 1996, personal communication). In the latter environment, Mexican race types are favoured as rootstocks. Additionally, if inter-racial incompatibility proves to be a problem then it is likely that scion lines will require different rootstocks, e.g. 'Hass' is predominantly Guatemalan while 'Shepard' is predominantly Mexican race.

The broad objectives of this project were to evaluate (impact on yield and fruit quality) a genetically diverse group of rootstocks grown in the major production regions of Australia and to develop suitable vegetative propagation systems that retain genetic uniformity between trees. Due to the high cost of labour comparative to other countries the project assessed the "accepted" advantage of using genetically identical rootstocks (vegetatively cloned) compared to a heterozygous seedling population. The 10-year project was broken up into three contracted terms which are detailed below:

Phase I of this project (AV01007, 1/1/2002 – 31/12/2004) included a Study Tour to South Africa, New Zealand and the USA where on return clonal propagation methodology used in various countries was investigated and the Ernst micro-propagation technology was adapted to propagated a range of commercial rootstocks (both seedling and cloned) from the various horticultural races. Rootstock field experiments using both seedling and cloned rootstocks were planted in the major commercial production districts in Australia. Rootstock material was imported from California and Spain and on release from Quarantine was propagated and prepared for evaluated. Highlights from AV01007 include:

1. Seed scarification significantly improved seed germination with seed scoring (four cuts longitudinally from pole to pole or removal of seed tips) having the greatest effect while seed coat removal also reduce germination time.
2. Research carried out in this project demonstrated that minimal wounding (a single stem cut) for KIBA application was sufficient for easily rooted (Mexican race) rootstocks but Guatemalan and West Indian race rootstocks required a 360° stem-wound for the development of good rooting.
3. There are significant differences in the sensitivity of rootstock leaves to anthracnose which is related to racial origin. Mexican-race rootstocks were highly sensitive to leaf lesions when grown under high humidity conditions while Guatemalan lines were moderately sensitive and the West Indian race lines highly resistant.

Phase II of this project (AV04007, 1/1/2005 – 30/06/2008) continued to research clonal propagation techniques for avocado rootstocks as well as monitor growth and record yields from the field experiments established in Phase I of the project. Additionally the project propagated and supplied trees for use by the QDPIF (now DAFF Qld) plant pathology team for their R&D program (AV07000). Highlights from AV04007 include:

1. Clonal propagation studies with rootstocks from the three botanical races showed that KIBA at 0.8% was the most effective concentration for rooting vegetative material while a post-etiolation temperature of 27°C gave improved rooting compared with 21°C.
2. In experimental replant sites previously infested by *Phytophthora cinnamomi* the most effective control of the disease was from the rootstocks 'SHSR-02' and 'Velvick' seedlings grafted to 'Hass'. When grafted to 'Shepard' the most resistant root rot rootstocks were 'SHSR-02', 'Velvick', 'V1' and 'Shepard' as a clone.
3. Mexican race rootstocks used in the experiments were significantly more susceptible to Phytophthora trunk canker than rootstocks from the Guatemalan and West Indian races.

Phase III of this project (AV08000, 1/7/2008 – 1/3/2013) has focussed on recording yields and postharvest performance of fruit from the regional rootstock trials planted in most production districts around Australia. Additionally, this phase of the project has located/developed potential *Phytophthora cinnamomi* resistant rootstocks resulting in the identification of one with strong commercial resistance to root rot with a further two entering the final stages of evaluation at the end of the project (SHS will continued to monitor the progress of these two rootstocks as an unfunded contribution to the project). The results from Phase III (AV08000) are reported in this document.

Implementation of results from this project has the potential to increase orchard productivity by an estimated 10-15% based on limited data of yield variability among seedling trees. This will lead to a significant increase in orchard efficiency making the Australian avocado industry more internationally competitive thereby positioning more favourably to compete with imports and to exploit export opportunities when they arise.

5. Agronomic Performance of Rootstocks

5.1 Introduction

The Australia avocado industry has continued to expand for the most part, using an *ad hoc* range of rootstocks selected by nurserymen for which there is no data to substantiate their performance. Despite a technically sound nursery scheme (ANVAS) to supply disease-free, true-to-type trees to industry, the development and use of superior rootstocks largely remains in limbo. 'Velvick' (West Indian race), is one local rootstock selected about 20 years ago where a body of performance data is slowly being developed both within Australia and overseas. Recent studies in Australia comparing postharvest anthracnose development of 'Hass' fruit from trees grafted to different rootstocks, have found that fruit from trees grafted to 'Velvick' (WI race) developed less disease compared with fruit from trees on 'Duke 6' (Mexican race) rootstocks (Willingham *et al*., 2001).

The main objective of this part of the project has been to identify potential rootstock material representative of the main botanical races (viz. Mexican, Guatemalan and West Indian). Once a selection was made the rootstocks were grown as either seedlings or vegetatively cloned from maternal trees, grafted to 'Hass' and 'Shepard' then planted in evaluation experiments in the main production zones of Australia. In total six sites across Australia were chosen with 'Hass' trees being planted at each of these sites, while due to environment requirements 'Shepard' experiments have been restricted to the Atherton Tablelands and Childers regions.

5.2 Materials and Methods

Rootstock lines were selected from the three horticultural races of *Persea americana* Mill. (Table 1). Parent trees of each line were chosen due to their relative isolation thus limiting the opportunity for out-crossing during pollination. Both seeds and scion wood for each rootstock were collected from the same tree. Vegetative propagation of rootstocks was achieved using a modified version of the "nurse-seed" technique as described by Ernst (1999). Once cloned rootstock trees were grafted to either 'Hass' or 'Shepard' scions. Concurrently, avocado seed were scarified by seedcoat removal and four shallow pole to pole cuts made into the seed that was then placed in potting media and held at 25 ± 2°C until germinated and when of sufficient size grafted to either of the scion varieties as required.

After grafting, trees were grown under nursery conditions using ANVAS protocol (Bender and Whiley, 2002) to maintain freedom from disease. When trees reached about 1 metre tall they were shipped to the respective experimental sites and planted in randomised block designs.

At each site tree nutrition, irrigation and general orchard husbandry was applied according to recommendations from the Agrilink Avocado Information Kit (Newett *et al*., 2001).

Growth measurements were collected annually from trees when quiescent in mid-winter at each of the experimental sites with tree diameter and height being recorded. These data were used to calculate the volume of tree canopies using a cylinder plus half sphere model. Once trees began fruiting, yield (kg) divided by canopy volume (m^3) was calculated to determine yield efficiency (YE $kg.m^{-3}$). Following the last harvest in 2012 trunk girth circumferences were measured above and below the graft and a trunk girth ratio (girth above graft/girth below graft) calculated. Correlations between the trunk girth ratio and total cumulative yield were examined. At crop maturity each year fruit weight and fruit numbers were recorded from each tree. Data was statistically analysed by ANOVA (Genstat 2012). For comparisons of cropping performance between seedling and cloned rootstocks of common origin variances about the mean of each 10 tree population were determined using Genstat and Bartlett's test.

Table 1 Racial origin of rootstocks used in the “Rootstock Improvement for the Australian Avocado Industry” experimental program. The three horticultural races are Mexican (M), Guatemalan (G) and West Indian (WI). Hybrids are designated by M x G or similar with the first letter indicating the higher estimated proportion of genes from that race.

Rootstock	Horticultural Race*	Rootstock	Horticultural race*
Mexican group		**Guatemalan group**	
Barr Duke	M	A10	G x M
Duke 7	M	A8	G
Franceschi	M	Edranol	G x M
Parida	M	Nabal	G
Shepard	M x G	Hass	G x M
SHSR-03	M x G	Peasley	G
Thomas	M	Plowman	G
Toro Canyon	M	Reed	G
Zutano	M x G	Rigato	G
		SHSR-02	G
		West Indian group	
		Ashdot	WI
		TT	WI
		Velvick	WI x G
		V1	WI x G

* Horticultural race designation has been determined by morphological characteristics published for the various races (Scora *et al*. 2002). Greater accuracy in designating racial origin would come from molecular analysis which has yet to be carried out at this level on the rootstocks listed above.

Research Sites

Experiment 1

Location: Pemberton, WA
Date planted: 15th December, 2004
Tree spacing: 6.5 x 3 m (500 trees.ha^{-1})

The site was chosen in southern WA representing the coolest and latest maturing production area in Australia. The climate is typically Mediterranean with cool wet winters and dry hot summers. The soil type is a gravely clay loam of moderate depth. Trees normally carry a double crop of fruit for 3-4 months each year as the new season’s crop is set prior to harvesting the previous year’s crop. Water quality is good but waterlogged soils can be a problem during wet winters. PRR has become a serious issue on older (10-12 years-of-age) orchards in this area. ‘Hass’ is the predominant commercial variety.

Experiment 2

Location: Carabooda, WA
Date planted: January, 2005
Tree spacing: 7 x 7 m (196 trees.ha^{-1})

This site was chosen about 100 km north of Perth due to its unique soils and declining water quality. The soil is deep, well-drained sand derived from ancient sand dunes. Water quality is becoming an issue with avocado production in this area as greater urban demands are being made on the underground source. The orchard was previously planted on the Mexican race rootstock ‘Topa Topa’ which is in the group most sensitive to salinity. The range of rootstocks supplied for evaluation to this site are of Guatemalan and West Indian origin as these two groups are reputed to have greater salinity tolerance. The climate is typical Mediterranean with mild, wet winters and hot, dry summers. ‘Hass’ is the predominant commercial variety.

Experiment 3

Location: Duranbah, NSW
Date planted: 14th September, 2005
Tree spacing: 9 x 6 m (184 trees.ha^{-1})

The site is at Duranbah in coastal northern NSW with a subtropical climate and a deep rich krasnozem soil. Fruit maturity is later than the Walkamin and Childers regions but earlier than the Hampton site. Spring temperatures are too cool for reliable production of 'Shepard' and 'Hass' is the main commercial variety grown. The land used for the experiment has previously supported an avocado orchard that became non-viable due to PRR. This is a high disease-pressure site and control of root rot will be of prime concern.

Experiment 4

Location: Hampton, QLD
Date planted: 20th January, 2005
Tree spacing: 9 x 6 m (184 trees.ha^{-1})

This site was chosen in the highlands of southern Queensland due to its late maturity and cool subtropical climate (summer "wet" and winter dry). The soil is a deep red clay loam of basaltic origin. It is representative of production from the southern inland areas of the east coast of Australia. 'Hass' is the predominant commercial variety. The site available for the experiment was previously under vegetable production.

Experiment 5

Location: Childers region, QLD
Date planted: 18th May, 2005
Tree spacing: 11 x 5 m (180 trees.ha^{-1})

This site is near Childers in the central Burnett region of coastal SE Queensland. It represents the major producing district in Australia. The climate is described as warm, subtropical with wet summers and dry winters. 'Hass' and 'Shepard' are both commercially produced in this region although some years are marginal for 'Shepard' production. The soil is a deep krasnozem of volcanic origin and is considered optimum for avocado production in eastern Australia. The site available for the experiment is being newly planted to avocados having previously supported sugar cane.

Experiment 6

Location: Walkamin, QLD
Date planted: 6-7th April, 2005
Tree spacing: 10 x 6 m (167 trees.ha^{-1})

This site is on the Atherton Tablelands in north Queensland and the climate is described as warm, subtropical with wet summers and dry winters. It represents the earliest-maturing district in Australia and successfully produces both 'Hass' and 'Shepard'. The soil is a deep krasnozem of volcanic origin and is considered optimum for avocado production in eastern Australia. The site available for the experiment has previously been planted to avocados with the orchard becoming unviable due to PRR. This is a high disease-pressure site and control of root rot will be off prime concern.

5.3 Results and Discussion

Since cropping data for 2007 and 2008 from the experimental sites was reported in AV04007 only annual data from 2009 to 2012 inclusive is included in this report except for cumulative yields which includes total production from the first crop (2007) through to 2012. Variance analyses have been determined for seedling and cloned rootstocks from 2008 through to 2012 and are presented in this report.

5.3.1 Experiment 1 (Pemberton, WA)

Although this was the first experimental plot to be planted the trees at this site did not produce their first crop until 2008. This area represents one of the most marginal in Australia for the production of avocados yet fills an important niche in the 12 month supply of fruit for domestic production. Frost during the first winter after planting and hail in the following spring retarded tree establishment and thereby delayed flowering and fruit set for one year.

Annual yield data for seedling rootstocks growing at the Pemberton site are presented in Table 2. Statistical differences between rootstocks were only recorded in 2009 and for the cumulative yield from 2008 to 2012 inclusive. For the 2009 crop the highest yielding rootstocks were 'Plowman' (7.3 $kg.tree^{-1}$) and 'Velvick' (5.8 $kg.tree^{-1}$). For the five year cumulative yield 'Velvick' produced the most fruit (167.1 $kg.tree^{-1}$) but was only significantly higher than 'Reed'. The 2012 crop was heavy across all farms in the region and in this experiment resulted in yields up to 31.7 $t.ha^{-1}$ ('Duke 7'), which is at the higher end of commercial production.

Table 2 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to nine seedling avocado rootstocks growing at Pemberton, Western Australia. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2008-12 ($kg.tree^{-1}$)
'A10'	3.5^{bc} (1.8)	25.1 (12.6)	24.0 (12.0)	51.6 (25.8)	136.9^{a}
'Duke 7'	0.8^{c} (0.4)	22.7 (11.4)	15.9 (8.0)	63.8 (31.7)	126.1^{a}
'Nabal'	3.2^{bc} (1.6)	30.7 (15.4)	27.6 (13.8)	29.1 (14.6)	118.1^{a}
'Plowman'	7.3^{a} (3.7)	36.3 (18.2)	25.4 (12.7)	54.0 (27.0)	148.1^{a}
'Reed'	0.6^{c} (0.3)	10.5 (5.3)	8.9 (4.5)	19.0 (9.5)	42.9^{b}
'SHSR-02'	3.5^{bc} (1.8)	27.4 (13.7)	30.9 (15.5)	53.6 (26.8)	149.2^{a}
'Toro Canyon'	1.9^{c} (1.0)	27.2 (13.6)	27.7 (13.9)	56.6 (28.3)	145.3^{a}
'Velvick'	5.8^{ab} (2.9)	28.8 (14.4)	40.8 (20.4)	53.1 (26.6)	167.1^{a}
'V1'	2.7^{bc} (1.4)	27.2 (13.6)	25.7 (12.9)	48.7 (24.4)	136.4^{a}
LSD ($P \leq 0.05$)	**3.5**	**ns[1]**	**ns**	**ns**	**62.5**

[1] ns = non significant ($P > 0.05$)

The annual yield efficiency (YE) of seedling rootstocks at the Pemberton site ranged between 0.3 to 1.4 $kg.m^3$ of canopy however there were no significant differences between treatments so data has not been presented. Mean annual fruit mass ranged between 168.9 to 289.8 g over the five years of the experiment however there were no significant differences between rootstocks so data has not been presented.

Annual yield data for cloned rootstocks growing at the Pemberton site are presented in Table 3. Statistical differences between rootstocks were recorded in 2010 and 2011 as well as for the cumulative yield from 2008-2012 inclusive. In both 2010 and 2011 'Zutano' was the highest yielding rootstock and produced the greatest cumulative weight of fruit (235.4 $kg.tree^{-1}$) over the five years yield was recorded. 'A10' was the second most productive cloned rootstock (172.9 $kg.tree^{-1}$) at this site but was only significantly greater than 'Franceschi'. Yield was exceptional in 2012 reaching 49.9 $t.ha^{-1}$ for 'Hass' trees grafted to cloned 'Zutano' rootstocks which is well above normal commercial production.

Table 3 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to eight cloned avocado rootstocks growing at Pemberton, Western Australia. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as t.ha^{-1}.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2008-12 (kg.tree^{-1})
'A10'	7.7 (3.9)	27.8^{b} (13.9)	12.6^{b} (6.3)	96.8 (48.4)	172.9^{ab}
'Barr Duke'	2.8 (1.4)	19.1^{b} (9.6)	10.0^{b} (5.0)	56.1 (28.1)	112.5^{bc}
'Duke 7'	1.9 (1.0)	30.7^{ab} (15.4)	7.7^{b} (3.9)	61.8 (30.9)	128.9^{bc}
'Franceschi'	3.6 (1.8)	25.2^{b} (12.6)	15.9^{b} (8.0)	41.7 (20.9)	104.6^{c}
'Nabal'	9.3 (4.7)	24.2^{b} (12.1)	22.8^{ab} (11.4)	77.9 (39.0)	159.1^{bc}
'Reed'	7.9 (4.0)	17.5^{b} (17.5)	10.2^{b} (5.1)	71.6 (35.8)	126.7^{bc}
'Velvick'	5.6 (2.8)	22.1^{b} (11.1)	14.3^{b} (7.2)	81.6 (40.8)	154.3^{bc}
'Zutano'	6.6 (3.3)	42.6^{a} (21.3)	38.0^{a} (19.0)	99.8 (49.9)	235.4^{a}
LSD (P ≤ 0.05)	**ns[1]**	**14.3**	**18.6**	**ns**	**66.4**

[1] ns = non significant ($P > 0.05$)

Annual YE was significantly different between rootstocks in 2009 and 2012 with the highest rate recorded for 'Velvick' (1.56 kg/m^3) in 2012 (Table 4). However, there was no consistency in YE of rootstocks across production years indicating that this trait is not genetically fixed and is likely to be an annual reaction between rootstock and the environment.

Table 4 Annual yield efficiency (kg/m^3) of 'Hass' trees grafted to eight cloned avocado rootstocks growing at Pemberton, Western Australia. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A10'	0.50^{ab}	0.80	0.24	1.34^{ab}
'Barr Duke'	0.17^{b}	0.69	0.19	0.70^{c}
'Duke 7'	0.11^{b}	1.76	0.15	0.84^{bc}
'Franceschi'	1.28^{a}	0.76	0.37	0.57^{c}
'Nabal'	0.64^{ab}	0.78	0.47	1.32^{ab}
'Reed'	0.31^{ab}	0.50	0.20	0.96^{bc}
'Velvick'	0.56^{ab}	0.91	0.31	1.56^{a}
'Zutano'	0.29^{bc}	1.18	0.62	1.31^{ab}
LSD (P ≤ 0.05)	**1.08**	**ns[1]**	**ns**	**0.52**

[1] ns = non significant ($P > 0.05$)

Annual mean fruit mass for cloned rootstocks growing at Pemberton was only significantly different in 2009 (Table 5) with the 'Franceschi' rootstock producing the largest fruit (237.1 g). This rootstock was also the lowest yielding in 2009 and it is likely that the large fruit size is a reflection of crop load.

Table 5 Annual mean fruit mass (g) from 'Hass' trees grafted to eight cloned avocado rootstocks growing at Pemberton, Western Australia. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A10'	188.9^{bc}	206.2	287.6	191.9
'Barr Duke'	152.2^{c}	240.4	273.2	202.9
'Duke 7'	230.2^{ab}	195.0	264.3	206.6
'Franceschi'	237.1^{a}	210.6	264.6	207.3
'Nabal'	214.0^{ab}	188.6	277.8	185.3
'Reed'	232.2^{ab}	192.5	291.2	203.9
'Velvick'	223.0^{ab}	187.7	247.8	194.6
'Zutano'	232.0^{ab}	200.6	279.5	200.9
LSD (P ≤ 0.05)	**46.4**	**ns[1]**	**ns**	**ns**

[1] ns = non significant ($P > 0.05$)

The comparative annual yield data between cloned and seedling rootstocks grown at Pemberton are presented in Table 6. Statistical differences were shown between treatments in 2009, 2011, 2012 and for the cumulative yield from 2008 to 2012 inclusive. In 2009, 'Hass' on the cloned rootstocks of 'Nabal' and 'Reed' cropped significantly higher than their seedling rootstock counterparts while in 2011 'Hass' on seedling 'Velvick' rootstocks cropped significantly higher than when the rootstock was cloned. The yields of clonal rootstocks 'A10', 'Nabal' and 'Reed' were significantly higher than their respective seedling rootstocks in 2012 while for the five-year cumulative yield the only significant difference was between the two 'Reed' rootstocks where the cloned produced more fruit than the seedling (Table 6).

The variance within seedling and cloned rootstocks populations were determined for each of the cropping years and data are presented in Table 7. For 'A10' and 'Velvick' there were no significant differences in variance between their seedling or cloned rootstocks in any of the cropping years or for the cumulative five-year yields. For 'Duke 7' the variance of the seedling rootstock population was significantly lower than the clones in 2009 while in 2011 the position was reversed. In 2009 and 2012 the variance of the seedling rootstock population of 'Nabal was significantly lower than the clones while the seedling rootstock of 'Reed' had significantly lower variance that than the clones in 2009, 2012 and for the cumulative five-year period (Table 7).

The data for this site indicates that there is no significant advantage of using a seedling or cloned rootstock for the production of 'Hass' avocados. The exception is 'Reed' where the cloned rootstock in two of the four years recorded yielded significantly more fruit than the seedling rootstock and over the five-year cumulative period was superior to the seedling. 'Reed' is one of the most susceptible rootstocks to PRR (Smith *et al*., 2010) that is commercially used by the Australian avocado industry. The experimental site at Pemberton was located alongside a six-year-old commercial orchard that was being treated to control PRR at the time of planting. Within the first 2-3 years after planting the experiment required commercial phosphonate treatment. The 'Reed' seedling rootstock trees showed the strongest symptoms of root rot infection and were the most difficult to maintain. Thus it is likely that the difference seen between the seedling and cloned 'Reed' trees was due to disease rather than propagation factors. When designing this research the perception was that cloned rootstocks would have less variance than the more heterozygous seedling populations of the same variety. The data in Table 7 does not support this where for the most part there are no significant differences between the seedling and clonal population variances or where indeed significance occurs it is mostly the seedling population that has the lowest variance (6 out of 7 comparisons). 24.1% of observations have significant variances.

Table 6 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to five avocado rootstocks propagated as both clones and seedlings growing at Pemberton, SW Western Australia. Means in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2008-12 (kg.tree^{-1})
'A10' clonal	7.7^{ab}	27.8	12.6^{bc}	96.8^{a}	172.9^{a}
'A10' seedling	3.5^{bc}	25.1	24.0^{abc}	51.6^{cd}	136.0^{a}
'Duke 7' clone	1.9^{c}	30.7	7.7^{c}	61.8^{abc}	128.9^{a}
'Duke 7' seedling	0.8^{c}	22.7	15.9^{bc}	63.8^{abc}	126.1^{a}
'Nabal' clone	9.3^{a}	24.2	22.8^{abc}	77.9^{ab}	159.1^{a}
'Nabal' seedling	3.2^{bc}	30.7	27.6^{ab}	29.1^{cd}	118.1^{ab}
'Reed' clone	7.9^{ab}	17.5	10.2^{bc}	71.6^{ab}	126.7^{a}
'Reed' seedling	0.6^{c}	10.5	8.9^{c}	19.0^{d}	42.9^{b}
'Velvick' clone	5.6^{abc}	22.1	14.3^{bc}	81.6^{ab}	154.3^{a}
'Velvick' seedling	5.8^{abc}	28.8	40.8^{a}	53.1^{bcd}	167.7^{a}
LSD (P ≤ 0.05)	**5.4**	**ns[1]**	**18.4**	**38.8**	**62.3**

[1] ns = non significant ($P > 0.05$)

Table 7 Yield variances between 'Hass' trees propagated to either seedling or cloned rootstocks from the same varietal source growing at Pemberton, SW Western Australia. Data are measured from 10 replications for each rootstock. Variances between trees and P values were determined using Genstat and Bartlett's test. Significant differences ($P \leq 0.05$) are indicated by highlighted P values.

Rootstock	Variances Among Trees		P value	Rootstock	Variances Among Trees		P value
	Rootstock Origin				Rootstock Origin		
	Seed	Clone			Seed	Clone	
A10				**Reed**			
Yield 2008	234	219	0.924	Yield 2009	1	45	**0.001**
Yield 2009	15	42	0.136	Yield 2010	105	66	0.493
Yield 2010	415	841	0.307	Yield 2011	112	205	0.383
Yield 2011	813	231	0.075	Yield 2012	452	3937	**0.004**
Yield 2012	1852	2711	0.579	Cumulative yield 2009/12	773	7285	**0.003**
Cumulative yield 2008/12	5662	6246	0.886				
Duke 7				**Velvick**			
Yield 2008	121	85	0.609	Yield 2008	362	185	0.331
Yield 2009	0.7	4.4	**0.014**	Yield 2009	35	52	0.570
Yield 2010	157	155	0.983	Yield 2010	287	266	0.909
Yield 2011	318	40	**0.005**	Yield 2011	861	378	0.236
Yield 2012	2301	1721	0.672	Yield 2012	1418	1364	0.955
Cumulative yield 2008/12	5497	2349	0.221	Cumulative yield 2008/12	4354	3128	0.630
Nabal							
Yield 2008	218	267	0.768				
Yield 2009	9	166	**0.001**				
Yield 2010	342	252	0.658				
Yield 2011	785	556	0.617				
Yield 2012	435	2872	**0.010**				
Cumulative yield 2008/12	4737	9063	0.348				

5.3.2 Experiment 2 (Carabooda, WA)

Data from the Carabooda site is limited to yield values collected from 'Hass' planted on five seedling rootstocks from 2009 to 2011 inclusive since significant tree losses occurred during the establishment phase of the experiment. The number of rootstocks was limited to include those with Guatemalan or West Indian parentage since there is a water quality issue on the farm and Mexican race rootstocks have low tolerance to salt. Yield data was not available from 2012 since the experimental trees were accidently harvested by farm staff without information being collected.

Significant differences between rootstocks were recorded for each year of the experiment and for the three-year cumulative yields (Table 8). In 2009, 'SHSR-03' produced significantly more fruit (34.7 $kg.tree^{-1}$) than 'A10' (17.1 $kg.tree^{-1}$) while in 2010 'A10' (32.2 $kg.tree^{-1}$) and 'Velvick' (31.3 $kg.tree^{-1}$) were the highest yielding cultivars but only significantly better than 'Plowman' (10.3 $kg.ha^{-1}$). In 2011, 'SHSR-03' (55.9 $kg.tree^{-1}$) and 'Nabal' (53.8 $kg.tree^{-1}$) produced significantly more fruit than 'A10' (5.3 $kg.tree^{-1}$). Over the three-year period 'Velvick' (128.7 $kg.ha^{-1}$) produced significantly more fruit than 'A10' (93.4 $kg.tree^{-1}$) and 'Plowman' (82.9 $kg.tree^{-1}$) but was not significantly different to the other rootstocks ('Nabal' and 'SHSR-04'). Production ($t.ha^{-1}$) was modest for the duration of the experiment but was likely to be much higher for 2012 as a heavy crop was set and harvested in the district during this year.

Table 8 Annual yields ($kg.tree^{-1}$) from 2009 to 2011 inclusive measured from 'Hass' grafted to five seedling avocado rootstocks growing at Carabooda, Western Australia. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Cumulative yield 2008-11 ($kg.tree^{-1}$)
'A10'	17.1^{b} (3.4)	32.2^{a} (6.3)	26.8^{b} (5.3)	93.4^{b}
'Nabal'	29.3^{ab} (5.7)	22.8^{ab} (4.5)	53.8^{a} (10.5)	120.8^{ab}
'Plowman'	24.4^{ab} (4.8)	10.6^{b} (2.1)	41.3^{ab} (8.1)	82.9^{b}
'SHSR-03'	34.7^{a} (6.8)	23.3^{ab} (4.6)	55.9^{a} (11.0)	119.1^{ab}
'Velvick'	27.6^{ab} (5.4)	31.3^{a} (6.1)	44.7^{ab} (8.8)	128.7^{a}
LSD (P ≤ 0.05)	**12.3**	**14.3**	**21.3**	**29.3**

5.3.3 Experiment 3 (Duranbah, NSW)

The experiment was planted on old avocado land which was infested by *Phytophthora cinnamomi*. Initially trees grew well but from 2010 a series of very wet summers were experienced in the district and many of the trees became either severely affected by PRR or died from the disease. In many cases replication numbers were depleted to the stage that statistical treatment of the data was not possible. The yield data presented in Table 9 are means from the number of surviving trees in each treatment.

Table 9 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to twelve seedling avocado rootstocks growing at Duranbah, NSW. Data are mean values calculated from the number of surviving trees. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A8'	16.6^{abc} (3.1)	10.5 (1.9)	30.7 (5.6)	47.5 (8.7)	117.8
'A10'	10.3^{bcd} (1.9)	5.7 (1.0)	32.3 (5.9)	36.3 (6.7)	91.4
'Barr Duke'	10.6^{bcd} (2.0)	16.4 (3.0)	44.8 (8.2)	58.3 (10.7)	140.7
'Nabal'	20.8^{ab} (3.8)	17.6 (3.2)	18.6 (3.4)	28.3 (5.2)	95.9
'Parida'	9.9^{bcd} (1.8)	5.1 (0.9)	48.5 (8.9)	72.9 (13.4)	152.8
'Peasley'	15.9^{abc} (2.9)	15.2 (2.8)	57.8 (10.6)	33.7 (6.2)	131.6
'Reed'	4.1^{d} (0.8)	5.4 (1.0)	43.6 (8.0)	54.7 (10.1)	115.8
'SHSR-02'	19.2^{abc} (3.5)	14.9 (2.7)	31.7 (5.8)	76.2 (14.0)	161.8
'SHSR-03'	13.2^{bc} (2.4)	12.3 (2.3)	23.1 (4.3)	8.7 (1.6)	69.6
'Toro Canyon'	8.0^{cd} (1.5)	9.8 (1.8)	43.5 (8.0)	70.1 (12.9)	141.0
'Velvick'	25.9^{a} (4.8)	13.7 (2.5)	81.2 (14.9)	70.1 (12.9)	344.5
'Velvick/Interstock'	16.0^{abc} (2.9)	12.5 (2.3)	48.7 (9.0)	49.9 (9.2)	140.3
LSD (P ≤ 0.05)	**11.4**	**ns**[1]	**ns**	**ns**	**ns**

[1] ns = non significant ($P > 0.05$)

Significant differences were recorded between rootstock yields at Duranbah during the 2009 cropping year where 'Velvick' (25.9 $kg.tree^{-1}$) recorded the highest production bettering 'A10', 'Barr Duke', 'Parida', 'Reed', 'SHSR-03' and 'Toro Canyon'. Although statistical analysis was not carried out 'Velvick' was easily the highest-yielding rootstock at this site based on the six-year cumulative yield data (Table 9), perhaps indicating that its vigour assisted in combating the level of PRR at the site.

5.3.4 Experiment 4 (Hampton, Qld)

The Hampton experiment began cropping in 2007 with the first two years yield data reported in AV04007. Annual yield data for seedling rootstocks covering 2009 to 2012 are reported in Table 10 along with the cumulative yield for each rootstock treatment from 2007 to 2012 inclusive. Significant differences between rootstocks were only recorded in 2009. In 2009, 'Zutano' was the highest yielding rootstock (72.2 $kg.tree^{-1}$), but was only significantly different to the 'Velvick'/Interstock combination (14.8 $kg.tree^{-1}$). 'Zutano' and 'Velvick' produced the highest cumulative yields but were not significantly different to the other rootstocks. Relatively heavy crops were carried in 2011 but this was followed by a very light year in 2012 largely due to inclement weather during flowering in the spring of 2011 (Table 10).

Table 10 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to eleven seedling avocado rootstocks growing at Hampton, S.E. Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A8'	47.8^{ab} (8.8)	44.7 (8.2)	118.2 (21.7)	5.7 (1.0)	246.0
'A10'	46.1^{ab} (8.5)	52.8 (9.7)	125.1 (23.0)	13.3 (2.5)	268.2
'Duke 7'	49.2^{ab} (9.1)	39.9 (7.3)	89.1 (16.4)	7.0 (1.3)	220.1
'Nabal'	48.1^{ab} (8.9)	60.7 (11.2)	96.8 (17.8)	26.3 (4.8)	275.9
'Plowman'	55.9^{ab} (10.3)	34.7 (6.4)	113.8 (20.9)	10.1 (1.9)	245.2
'Reed'	66.4^{ab} (12.2)	36.7 (6.8)	105.8 (19.5)	11.7 (2.2)	242.9
'SHSR-02'	64.3^{ab} (11.8)	40.1 (7.3)	96.6 (17.8)	22.3 (4.1)	280.9
'SHSR-03'	40.2^{bc} (7.4)	40.4 (7.4)	98.8 (18.2)	7.4 (1.4)	226.7
'Velvick'	62.5^{ab} (11.5)	56.4 (10.4)	101.3 (18.6)	20.1 (3.4)	303.6
'Velvick'/Interstock	14.8^{c} (2.7)	51.1 (9.4)	92.2 (17.0)	16.2 (2.3)	192.7
'Zutano'	72.2^{a} (13.3)	50.5 (9.3)	132.8 (24.4)	4.3 (0.8)	304.4
LSD ($P \leq 0.05$)	**30.7**	**ns**[1]	**ns**	**ns**	**ns**

[1] ns = non significant ($P > 0.05$)

Yield efficiency for seedling rootstocks ranged between 0.3 to 1.9 kg/m^3 of tree canopy but was not significantly different between rootstocks for the years that yield was recorded hence YE data is not presented. Mean fruit mass ranged from 220 to 346 g but was not significantly different between rootstocks in any of the years it was measured hence fruit mass data is not presented.

Annual yields for cloned rootstocks growing at Hampton were significantly different between rootstocks in 2011 and 2012 (Table 11). 'SHSR-03', 'Velvick' and 'Zutano' were the three highest yielding rootstocks in 2011 producing 135.9, 134.7 and 130.0 $kg.tree^{-1}$, respectively. This was the heaviest crop recorded at this site being at the higher end of production for avocados in Queensland with yields recorded up to 25 $t.ha^{-1}$ ('SHSR-03'). The light crop carried in 2012 resulted in 'Hass' and 'Reed' recording the highest yields albeit they were well below a reasonable commercial level at 9.9 and 5.0 $t.ha^{-1}$, respectively. These two rootstocks underperformed the previous year and potentially had more carbohydrate reserves available for flowering and fruit set (Whiley, 1994) thus partially offsetting the inclement climatic conditions during spring, 2011. Over the six-year period yield was collected 'SHSR-03' (331.9 kg/ha), 'Velvick' (297.7 kg/ha) and 'Zutano' (293.6 kg/ha) were the three highest yielding rootstocks although the latter two were not significantly different to 'A8', 'A10', and 'Duke 7' (Table 11).

Table 11 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to ten cloned avocado rootstocks growing at Hampton, S.E. Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as tonnes per ha.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A8'	63.4 (11.7)	28.1 (5.2)	113.5^{abc} (20.9)	1.3^{b} (0.2)	251.6^{bc}
'A10'	66.1 (12.2)	29.2 (5.4)	117.6^{abc} (21.6)	1.4^{b} (0.3)	252.6^{bc}
'Duke 7'	97.3 (17.9)	8.4 (1.5)	100.1^{c} (18.4)	1.2^{b} (0.2)	262.6^{bc}
'Hass'	77.8 (14.3)	23.5 (4.3)	99.7^{c} (18.3)	9.9^{a} (1.8)	242.3^{cd}
'Nabal'	64.5 (11.9)	18.3 (3.4)	125.7^{ab} (23.1)	1.6^{b} (0.3)	233.6^{cd}
'Plowman'	70.6 (13.0)	11.9 (2.2)	103.3^{bc} (19.0)	0.7^{b} (0.1)	234.6^{cd}
'Reed'	56.6 (10.4)	15.6 (2.9)	97.4^{c} (17.9)	5.0^{ab} (0.9)	202.2^{d}
'SHSR-03'	91.6 (16.9)	38.3 (7.0)	135.9^{a} (25.0)	2.7^{b} (0.5)	331.9^{a}
'Velvick'	87.2 (16.0)	29.2 (5.4)	134.7^{a} (24.8)	1.8^{b} (0.3)	297.7^{ab}
'Zutano'	83.6 (15.4)	31.6 (5.8)	130.0^{a} (23.9)	2.5^{b} (0.5)	293.6^{ab}
LSD ($P \leq 0.05$)	**ns[1]**	**ns**	**22.8**	**5.3**	**47.3**

[1] ns = non significant ($P > 0.05$)

Table 12 Annual yield efficiency (kg/m^3) of 'Hass' trees grafted to ten cloned avocado rootstocks growing at Hampton, S.E. Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A8'	1.62	0.73	1.03^{ab}	0.01
'A10'	1.10	0.62	0.99^{abc}	0.01
'Duke 7'	2.04	0.48	0.83^{bc}	0.09
'Hass'	1.48	0.36	0.86^{bc}	0.11
'Nabal'	1.21	0.52	1.16^{a}	0.02
'Plowman'	1.32	0.34	1.01^{abc}	0.01
'Reed'	1.02	0.59	0.78^{c}	0.04
'SHSR-03'	1.59	0.58	1.06^{ab}	0.02
'Velvick'	1.57	0.56	1.12^{a}	0.02
'Zutano'	1.41	0.56	0.98^{abc}	0.03
LSD ($P \leq 0.05$)	**ns[1]**	**ns**	**0.23**	**ns**

[1] ns = non significant ($P > 0.05$)

The YE of 'Hass' grafted to cloned rootstocks showed no consistency within rootstocks over the reported period documented in Table 12. In 2011, 'Nabal' and 'Velvick' recorded the highest YE's of 1.16 and 1.12 kg/m^3 of tree canopy, respectively. There were no significant differences in mean fruit mass between the rootstock treatments over all the years that fruit was measured so data has not been included.

Yield comparisons made between seedling and cloned rootstocks common to the Hampton site were significantly different for each year of the experiment (Table 13). In 2009, the yield between the seedling and cloned rootstocks of "Duke 7' and 'SHSR-03' were significantly different and in both cases the cloned rootstock produced more fruit than the seedling. In this year there was no significant difference in yield between the seedling and clones of the other rootstocks. In 2010, the seeding rootstocks of 'Duke 7', 'Nabal' and 'Velvick' had significantly higher yields than their clones (Table 13) while in 2011 the cloned rootstocks of 'Nabal', 'SHSR-03' and 'Velvick' had significantly higher yields than their seedling rootstocks. 'Nabal' and 'Velvick' were the only two rootstocks to record significant differences in yield between the seedling and cloned lines in 2012 and in both cases the seedling was the highest yielding rootstock.

Over the six years of the experiment 'SHSR-03' produced the highest yield (331.9 kg.tree^{-1}) but was not significantly greater than 'Zutano' seedling, 'Velvick' seeding, 'Velvick' clone, 'Zutano' clone and 'A10' seedling (Table 13).

Table 13 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to nine avocado rootstocks propagated as both clones and seedlings growing at Hampton, S.E. Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	**Yield 2009 (kg.tree^{-1})**	**Yield 2010 (kg.tree^{-1})**	**Yield 2011 (kg.tree^{-1})**	**Yield 2012 (kg.tree^{-1})**	**Cumulative yield 2007-12 (kg.tree^{-1})**
'A8' clone	63.6^{bcde}	28.1^{cdef}	113.5^{abcdef}	1.3^{c}	251.6^{bcde}
'A8' seedling	47.8^{de}	44.7^{abc}	118.2^{abcde}	5.7^{c}	246.0^{bcde}
'A10'clone	66.1^{bcde}	29.2^{cdef}	117.5^{abcde}	1.4^{c}	252.6^{bcde}
'A10' seedling	46.1^{de}	52.8^{abc}	126.6^{abcd}	13.3^{abc}	268.2^{abcd}
'Duke 7' clone	97.3^{a}	8.4^{f}	100.1^{def}	1.2^{c}	262.6^{bcde}
'Duke 7' seedling	49.2^{de}	39.9^{abcd}	89.1^{f}	7.0^{bc}	220.1^{de}
'Nabal' clone	64.6^{bcde}	18.3^{def}	125.7^{abcd}	1.6^{c}	233.6^{cde}
'Nabal' seedling	48.1^{de}	60.7^{a}	96.8^{ef}	26.3^{a}	275.9^{abcd}
'Plowman' clone	70.6^{abcde}	11.9^{ef}	103.3^{cdef}	0.7^{c}	234.6^{cde}
'Plowman' seedling	55.9^{cde}	34.7^{abcde}	114.7^{abcdef}	11.2^{bc}	245.2^{bcde}
'Reed' clone	56.6^{cde}	15.6^{def}	97.3^{ef}	5.0^{c}	202.2^{e}
'Reed' seedling	66.4^{bcde}	36.7^{abcde}	105.4^{bcdef}	11.7^{bc}	242.9^{bcde}
'SHSR-03' clone	91.7^{ab}	38.3^{abcd}	135.9^{a}	2.7^{c}	331.9^{a}
'SHSR-03' seedling	40.2^{e}	40.4^{abcd}	98.8^{def}	7.4^{bc}	226.7^{de}
'Velvick' clone	87.2^{ab}	29.2^{cdef}	134.7^{a}	1.8^{c}	297.7^{abc}
'Velvick' seedling	62.5^{bcde}	56.4^{ab}	101.3^{def}	20.1^{ab}	303.6^{ab}
'Zutano' clone	83.6^{abc}	31.6^{bcdef}	130.0^{abc}	2.5^{c}	293.6^{abc}
'Zutano' seedling	72.2^{abcd}	50.5^{abc}	133.3^{ab}	4.8^{c}	304.4^{ab}
LSD ($P \leq 0.05$)	**27.3**	**26.3**	**28.2**	**5.3**	**64.4**

Table 14 Yield variances between 'Hass' trees propagated to either seedling or cloned rootstocks from the same varietal source growing at Hampton, SE Queensland. Data are measured from 10 replications for each rootstock. Variances between trees and P values were determined using Genstat and Bartlett's test. Significant differences ($P \leq 0.05$) are indicated

Rootstock	Variances Among Trees – Rootstock Origin: Seed	Clone	P value	Rootstock	Variances Among Trees – Rootstock Origin: Seed	Clone	P value
A8				**Reed**			
Yield 2008	121	311	0.177	Yield 2008	234	223	0.942
Yield 2009	924	1741	0.359	Yield 2009	558	873	0.515
Yield 2010	1588	547	0.128	Yield 2010	1376	144	**0.003**
Yield 2011	1068	818	0.698	Yield 2011	1674	676	0.203
Yield 2012	78	2	**0.001**	Yield 2012	119	26	**0.035**
Cumulative yield 2008/12	5452	3045	0.857	Cumulative yield 2009/12	3475	3931	0.238
A10				**SHSR-03**			
Yield 2008	439	506	0.835	Yield 2008	377	158	0.210
Yield 2009	905	1709	0.358	Yield 2009	234	748	0.098
Yield 2010	355	916	0.175	Yield 2010	1200	1420	0.806
Yield 2011	277	1239	0.075	Yield 2011	1452	1469	0.987
Yield 2012	505	8	**0.001**	Yield 2012	252	8	**0.001**
Cumulative yield 2008/12	3475	3931	0.398	Cumulative yield 2008/12	3475	3931	0.176
Duke 7				**Velvick**			
Yield 2008	233	606	0.170	Yield 2008	711	422	0.448
Yield 2009	1304	2612	0.315	Yield 2009	784	530	0.539
Yield 2010	1470	92	**0.001**	Yield 2010	2567	1667	0.530
Yield 2011	853	498	0.435	Yield 2011	2920	533	**0.019**
Yield 2012	65	3	**0.001**	Yield 2012	2238	8	**0.001**
Cumulative yield 2008/12	3475	3931	0.211	Cumulative yield 2008/12	3475	3931	0.093
Nabal				**Zutano**			
Yield 2008	438	262	0.456	Yield 2008	323	373	0.834
Yield 2009	1335	1273	0.945	Yield 2009	1528	980	0.518
Yield 2010	1819	291	**0.012**	Yield 2010	443	1210	0.151
Yield 2011	434	689	0.503	Yield 2011	1589	154	**0.002**
Yield 2012	888	3.4	**0.001**	Yield 2012	68	28	0.197
Cumulative yield 2008/12	3475	3931	0.506	Cumulative yield 2008/12	3475	3931	**0.027**
Plowman							
Yield 2008	532	260	0.302				
Yield 2009	2512	785	0.098				
Yield 2010	1731	116	**0.001**				
Yield 2011	1925	701	0.158				
Yield 2012	315	1	**0.001**				
Cumulative yield 2008/12	3475	3931	**0.001**				

For the most part the variances between seedling and cloned rootstocks of the same variety were not significantly different at the experimental site at Hampton (Table 14). All cloned rootstocks with the exception of 'Zutano' had significantly lower variance in 2012 than their seedling counterparts however this is likely due to the extremely poor yields produced by the clones with many trees not producing fruit. Thus disregarding the 2012 result significant variances between seedling and cloned pairs of rootstocks were determined for 'Duke 7', 'Nabal', 'Plowman' and 'Reed' in 2010 where in each case the cloned rootstock had the lowest variance and in 2011 the cloned rootstock of 'Velvick' and 'Zutano' had significantly lower variance (Table 14). Variance measured for cumulative yield was only significantly different for 'Plowman' and 'Zutano' wherein both rootstocks the seedling had the least variance. Across all rootstocks and years at the Hampton site only 29.6% of the seedling/cloned comparisons were significantly different. Disregarding results from 2012 this falls to 14.8% of observations questioning the validity of increased uniformity in cloned rootstock populations.

5.3.5 Experiment 5 (Childers, Qld)

At the site near Childers rootstock research was carried out using 'Hass' and 'Shepard' scions and results are presented separately below.

Hass

The results of annual yields from seedling rootstocks grafted to 'Hass' scions are presented in Table 15. Significant differences in annual yield between rootstocks were recorded in 2009, 2011 and 2012. In 2009, the highest yielding rootstocks were 'A8' (88.1 $kg.tree^{-1}$), 'Reed' (82.6 $kg.tree^{-1}$), 'Velvick' 80.8 $kg.tree^{-1}$), and 'Peasley' (76.2 $kg.tree^{-1}$). In 2011, the highest yields were from 'A8', 'A10', 'Velvick' and 'Peasley'. A large drop in yield was recorded across the experiment in 2012 with 'Reed' the only rootstock to match previous year's performance although it was not significantly higher than 'Velvick', 'V1' and 'Velvick'/Interstock. January 2011 heralded the start of a series of wet summers in the Bundaberg region which has led to significant decline in tree health in this orchard. Significant defoliation of trees occurred during the flowering in 2011 with further decline in tree health through the 2012 summer when above average rainfall re-occurred. While some decline in yield would be expected after the 20+ $t.ha^{-1}$ crops produced in 2011, the development of Phytophthora root rot has exacerbated to the decline in yield. The highest cumulative yields recorded over six years were from the seedling rootstocks 'Reed' (463.3 $kg.tree^{-1}$), 'Velvick' (456.4 $kg.tree^{-1}$), 'A8' (430.9 $kg.tree^{-1}$) and 'Nabal' (399.3 $kg.tree^{-1}$).

Table 15 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to eleven seedling avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A8'	88.1^{a} (15.9)	82.8 (14.9)	175.4^{a} (31.5)	28.4^{b} (5.1)	430.9^{ab}
'A10'	66.2^{bcd} (11.9)	62.7 (11.3)	162.0^{ab} (29.2)	28.4^{b} (5.1)	365.5^{bcd}
'Nabal'	64.8^{bcd} (11.7)	91.3 (16.4)	134.4^{abcd} (24.2)	51.9^{b} (9.3)	399.3^{abc}
'Peasley'	76.2^{abc} (13.7)	62.3 (11.2)	146.2^{abc} (26.3)	21.2^{b} (3.8)	355.3^{bcd}
'Reed'	82.6^{ab} (14.9)	101.1 (18.2)	112.8^{bcd} (20.3)	106.6^{a} (19.2)	463.3^{a}
'SHSR-02'	61.2^{cde} (11.0)	68.5 (12.3)	126.6^{abcd} (22.8)	23.7^{b} (4.3)	323.9^{cd}
'SHSR-03'	54.0^{de} (9.7)	60.8 (10.9)	126.1^{abcd} (22.7)	14.9^{b} (2.7)	297.7^{d}
'Toro Canyon'	68.0^{bcd} (12.2)	75.9 (13.7)	133.4^{abcd} (24.0)	44.0^{b} (7.9)	344.9^{bcd}
'Velvick'	80.8^{abc} (14.5)	76.7 (13.8)	158.0^{ab} (28.4)	61.0^{ab} (11.0)	456.4^{a}
'Velvick'/IS	43.7^{e} (7.9)	93.6 (16.8)	96.4^{cd} (17.4)	55.7^{ab} (10.0)	287.2^{d}
'V1'	63.4^{bcde} (11.4)	63.0 (11.3)	91.4^{d} (16.5)	57.2^{ab} (10.3)	346.9^{bcd}
LSD ($P \leq 0.05$)	**19.8**	**ns[1]**	**53.0**	**52.0**	**89.7**

[1] ns = non significant ($P > 0.05$)

The trees in this experiment were collectively the fastest growing across all sites and by 2010 had completely filled in the rows to the extent that the canopies had grown together. At this point tree measurements to calculate discrete canopy volumes were not possible hence YE's for 2011 and 2012 were not determined. Yield efficiency data for 2009 and 2010 are presented in Table 16 where significant differences were determined between rootstocks in 2009. 'A8', 'Peasley', 'Toro Canyon' and 'Reed' with YE's of 1.57, 1.51, 1.41 and 1.35 were significantly higher than the remaining rootstocks. No significant differences were recorded in 2010. Although only two years data are available for YE there is no consistency in performance between 2009 and 2010 suggesting that this parameter is directly related to annual crop load rather than a genetic influence that consistently reflects annual crop load as a fixed ratio of canopy volume.

Table 16 Annual yield efficiency (kg/m^3) of 'Hass' trees grafted to eleven seedling avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstocks	2009	2010
'A8'	1.57^{a}	0.78
'A10'	1.10^{cd}	0.52
'Nabal'	1.09^{cd}	0.76
'Peasley'	1.51^{a}	0.61
'Reed'	1.35^{abc}	0.86
'SHSR-02'	1.17^{bcd}	0.68
'SHSR-03'	1.12^{bcd}	0.63
'Toro Canyon'	1.41^{ab}	0.77
'Velvick'	1.17^{bcd}	0.74
'Velvick/Interstock'	0.98^{d}	0.70
'V1'	1.03^{d}	0.68
LSD (P ≤ 0.05)	**0.30**	**ns[1]**

[1] ns = non significant ($P > 0.05$)

There were no significant differences between rootstocks in annual fruit mass hence data has not been presented.

Significant differences in yield were determined between cloned rootstock treatments for each year from 2009 to 2012 at the Childers experiment and data are presented in Table 17.

In 2009, 'V1' (70.1 kg.tree^{-1}), 'SHSR-03' (64.1 kg.tree^{-1}) and 'Duke 7' (55.5 kg.tree^{-1}) were the highest yielding cloned rootstocks returning 12.6, 11.5 and 10.0 t.ha^{-1}, respectively. 'V1' (131.7 kg.tree^{-1}) and 'Velvick (119.1) were the two highest yielding rootstocks in 2010 with 23.7 and 21.4 t.ha^{-1}, respectively. In 2011, the highest yields were recorded from 'SHSR-03' (157.6 kg.tree^{-1}), 'A10' (145.0 kg.tree^{-1}), 'Duke 7' (132.5 kg.tree^{-1}), 'A8' (128.5 kg.tree^{-1}), 'Nabal' (121.8 kg.tree^{-1}) and 'V1' (118.0 kg.tree^{-1}) returning 28.4, 26.1, 23.9, 23.1, 21.9 and 21.2 t.ha^{-1}, respectively. As noted for the seedling rootstock experiment at this site a significant decline in tree health occurred between 2011 and 2012 due to the preceding wet summers that had a negative impact on tree performance. Nevertheless, some rootstocks were still able to maintain production at approximately 20 t.ha^{-1}. The rootstocks 'Zutano' (110.8 kg.tree^{-1}), 'V1' (110.4 kg.tree^{-1}), 'Thomas' (94.7 kg.tree^{-1}) and 'Velvick' (89.8 kg.tree^{-1}) were the highest yielding in 2012 with 19.9, 19.9, 17.0 and 16.2 t.ha^{-1}, respectively (Table 17).

Table 17 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to nine cloned avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as tonnes per ha.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A8'	49.7^{bcd} (8.9)	52.0^{e} (9.4)	128.5^{ab} (23.1)	20.6^{c} (3.7)	275.8^{e}
'A10'	49.8^{bcd} (8.9)	89.8^{de} (16.2)	145.0^{a} (26.1)	22.0^{c} (4.0)	327.6^{de}
'Duke 7'	55.5^{abc} (10.0)	93.6^{bcd} (16.9)	132.5^{ab} (23.9)	41.4^{c} (7.5)	358.8^{bcd}
'Nabal'	49.0^{bcd} (8.8)	82.9^{cd} (14.9)	121.8^{ab} (21.9)	48.9^{bc} (8.8)	341.9^{cd}
'SHSR-03'	64.1^{ab} (11.5)	91.5^{cd} (16.5)	157.6^{a} (28.4)	43.1^{c} (7.8)	413.4^{b}
'Thomas'	41.7^{cd} (7.5)	76.0^{cde} (13.7)	60.0^{c} (10.8)	94.7^{ab} (17.0)	300.3^{de}
'Velvick'	39.2^{d} (7.1)	119.1^{ab} (21.4)	92.2^{bc} (16.6)	89.8^{ab} (16.2)	403.1^{bc}
'V1'	70.1^{a} (12.6)	131.7^{a} (23.7)	118.0^{ab} (21.2)	110.4^{a} (19.9)	499.5^{a}
'Zutano'	36.0^{d} (6.5)	96.5^{bc} (17.4)	73.6^{c} (13.2)	110.8^{a} (19.9)	363.5^{bcd}
LSD ($P \leq 0.05$)	**15.7**	**26.3**	**43.8**	**46.0**	**66.0**

The cumulative yields of the cloned rootstocks for the six years of production are presented in Table 17. The total production from 'V1' (499.5 $kg.tree^{-1}$) was significantly higher than any other cloned rootstock grown at this site. Other cloned rootstocks that performed above average are 'SHSR-03' (413.4 $kg.tree^{-1}$) and 'Velvick' (403.1 $kg.tree^{-1}$).

The yield efficiency of cloned rootstocks was only determined for 2009 and 2010 for the reasons outlined for the seedling experiment above. In. 2009 there were no significant differences between rootstock YE however in 2010 the highest YE's largely were determined from the highest yielding rootstocks, i.e. 'V1' (0.91:131.7 $kg.tree^{-1}$), 'Velvick' (0.87:119.1 $kg.tree^{-1}$) and 'Duke 7' (0.81:93.6 $kg.tree^{-1}$).

Table 18 Annual yield efficiency (kg/m^3) of 'Hass' trees grafted to nine cloned avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010
'A8'	1.31	0.62^{bcd}
'A10'	0.80	0.50^{d}
'Duke 7'	1.08	0.81^{ab}
'Nabal'	0.76	0.56^{cd}
'SHSR-03'	1.02	0.59^{bcd}
'Thomas'	0.97	0.76^{abc}
'Velvick'	0.70	0.87^{a}
'V1'	1.04	0.91^{a}
'Zutano'	1.37	0.80^{abc}
LSD ($P \leq 0.05$)	**ns[1]**	**0.25**

[1] ns = non significant ($P > 0.05$)

The annual mean fruit mass was significantly different between rootstocks in 2009 and 2011 (Table 19). 'Zutano', 'Velvick', and 'V1' cloned rootstocks produced the largest fruit in 2009 and also in 2011. This was an exceptionally good result for 'V1' since across these years it was also one of the highest producing rootstocks.

Table 19 Annual mean fruit mass (g) of 'Hass' trees grafted to nine cloned avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A8'	200.1^{bc}	184.3	173.1^{d}	163.7
'A10'	196.1^{c}	184.2	196.0^{c}	159.0
'Duke 7'	190.5^{c}	198.9	203.0^{bc}	177.2
'Nabal'	193.7^{c}	189.1	196.0^{c}	171.5
'SHSR-03'	195.9^{c}	187.1	190.7^{cd}	168.9
'Thomas'	198.7^{c}	188.4	188.5^{cd}	152.8
'Velvick'	214.3^{a}	197.5	209.3^{abc}	157.8
'V1'	213.3^{ab}	183.7	224.3^{ab}	175.7
'Zutano'	214.3^{a}	186.2	228.6^{a}	164.7
LSD (P ≤ 0.05)	**13.6**	**ns[1]**	**21.8**	**ns**

[1] ns = non significant ($P > 0.05$)

Table 20 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive and the cumulative yield from 2007 to 2012 measured from 'Hass' grafted to six avocado rootstocks propagated as both clones and seedlings growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A8' clone	49.8^{de}	52.0	128.5^{abc}	20.6^{cd}	275.8^{h}
'A8' seedling	88.1^{a}	82.8	175.4^{a}	28.4^{cd}	430.9^{bc}
'A10' clone	49.8^{de}	69.8	145^{ab}	22.0^{cd}	327.6^{fgh}
'A10' seedling	66.2^{bc}	62.7	161.9^{a}	27.0^{cd}	365.5^{cdef}
'Nabal' clone	49.0^{de}	82.9	121.8^{bc}	48.9^{bcd}	341.9^{efgh}
'Nabal' seedling	64.8^{bcd}	91.3	134.4^{abc}	51.9^{bcd}	399.3^{bcde}
'SHSR-03' clone	64.1^{cd}	91.5	157.6^{ab}	43.1^{cd}	413.4^{bcd}
;SHSR-03' seedling	54.0^{cde}	60.8	126.1^{bc}	14.9^{d}	297.7^{gh}
'Velvick' clone	39.2^{e}	119.1	92.2^{c}	89.8^{ab}	403.1^{bcde}
'Velvick' seedling	80.8^{ab}	93.6	158.0^{ab}	61.0^{bc}	456.4^{ab}
'V1' clone	70.1^{bc}	131.7	118.0^{bc}	110.4^{a}	499.5^{a}
'V1' seedling	63.4^{ab}	76.7	91.4^{c}	57.2^{bcd}	346.9^{defg}
LSD (P ≤ 0.05)	**16.2**	**ns[1]**	**48.2**	**45.9**	**67.5**

[1] ns = non significant ($P > 0.05$)

Yield comparisons made between seedling and cloned rootstocks common to the Childers site were significantly different in 2009, 2011 and 2012 (Table 20). In 2009, the seedling rootstocks of 'A8', 'A10' and 'Velvick' all produced higher yields than their related cloned rootstocks. There were no significant differences in yield between the seedling/cloned pairs of the remaining rootstocks. 'Velvick' was the only rootstock in 2011 where the yields of the seedling/cloned pair were significantly different with the seedling rootstock having a higher yield than the clone. In 2012, there was no significant difference between the seedling/cloned pairs of rootstocks with the exception of 'V1' where the cloned rootstock produced a significantly higher yield than the seedling (Table 20).

With respect to the six-year cumulative yield the cloned 'V1' was the outstanding rootstock with a significantly higher yield (499.5 kg.tree^{-1}) all other rootstocks with the exception of seedling 'Velvick'

(456.4 kg.tree^{-1}). Other rootstocks that performed at the higher end of the group were seedling 'A8' (430.9 kg.tree^{-1}), cloned 'SHSR-03' (413.4 kg.tree^{-1}) and the cloned 'Velvick' (403.1 kg.tree^{-1}).

Table 21 Yield variances between 'Hass' trees propagated to either seedling or cloned rootstocks from the same varietal source growing near Childers, central Queensland. Data are measured from 10 replications for each rootstock. Variances between trees and P values were determined using Genstat and Bartlett's test. Significant differences ($P \leq 0.05$) are indicated by highlighted P values.

Rootstock	Variances Among Trees		P value	Rootstock	Variances Among Trees		P value
	Rootstock Origin				Rootstock Origin		
	Seed	Clone			Seed	Clone	
A8				**SHSR-03**			
Yield 2008	200	145	0.640	Yield 2008	278	111	0.186
Yield 2009	561	540	0.955	Yield 2009	354	212	0.457
Yield 2010	1409	1098	0.716	Yield 2010	686	2062	0.116
Yield 2011	3241	3452	0.927	Yield 2011	2528	2381	0.930
Yield 2012	1192	1191	0.999	Yield 2012	506	3698	**0.007**
Cumulative yield 2008/12	5797	9887	0.438	Cumulative yield 2009/12	5360	8609	0.491
A10				**V1**			
Yield 2008	524	315	0.461	Yield 2008	314	97	0.094
Yield 2009	628	148	**0.043**	Yield 2009	250	220	0.854
Yield 2010	1193	692	0.429	Yield 2010	1761	968	0.386
Yield 2011	2059	2840	0639	Yield 2011	3369	2269	0.565
Yield 2012	1319	1707	0.707	Yield 2012	4615	4639	0.936
Cumulative yield 2008/12	7077	6095	0.828	Cumulative yield 2008/12	8216	2819	0.127
Nabal				**Velvick**			
Yield 2008	297	300	0.985	Yield 2008	105	128	0.774
Yield 2009	46	198	**0.041**	Yield 2009	440	421	0.948
Yield 2010	1574	933	0.448	Yield 2010	1266	351	0.069
Yield 2011	1600	1908	0.797	Yield 2011	5833	5324	0.894
Yield 2012	2564	2928	0.846	Yield 2012	5697	2396	0.213
Cumulative yield 2008/12	7246	4719	0.533	Cumulative yield 2008/12	6555	965	**0.009**

Yield variances between the paired seedling/cloned rootstocks of six rootstock varieties are presented in Table 21. Of the 36 paired comparisons significant differences were only measured in four cases (11% of the sample). In two cases ('A10'/2009 and 'Velvick'/2008-12) the cloned rootstock had lower variance than the seedling of the variety while in the other two cases ('Nabal'/2009 and 'SHSR-03'/2012) the seedling had less variance than the cloned equivalent.

Shepard

'Shepard' is the earliest maturing variety grown in Australia and due to its sensitivity to low temperatures during flowering commercial production is restricted to the warmest growing areas being the Bundaberg region and the Atherton Tablelands. Annual yield data from a seedling rootstock experiment established at Childers are reported in Table 22.

There were no significant differences between rootstock yield in 2009 but significant differences between rootstocks were recorded in 2010, 2011 and 2012. 'Velvick' was the highest yielding (112.8 kg.tree^{-1}) rootstock in 2010 with high yields in 2010 were 'Plowman' (103.5 kg.tree^{-1}), 'Nabal' (97.8 kg.tree^{-1}) and 'Reed' (96.1 kg.tree^{-1}). The higher yielding rootstocks in 2011 were 'Velvick' (88.6 kg.tree^{-1}), 'Parida' (79.4 kg.tree^{-1}) and 'Nabal' (78.7 kg.tree^{-1}) while in 2012 'Velvick' (88.2 kg.tree^{-1})

produced a significantly higher yield than all other rootstocks. The highest cropping year was 2010 when production of the highest yielding rootstocks reached 17-20 $t.ha^{-1}$ which is in the realms of the upper limit for this variety. Production in 2012 was affected by both a cool, wet spring (2011) during flowering and deterioration in tree health due to the progression of Phytophthora root rot after the above average rainfall during the summers of 2011 and 2012.

With respect to the six-year cumulative yield 'Velvick' (339.2) produced significantly more fruit than any other rootstock. Other high-yielding rootstocks were 'Plowman' (282.2 $kg.tree^{-1}$) and 'Nabal' (279.8 $kg.tree^{-1}$). Le Lagadec (2011) reporting on rootstock research conducted on the same farm from 2006-2010 found a similar result with 'Velvick' seedling rootstock producing the highest yield over five years when grafted to 'Shepard' scions.

Table 22 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive and the cumulative yield from 2007-12 measured from 'Shepard' grafted to ten seedling avocado rootstocks growing near Childers, central Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A10'	46.6 (8.4)	79.6^{bcd} (14.3)	49.7^{de} (8.9)	45.3^{bc} (8.2)	221.3^{cd}
'Edranol'	55.4 (10.0)	68.8^{d} (12.4)	51.6^{cde} (9.3)	40.5^{c} (7.3)	216.3^{d}
'Nabal'	40.7 (7.3)	97.8^{ab} (17.6)	78.7^{ab} (14.2)	62.6^{b} (11.3)	279.8^{b}
'Parida'	45.4 (8.2)	90.0^{abcd} (16.2)	79.4^{ab} (14.3)	56.6^{bc} (10.2)	271.4^{bc}
'Plowman'	51.0 (9.2)	103.5^{ab} (18.6)	71.4^{abc} (12.9)	56.3^{bc} (10.1)	282.2^{b}
'Reed'	47.3 (8.5)	96.1^{ab} (17.3)	72.0^{abc} (13.0)	61.6^{b} (11.1)	272.2^{bc}
'Shepard'	49.5 (8.9)	95.4^{abc} (17.2)	65.1^{bcd} (11.7)	52.1^{bc} (9.4)	257.2^{bcd}
'SHSR-02'	53.0 (9.5)	94.6^{abc} (17.0)	52.2^{cde} (9.4)	37.7^{c} (6.8)	247.0^{bcd}
'Toro Canyon'	33.9 (6.1)	72.0^{cd} (13.0)	39.5^{e} (7.1)	62.9^{b} (11.3)	218.1^{d}
'Velvick'	55.9 (10.1)	112.8^{a} (20.3)	88.6^{a} (15.9)	88.2^{a} (15.9)	339.2^{a}
LSD ($P \leq 0.05$)	**ns[1]**	**23.9**	**20.4**	**20.5**	**51.7**

[1] ns = non significant ($P > 0.05$)

There were no significant differences determined for yield efficiency and mean fruit mass between rootstocks over the four cropping years so data are not presented.

5.3.6 Experiment 6 (Walkamin, Qld)

At the Walkamin site rootstock research was carried out using 'Hass' and 'Shepard' scions and results are presented separately below.

Hass

The annual yields for seedling rootstocks grafted to 'Hass' scions are reported in Table 23. Significant differences between rootstock yields occurred from 2010 to 2012 inclusive. In 2010, 'Velvick' (83.2 $kg.tree^{-1}$), 'Barr Duke' (76.2 $kg.tree^{-1}$), 'A10' (70.6 $kg.tree^{-1}$) and 'SHSR-02' (69.8 $kg.tree^{-1}$) were the highest yielding rootstocks. Similar results were achieved in 2011 with 'A10' (108.4 $kg.tree^{-1}$), 'Barr Duke' (102.0 $kg.tree^{-1}$), 'Rigato' (98.2 $kg.tree^{-1}$), 'Velvick' (96.5 $kg.tree^{-1}$), 'Zutano' (95.7 $kg.tree^{-1}$), and 'SHSR-02' (87.4 $kg.tree^{-1}$) in the top yielding echelon of rootstocks. In 2012, 'Rigato' (164.6 $kg.tree^{-1}$), 'Velvick' (158.2 $kg.tree^{-1}$) and 'Barr Duke' (156.4 $kg.tree^{-1}$) were the highest yielding rootstocks. There was some consistency with high-yielding rootstocks across these 3 years of production.

With respect to cumulative yield over six cropping years 'Velvick' (389.9 $kg.tree^{-1}$) and 'Barr Duke' (389.8 $kg.tree^{-1}$) were the two highest yielding rootstocks. Other rootstocks that produced significant crops over the six years of the experiment were 'Rigato' (368.9 $kg.tree^{-1}$), 'A10' (340.1 $kg.tree^{-1}$), 'Zutano' (329.9 $kg.tree^{-1}$) and SHSR-02 (323.5 $kg.tree^{-1}$).

This experiment had difficulty during establishment due to being planted in old avocado ground where the previous orchard had been removed due to Phytophthora root rot infestation hence the experimental trees were exposed to the disease from the time of planting. Additionally, Cyclone Larry caused significant damage to the trees about 18 months after they had been planted. This was followed by kangaroo damage to trunks which had large pieces of bark eaten back to the wood. These events are likely responsible for the experiment not reaching full production (20+ $t.ha^{-1}$) until the sixth cropping year (Table 23).

Table 23 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from 'Hass' grafted to ten seedling avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
'A8'	24.6 (4.1)	68.5^{abc} (11.4)	84.2^{ab} (14.1)	109.2^{cde} (18.2)	295.0^{abc}
'A10'	24.0 (4.0)	70.6^{ab} (11.8)	108.4^{a} (18.1)	124.9^{abcd} (20.9)	340.1^{ab}
'Barr Duke'	21.6 (3.6)	76.2^{a} (12.7)	102.0^{a} (17.0)	156.4^{ab} (26.1)	372.4^{a}
'Duke 7'	9.2 (1.5)	39.5^{cd} (6.6)	72.0^{bc} (12.0)	79.6^{e} (13.3)	203.8^{cd}
'Nabal'	25.0 (4.2)	44.2^{bcd} (7.4)	71.6^{bc} (12.0)	116.5^{bcde} (19.5)	267.3^{bcd}
'Reed'	14.2 (2.4)	37.6^{d} (6.3)	46.9^{c} (7.8)	83.8^{de} (14.0)	169.4^{d}
'Rigato'	21.6 (3.6)	67.5^{abc} (11.3)	98.2^{ab} (16.4)	164.6^{a} (27.5)	368.9^{ab}
'SHSR-02'	25.9 (4.3)	69.8^{ab} (11.7)	87.4^{ab} (14.6)	121.5^{abcde} (20.3)	323.5^{ab}
'Velvick'	27.0 (4.5)	83.2^{a} (13.9)	96.5^{ab} (16.1)	158.2^{ab} (26.4)	389.8^{a}
'Zutano'	25.7 (4.3)	62.5^{abcd} (10.4)	95.7^{ab} (16.0)	135.5^{abc} (22.6)	329.9^{ab}
LSD ($P \leq 0.05$)	**ns[1]**	**29.4**	**29.4**	**44.4**	**101.9**

[1] ns = non significant ($P > 0.05$)

There were no significant differences recorded in yield efficiency or mean fruit mass between rootstocks over the four cropping years covered in this report so data has not been presented.

Annual yield data from 2009 to 2012 inclusive measured from nine cloned rootstocks grafted to 'Hass' scions in an experiment planted near Childers are presented in Table 24. Significant differences in yield were measured from 2009 to 2011 inclusive. In 2009, the highest yielding rootstocks were 'A8' (18.2 $kg.tree^{-1}$) and 'A10' (17.0 ($kg.tree^{-1}$) and again in 2010 with 'A10' producing 65.7 $kg.tree^{-1}$ and 'A8' producing 61.0 $kg.tree^{-1}$. These two rootstocks were also the highest yielding in 2011 producing 85.3 and 72.4 $kg.tree^{-1}$ respectively (Table 24). Although not significantly different to other rootstocks 'A10' was the highest yielding in 2012.

Based on annual yield performance it is not surprising that 'A10' recorded the highest cumulative yield at 290.3 $kg.tree^{-1}$. Other high yielding rootstocks included 'A8' (269.8 $kg.tree^{-1}$) and 'Zutano' (234.6 $kg.tree^{-1}$). This experiment was similarly affected by planting in soils infested with *Phytophthora cinnamomi* and damage from Cyclone Larry and kangaroos. Production has been building as tree health recovered but is only reaching its maximum in the sixth cropping year.

Table 24 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as t.ha^{-1}.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A8'	18.2^{a} (3.0)	61.0^{a} (10.2)	72.4^{ab} (12.1)	109.6 (18.3)	269.8^{ab}
'A10'	17.0^{ab} (2.8)	65.7^{a} (11.0)	85.3^{a} (14.2)	125.1 (20.9)	290.3^{a}
'Barr Duke'	9.2^{cd} (1.5)	34.7^{b} (5.8)	53.9^{bc} (9.0)	94.5 (15.8)	192.9^{bcd}
'Duke 7'	8.9^{cd} (14.9)	29.7^{bc} (5.0)	50.5^{bc} (8.4)	101.2 (16.9)	204.9^{abcd}
'Hass'	7.5^{cd} (1.3)	18.1^{c} (3.0)	43.7^{c} (7.3)	74.6 (12.5)	148.6^{cd}
'Reed'	7.0^{d} (1.2)	33.2^{bc} (5.5)	36.1^{c} (6.0)	47.0 (7.9)	120.5^{d}
'Thomas'	9.5^{bcd} (1.6)	28.3^{bc} (4.7)	63.5^{abc} (10.6)	100.4 (16.8)	212.1^{abcd}
'Velvick'	11.1^{abcd} (1.9)	22.5^{bc} (3.8)	59.6^{abc} (10.0)	113.8 (19.0)	206.3^{abcd}
'Zutano'	15.1^{abc} (2.5)	53.1^{a} (8.9)	64.7^{abc} (10.8)	93.9 (15.7)	234.6^{abc}
LSD ($P \leq 0.05$)	**7.7**	**16.6**	**29.2**	**ns[1]**	**92.6**

[1] ns = non significant ($P > 0.05$)

Annual yield efficiency (YE) data were significantly difference between the cloned rootstocks from 2009 to 2011inclusive and are presented in Table 25. The highest YE ratios recorded in 2009 and 2010 were for 'A8' (1.83 and 2.82, respectively). In 2011, 'A8' recorded the second highest YE (2.11) behind 'Barr Duke' (2.32). The consistently high YE for 'A8' can in part be attributed to the high yields produced by this rootstock over the term of the experiment (Table 24). However, the cloned version of this rootstock at the Walkamin site did produce a tree with slightly lower vigour than some of the other heavy cropping rootstocks, e.g. 'A10'.

Annual mean fruit mass data were significantly different between the cloned rootstocks in 2009, 2010 and 2012 and are presented in Table 26. In 2009, the largest fruit were produced by 'Thomas' (253.8 g), 'Velvick' (244.9 g) and 'Barr Duke' (235.2 g) while in 2010 the rootstocks with the largest fruit were 'Duke 7' (280.0 g), 'Barr Duke' (265.9 g) and 'Velvick' (264.4 g). In 2012, 'Hass' (212.6 g), Duke 7' 209.2 g) and 'Barr Duke' (249.2 g) rootstocks produced the largest fruit. In each of the years where significant differences were measured in fruit mass rootstocks with the largest fruit were the lowest yielding indicating that crop load was the greatest contributor to fruit mass (Tables 24 and 26).

Table 25 Annual yield efficiency (kg/m^{3}) of 'Hass' trees grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A8'	1.83^{a}	2.82^{a}	2.11^{ab}	2.00
'A10'	0.82^{bc}	2.46^{ab}	1.97^{abc}	1.85
'Barr Duke'	0.67^{bc}	1.86^{bc}	2.32^{a}	2.26
'Duke 7'	1.27^{ab}	1.85^{bc}	2.09^{ab}	2.26
'Hass'	0.32^{c}	0.69^{d}	1.01^{d}	1.12
'Reed'	1.27^{ab}	2.53^{ab}	1.87^{abc}	1.52
'Thomas'	0.48^{c}	0.67^{d}	1.29^{cd}	1.43
'Velvick'	0.54^{c}	0.32^{cd}	1.56^{bcd}	1.66
'Zutano'	0.97^{bc}	1.77^{bc}	1.73^{abcd}	1.52
LSD ($P \leq 0.05$)	**0.65**	**0.87**	**0.72**	**ns[1]**

[1] ns = non significant ($P > 0.05$)

Table 26 Annual mean fruit mass (g) from 'Hass' trees grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A8'	203.9^{c}	226.6^{d}	268.8	193.8^{ab}
'A10'	219.7^{bc}	230.6^{cd}	250.5	186.2^{ab}
'Barr Duke'	235.2^{ab}	265.9^{ab}	287.2	208.3^{a}
'Duke 7'	238.9^{ab}	280.0^{a}	290.7	209.2^{a}
'Hass'	240.0^{ab}	255.0^{abc}	284.8	212.6^{a}
'Reed'	224.8^{bc}	235.9^{cd}	217.0	202.1^{a}
'Thomas'	253.8^{a}	250.7^{bcd}	279.2	214.6^{a}
'Velvick'	244.9^{ab}	264.4^{ab}	236.5	202.3^{a}
'Zutano'	201.1^{c}	247.8^{bcd}	259.1	165.3^{b}
LSD ($P \leq 0.05$)	**28.6**	**27.6**	**ns[1]**	**29.9**

[1] ns = non significant ($P > 0.05$)

Yield comparisons made between 'Hass' trees grafted to seedling and cloned rootstocks common to the Walkamin site were significantly different from 2009 to 2012 inclusive (Table 27). In 2009, the 'Velvick' and 'Barr Duke' seedling rootstocks had significantly higher yields than their cloned counterparts while there were no significant yield differences between the other pairs of seedling/cloned rootstocks. Similarly in 2010 and 2011 'Barr Duke' and 'Velvick' were the only rootstocks to recorded significant yield differences with the seedling rootstocks cropping higher than their respective cloned rootstocks (Table 27). In 2012, 'Barr Duke' and 'Reed' seedling rootstocks had significantly higher yields than the cloned pairs with no significant differences between the other pairs of rootstocks.

With respect to the six-year cumulative yield data the four highest-yielding rootstocks were the seedlings of 'Velvick' (389.8 $kg.tree^{-1}$), 'Barr Duke' (372.4 $kg.tree^{-1}$), 'A10' (340.1 $kg.tree^{-1}$) and 'Zutano' (329.9 $kg.tree^{-1}$). Of these the cumulative yields of 'Velvick', 'Barr Duke' and 'Zutano' seedlings were significantly greater than their cloned counterparts. Yields were not significantly different between the rootstock pairs of any of the other varieties.

Table 27 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Hass' grafted to seven avocado rootstocks propagated as both clones and seedlings growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A8' clone	18.2^{abcd}	61.0^{abcd}	72.4^{bcd}	109.6^{bc}	269.8^{cde}
'A8' seedling	24.6^{ab}	68.5^{ab}	84.2^{abc}	109.2^{bc}	295.0^{abcd}
'A10' clone	17.0^{abcd}	65.7^{ab}	85.3^{abc}	125.1^{abc}	290.3^{bcd}
'A10' seedling	24.0^{ab}	70.6^{ab}	108.4^{a}	124.9^{abc}	340.1^{abc}
'Barr Duke' clone	9.2^{d}	34.7^{ef}	50.5^{de}	94.5^{bc}	192.9^{efg}
'Barr Duke' seedling	21.6^{abc}	76.2^{ab}	102.0^{a}	156.4^{a}	372.4^{ab}
'Duke 7' clone	8.9^{d}	29.7^{ef}	53.9^{de}	101.2^{bc}	204.9^{defg}
'Duke 7' seedling	9.2^{d}	39.5^{cdef}	72.0^{bcd}	79.6^{cd}	203.8^{defg}
'Reed' clone	7.0^{d}	33.2^{ef}	36.1^{e}	47.0^{d}	120.5^{g}
'Reed' seedling	14.2^{bcd}	37.6^{def}	46.9^{de}	121.5^{abc}	169.4^{fg}
'Velvick' clone	11.1^{cd}	22.5^{f}	59.6^{cde}	113.8^{abc}	206.3^{defg}
'Velvick' seedling	27.0^{a}	83.2^{a}	96.5^{ab}	158.2^{a}	389.8^{a}
'Zutano' clone	15.1^{bcd}	53.1^{bcde}	64.7^{cde}	93.9^{bc}	234.6^{def}
'Zutano' seedling	25.7^{ab}	62.5^{abc}	95.7^{ab}	135.5^{ab}	329.9^{abc}
LSD ($P \leq 0.05$)	**11.9**	**24.7**	**29.1**	**45.9**	**95.2**

Yield variances between the paired seedling/cloned rootstocks of seven rootstock varieties grafted to 'Hass' growing at the Walkamin site are presented in Table 28. Of the 42 paired comparisons significant differences were measured in twelve cases (28.6% of the sample). In one case ('A10'/2011) the seedling rootstock had lower variance than the clone of the variety while in the other eleven cases ('A8'/2009, 'Barr Duke/2008, 2009 & cumulative yield, 'Reed'/2008-2011 and 'Zutano'/2008-2009) the clones had less variance than the seedling equivalent. In some cases the reduced variance in the clones is due to low yields recorded by these rootstocks, e.g. 'Barr Duke'/2009, 'Reed'/2009 and 'Zutano'/2009 indicating that lower variance may not be always a sign of reduced genetic variability.

Table 28 Yield variances between 'Hass' trees propagated to either seedling or cloned rootstocks from the same varietal source growing at Walkamin, north Queensland. Data are measured from 10 replications for each rootstock. Variances between trees and P values were determined using Genstat and Bartlett's test. Significant differences ($P \leq 0.05$) are indicated by highlighted P values.

Rootstock	Variances Among Trees – Rootstock Origin		P value	Rootstock	Variances Among Trees – Rootstock Origin		P value
	Seed	Clone			Seed	Clone	
A8				**Reed**			
Yield 2008	125	93	0.671	Yield 2008	116	8	**0.001**
Yield 2009	322	56	**0.016**	Yield 2009	163	19	**0.004**
Yield 2010	730	335	0.261	Yield 2010	610	131	**0.032**
Yield 2011	665	406	0.474	Yield 2011	1458	360	**0.049**
Yield 2012	1504	1621	0.913	Yield 2012	2777	1131	0.215
Cumulative yield 2008/12	8387	4516	0.370	Cumulative yield 2009/12	6926	2134	0.190
A10				**Velvick**			
Yield 2008	95	77	0.761	Yield 2008	286	150	0.350
Yield 2009	164	141	0.819	Yield 2009	304	129	0.218
Yield 2010	1265	624	0.307	Yield 2010	1714	451	0.060
Yield 2011	583	2330	**0.050**	Yield 2011	557	2100	0.061
Yield 2012	1816	6454	0.079	Yield 2012	1902	3200	0.462
Cumulative yield 2008/12	9989	20779	0.302	Cumulative yield 2008/12	15588	12817	0.783
Barr Duke				**Zutano**			
Yield 2008	294	19	**0.001**	Yield 2008	130	8	**0.001**
Yield 2009	460	31	**0.001**	Yield 2009	437	148	**0.013**
Yield 2010	1528	600	0.180	Yield 2010	1091	1057	0.963
Yield 2011	1139	536	0.276	Yield 2011	1803	859	0.284
Yield 2012	3137	1243	0.184	Yield 2012	3727	2030	0.378
Cumulative yield 2008/12	19451	4789	**0.049**	Cumulative yield 2008/12	19307	8052	0.209
Duke 7							
Yield 2008	43	65	0.537				
Yield 2009	102	37	0.145				
Yield 2010	569	484	0.815				
Yield 2011	1995	318	**0.012**				
Yield 2012	3473	3850	0.881				
Cumulative yield 2008/12	7721	7768	0.993				

Shepard

Annual yield data from a seedling rootstock experiment grafted to 'Shepard' scions and established at Walkamin are reported in Table 29. Significant yield differences between rootstocks were determined in each of the four years of the experiment. In 2009, the highest yielding rootstocks were 'Reed' (54.1 $kg.tree^{-1}$), 'A8' (53.3 $kg.tree^{-1}$) and 'V1' (47.4 $kg.tree^{-1}$) while 'Velvick' (110.8 $kg.tree^{-1}$), 'V1' (108.7 $kg.tree^{-1}$) and 'SHSR-02' (95.1 $kg.tree^{-1}$) were the highest yielding rootstocks in 2010 and again in 2011 (Table 29). In 2012, 'Velvick' (171.1 $kg.tree^{-1}$), 'SHSR-02' (168.5 $kg.tree^{-1}$) and 'V1' (162.8 $kg.tree^{-1}$) were again the highest yielding rootstocks indicating consistency across the duration of the experiment. This experiment was damaged by Cyclone Larry 18 months after it was planted which is probably why production has not peaked until the sixth cropping year (2012). It is unusual for 'Shepard' to produce in excess of 20 $t.ha^{-1}$ and quite exceptional to achieve above 28 $t.ha^{-1}$ as some rootstocks ('Velvick' and 'SHSR-02') did in 2012. 'Shepard' is an early maturing variety and harvesting soon after fruit reached commercial maturity as was done with this experiment has maintained consistent high production from the top performing rootstocks (Whiley *et al.* 1996 a,b).

These three rootstocks also dominated the cumulative yield production with ‘Velvick’, ‘V1’ and ‘SHSR-02’ producing 468.1, 451.4 and 428.4 $kg.tree^{-1}$, respectively and had significantly higher cumulative yields than ‘A8’, ‘A10’, ‘Duke 7’, ‘Nabal’, ‘SHSR-03’ and ‘Zutano’ (Table 29).

Table 29 Annual yields ($kg.tree^{-1}$) from 2009 to 2012 inclusive measured from ‘Shepard’ grafted to ten seedling avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as $t.ha^{-1}$.

Rootstock	Yield 2009 ($kg.tree^{-1}$)	Yield 2010 ($kg.tree^{-1}$)	Yield 2011 ($kg.tree^{-1}$)	Yield 2012 ($kg.tree^{-1}$)	Cumulative yield 2007-12 ($kg.tree^{-1}$)
‘A8’	53.3^{a} (8.9)	75.8^{bc} (12.7)	59.3^{d} (9.9)	109.2^{c} (18.2)	290.5^{cd}
‘A10’	20.0^{c} (3.3)	61.0^{c} (10.2)	78.0^{bcd} (13.0)	90.6^{c} (15.1)	263.0^{cd}
‘Duke 7’	28.1^{bc} (4.7)	53.2^{c} (8.9)	52.1^{d} (8.7)	72.5^{c} (12.1)	217.1^{d}
‘Nabal’	36.7^{abc} (6.1)	64.9^{c} (10.8)	91.9^{abc} (15.4)	86.8^{c} (14.5)	295.4^{cd}
‘Reed’	54.1^{a} (9.0)	75.4^{bc} (12.6)	81.9^{bcd} (13.7)	120.2^{abc} (20.1)	347.4^{bc}
‘SHSR-02’	38.6^{abc} (6.5)	95.1^{ab} (15.9)	99.7^{ab} (16.6)	168.5^{ab} (28.1)	428.4^{ab}
‘SHSR-03’	37.8^{abc} (6.3)	64.3^{c} (10.7)	68.6^{cd} (11.5)	94.4^{c} (15.8)	268.8^{cd}
‘Velvick’	34.6^{abc} (5.8)	110.8^{a} (18.5)	116.6^{a} (19.5)	171.1^{a} (28.6)	468.1^{a}
‘V1’	47.4^{ab} (7.9)	108.7^{a} (18.2)	106.9^{ab} (17.9)	162.8^{ab} (27.2)	451.4^{ab}
‘Zutano’	30.6^{bc} (5.1)	73.3^{bc} (12.2)	68.4^{cd} (11.4)	118.6^{bc} (19.8)	295.2^{cd}
LSD ($P \leq 0.05$)	**20.1**	**26.5**	**30.5**	**51.2**	**108.0**

There were no significant differences between rootstocks for annual yield efficiency and mean fruit mass so data from these two parameters has not been presented.

Annual yield data from ‘Shepard’ trees grafted to nine cloned rootstocks growing at Walkamin from 2009 to 2012 inclusive are presented in Table 30. Significant differences between rootstock yields were recorded for each year of the experiment. In 2009, ‘Thomas’ (43.4 $kg.tree^{-1}$), ‘Velvick’ (36.5 $kg.tree^{-1}$), ‘A10’ (34.3 $kg.tree^{-1}$) and ‘Shepard’ (33.1 $kg.tree^{-1}$) were the highest yielding rootstocks. ‘Thomas’ (106.1 $kg.tree^{-1}$) had a significantly higher yield than all other rootstocks in 2010 and was again in the top echelon of rootstocks, although not significantly different to them, in 2011. In 2012, the three highest yielding rootstocks were ‘Thomas’ (160.3 $kg.tree^{-1}$), ‘Zutano’ (129.4 $kg.tree^{-1}$) and ‘SHSR-03’ (128.6 $kg.tree^{-1}$) with production exceeding 20 $t.ha^{-1}$.

‘Thomas’ (419.3 $kg.tree^{-1}$) had the highest cumulative yield over the six-year production period of the experiment which was significantly greater than all other rootstocks (Table 30). Other rootstocks with high cumulative totals were ‘Shepard’ (324.7 $kg.tree^{-1}$), ‘SHSR-03’ (324.2 $kg.tree^{-1}$) and ‘A10’ (320.9 $kg.tree^{-1}$). The ‘Shepard’ rootstock is basically a rooted cutting of the scion variety since no graft was made when the root system was cloned. It is interesting to see that when grown on its own roots this cutting is as productive as some of the higher cropping rootstock varieties.

Table 30 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Shepard' grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. Data in parentheses are yield expressed as t.ha^{-1}.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A10'	34.3^{abc} (5.7)	75.2^{bc} (12.6)	74.7^{a} (12.5)	125.0^{bc} (20.9)	320.9^{b}
'Barr Duke'	22.3^{cd} (3.7)	69.1^{bc} (11.5)	72.0^{a} (12.0)	113.5^{bc} (19.0)	285.6^{b}
'Duke 7'	6.2^{e} (1.0)	53.9^{c} (9.0)	35.1^{b} (5.9)	61.9^{de} (10.3)	146.8^{c}
'Nabal'	13.9^{de} (2.3)	21.7^{d} (3.6)	35.6^{b} (5.9)	45.0^{e} (7.5)	108.1^{c}
'Shepard'	33.1^{abc} (5.5)	79.6^{b} (13.3)	87.0^{a} (14.5)	106.6^{bc} (17.8)	324.7^{b}
'SHSR-03'	28.9^{bc} (4.8)	75.1^{bc} (5.6)	86.4^{a} (14.4)	128.6^{ab} (21.5)	324.2^{b}
'Thomas'	43.4^{a} (7.2)	106.1^{a} (17.7)	93.5^{a} (15.6)	160.3^{a} (26.8)	419.3^{a}
'Velvick'	36.5^{ab} (6.1)	70.5^{bc} (11.8)	82.4^{a} (13.8)	92.9^{cd} (15.5)	295.8^{b}
'Zutano'	28.6^{bc} (4.8)	72.3^{bc} (12.1)	78.4^{a} (12.5)	129.4^{ab} (21.6)	302.8^{b}
LSD (P ≤ 0.05)	**14.0**	**23.0**	**27.0**	**32.8**	**86.6**

Annual yield efficiency data for 'Shepard' trees grafted to cloned rootstocks are presented in Table 31. Significant differences between rootstocks were recorded from 2009 to 2011 inclusive. In 2009, 'Velvick' (1.91), 'SHSR-03' (1.76), 'Barr Duke' (1.43) and 'Shepard (1.43) recorded the highest YE ratios of all rootstocks. 'Duke 7' (3.56) had a significantly higher YE than all other rootstocks in 2010 while in 2011 'Velvick' (2.12) and 'Shepard' (2.03) had the highest YE's recorded. Although 'Thomas' was the highest yielding rootstock its YE was comparatively low in each year of production (Table 31). 'Shepard' grafted to cloned 'Thomas' was easily the most vigorous rootstock in the experiment with the largest trees thereby assisting high annual production. 'SHSR-03 produced a 'Shepard' tree of smaller stature and maintained a high YE across the production years suggesting that rootstock/scion genetics were resulting in a more efficient tree.

Table 31 Annual yield efficiency (kg/m^3) of 'Shepard' trees grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A10'	1.63^{ab}	2.17^{b}	1.68^{abcd}	2.62
'Barr Duke'	1.43^{abc}	2.52^{b}	1.95^{ab}	2.47
'Duke 7'	1.02^{c}	3.56^{a}	1.35^{cd}	2.09
'Nabal'	1.33^{bc}	1.42^{c}	1.39^{bcd}	1.77
'Shepard'	1.43^{abc}	2.36^{b}	2.03^{a}	2.49
'SHSR-03'	1.76^{ab}	2.15^{b}	1.89^{abc}	2.67
'Thomas'	1.27^{bc}	1.95^{bc}	1.23^{d}	2.23
'Velvick'	1.91^{a}	2.25^{b}	2.12^{a}	2.11
'Zutano'	1.39^{bc}	2.07^{b}	1.75^{abcd}	2.35
LSD (P ≤ 0.05)	**0.48**	**0.65**	**0.59**	**ns[1]**

[1] ns = non significant ($P > 0.05$)

Annual mean fruit mass data for 'Shepard' trees grafted to cloned rootstocks grown at Walkamin are presented in Table 77. Significant differences between rootstocks were recorded in 2009, 2010 and 2012. In 2009 the largest fruit were produced by 'Duke 7' (288.5 g) and 'Velvick' (279.8 g) while 'Duke 7' (290.0 g) and 'Nabal' (255.5 g) produced the largest fruit in 2010. Similarly in 2012, 'Nabal' (239.7 g) and 'Duke 7' (238.9 g) produced fruit with greater mass than the other rootstocks (Table 32).

These two rootstocks were the lowest producing across each year of the experiment (Table 30) hence it is likely that the larger fruit are a direct result of low crop load.

Table 32 Annual mean fruit mass (g) from 'Shepard' trees grafted to nine cloned avocado rootstocks growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	2009	2010	2011	2012
'A10'	233.4^{d}	231.4^{d}	243.7	213.5^{d}
'Barr Duke'	278.2^{abc}	261.6^{b}	257.9	226.3^{abcd}
'Duke 7'	288.5^{a}	290.0^{a}	211.0	238.9^{ab}
'Nabal'	255.9^{bcd}	271.1^{ab}	204.9	239.7^{a}
'Shepard'	262.1^{abc}	236.1^{cd}	235.5	214.4^{cd}
'SHSR-03'	250.7^{cd}	255.5^{bc}	224.9	217.4^{bcd}
'Thomas'	259.9^{bcd}	236.8^{cd}	241.3	220.5^{abcd}
'Velvick'	279.8^{ab}	239.4^{cd}	244.9	209.0^{d}
'Zutano'	279.3^{ab}	260.8^{b}	217.0	235.5^{abc}
LSD (P ≤ 0.05)	**27.6**	**20.9**	**ns[1]**	**21.6**

[1] ns = non significant ($P > 0.05$)

Table 33 Annual yields (kg.tree^{-1}) from 2009 to 2012 inclusive measured from 'Shepard' grafted to six avocado rootstocks propagated as both clones and seedlings growing at Walkamin, north Queensland. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA.

Rootstock	Yield 2009 (kg.tree^{-1})	Yield 2010 (kg.tree^{-1})	Yield 2011 (kg.tree^{-1})	Yield 2012 (kg.tree^{-1})	Cumulative yield 2007-12 (kg.tree^{-1})
'A10' clone	34.3^{ab}	75.2^{b}	74.7^{bc}	125.0^{bc}	320.9^{b}
'A10' seedling	20.0^{bcd}	61.0^{b}	78.0^{bc}	90.6^{cde}	263.0^{bc}
'Duke 7' clone	6.2^{d}	53.9^{b}	35.1^{d}	61.9^{ef}	146.8^{de}
'Duke 7' seedling	28.1^{abc}	53.2^{b}	52.1^{cd}	72.5^{def}	217.1^{cd}
'Nabal' clone	13.9^{cd}	21.7^{c}	35.6^{d}	45.0^{f}	108.1^{e}
'Nabal' seedling	36.6^{a}	64.9^{b}	91.9^{ab}	86.8^{cde}	295.4^{bc}
'SHSR-03' clone	28.9^{abc}	75.1^{b}	86.4^{b}	128.6^{b}	324.2^{b}
'SHSR-03' seedling	37.8^{a}	64.3^{b}	68.6^{bc}	94.4^{cde}	268.8^{bc}
'Velvick' clone	36.5^{a}	70.5^{b}	82.4^{b}	92.8^{bcde}	295.8^{bc}
'Velvick' seedling	34.6^{ab}	110.76^{a}	116.6^{a}	171.1^{a}	468.1^{a}
'Zutano' clone	28.6^{abc}	72.3^{b}	78.4^{bc}	129.4^{b}	302.8^{bc}
'Zutano' seedling	30.6^{ab}	73.3^{b}	68.4^{bc}	118.6^{bc}	295.2^{bc}
LSD (P ≤ 0.05)	**16.1**	**25.6**	**25.6**	**40.3**	**92.4**

Yield comparisons made between 'Shepard' trees grafted to seedling and cloned rootstocks common to the Walkamin site were significantly different from 2009 to 2012 inclusive (Table 33). In 2009, cloned 'A10' has a significantly higher yield than its seedling pair while seedling 'Duke 7' and 'Nabal' had significantly higher yields than their respective cloned pairs. Seedling 'Nabal' and 'Velvick' had significantly higher yields than their respective cloned pairs while yield difference between the seedling and cloned rootstocks of other varieties were not significant in 2010 (Table 33). These results were repeated in 2011. In 2012, the seedlings of 'Nabal' and 'Velvick' again produced significantly higher yields than their respective clonal pairs while the clone of 'SHSR-04' had a significantly higher yield than its seedling pair. There were no significant yield differences between the other rootstock pairs.

‘Shepard’ grafted to ‘Velvick’ seedling rootstock produced significantly higher yields than all other rootstocks over the six years production of the experiment confirming a similar result reported by Le Lagadec (2011) when evaluating ‘Shepard’ grafted to a number of rootstocks in the Childers region.

Table 34 Yield variances between ‘Shepard’ trees propagated to either seedling or cloned rootstocks from the same varietal source growing at Walkamin, north Queensland. Data are measured from 10 replications for each rootstock. Variances between trees and P values were determined using Genstat and Bartlett’s test. Significant differences (P ≤ 0.05) are indicated by highlighted P values.

Rootstock	Variances Among Trees		P value	Rootstock	Variances Among Trees		P value
	Rootstock Origin				Rootstock Origin		
	Seed	Clone			Seed	Clone	
A10				**SHSR-03**			
Yield 2008	120	67	0.400	Yield 2008	82	144	0.418
Yield 2009	466	363	0.716	Yield 2009	767	253	0.114
Yield 2010	1188	1226	0.963	Yield 2010	1165	930	0.742
Yield 2011	654	635	0.770	Yield 2011	1367	1770	0.707
Yield 2012	3183	1887	0.475	Yield 2012	2581	664	0.072
Cumulative yield 2008/12	16852	10343	0.504	Cumulative yield 2009/12	15911	6638	0.238
Duke 7				**Velvick**			
Yield 2008	129	3	**0.001**	Yield 2008	198	45	**0.037**
Yield 2009	105	13	**0.005**	Yield 2009	371	336	0.884
Yield 2010	404	1423	0.075	Yield 2010	461	745	0.485
Yield 2011	688	429	0.492	Yield 2011	294	976	0.089
Yield 2012	780	542	0.632	Yield 2012	5188	2903	0.400
Cumulative yield 2008/12	4333	3745	0.847	Cumulative yield 2008/12	9367	11221	0.792
Nabal				**Zutano**			
Yield 2008	89	4	**0.001**	Yield 2008	85	101	0.809
Yield 2009	433	251	0.430	Yield 2009	318	271	0.815
Yield 2010	1055	478	0.254	Yield 2010	158	888	**0.019**
Yield 2011	1104	1197	0.907	Yield 2011	812	1446	0.403
Yield 2012	1355	1033	0.714	Yield 2012	1809	2256	0.762
Cumulative yield 2008/12	8446	10692	0.748	Cumulative yield 2008/12	5946	8705	0.602

Yield variances between the paired seedling/cloned rootstocks of six rootstock varieties grafted to ‘Shepard’ growing at the Walkamin site are presented in Table 34. Of the 36 comparisons only five (13.8% of the sample) had significantly different variances between seedling and cloned pair – four favouring the clone and one favouring the seedling. The ‘Duke 7’ clone had very low yields in 2008 (data not presented) and 2009 which were likely the result of the low variance measure. This was similar for ‘Nabal’ and ‘Velvick’ in 2008 (data not presented) when most trees either didn’t produce fruit or those that cropped had very low numbers thus resulting in a low variance across the population. Hence these data points are not considered a true representation of the comparative variance between cloned and seedling rootstock.

5.4 Conclusions

At the beginning of this rootstock improvement project in 2002 the Australian avocado industry had fallen behind other mainstream producing countries, viz. USA (California), Israel and South Africa, that had been investing for many years in rootstock research for productivity gains by developing Phytophthora root rot resistance, salinity tolerance and rootstocks with high and sustainable production. The agronomic program of this component of the project was designed to answer several questions on rootstocks for Australian avocado growers which are summarised as:

1. Due to the wide genetic diversity of potential rootstock material in Australia drawn from the three horticultural races, viz. Mexican, Guatemalan and West Indian, is there any specific genetic group that has enhanced compatibility when grafted to 'Hass' or 'Shepard' that will consistently improve yield?
2. Will different rootstocks be more suited for each production region across the country considering significant differences in environmental (both soils and climate) conditions?
3. Will the use of cloned rootstocks enhance production over the seedling rootstocks currently used through providing greater genetic uniformity?

Table 35 summarises results relating to the three highest yielding rootstocks at each of the experimental sites. At each rootstock site there were differences in the composition of the top three yielding rootstocks regardless of them being seedling or cloned (Table 35). To assess overall rootstock performance a score was assigned to the three highest yielding rootstocks at each site (Table 35) reflecting their relative position in the ranking, i.e. 1st position equals 3; 2nd position equals 2 and 3rd position equals 1. Since each rootstock did not occur at every experimental site these scores have been divided by the number of times individual rootstocks appeared in each experiment (both seedling and cloned). The calculated scores are tabulated in Table 36.

Table 35 Cumulative fruit yields (kg.tree^{-1}) at each experimental site for the three heaviest producing rootstocks. At Pemberton there were five cropping cycles, at Carabooda four cropping cycles and at all other sites there were six cropping cycles. Data in parentheses are the cumulative yields (kg.tree^{-1}) for the respective rootstocks at each experimental site. Cumulative yields of highlighted rootstocks are significantly different ($P \leq 0.05$) to the other rootstocks, in their respective experiments, not listed in this table.

Location	**Rootstock type**		**Location**	**Rootstock type**	
Scion	**Seedling**	**Cloned**	**Scion**	**Seedling**	**Cloned**
Pemberton			**Carabooda**		
Hass	Velvick (167.1)	Zutano (235.4)	Hass	**Velvick (128.7)**	-
Hass	SHSR-02 (149.2)	A10 (172.9)	Hass	Nabal (120.8)	-
Hass	Plowman (148.1)	Nabal (159.1)	Hass	SHSR-03 (119.1)	-
Duranbah			**Hampton**		
Hass	Velvick (344.5)	-	Hass	Zutano (304.4)	**SHSR-03 (331.9)**
Hass	SHSR-02 (161.8)	-	Hass	Velvick (303.6)	Velvick (297.7)
Hass	Parida (152.8)	-	Hass	Nabal (275.9)	Zutano (293.6)
Childers			**Walkamin**		
Hass	Reed (463.3)	**V1 (499.5)**	Hass	Velvick (389.8)	A10 (290.3)
Hass	Velvick (456.4)	SHSR-03 (413.4)	Hass	Zutano (329.9)	A8 (269.8)
Hass	A8 (430.9)	Velvick (403.1)	Hass	Barr Duke (372.4)	Zutano (234.6)
Shepard	**Velvick (389.8)**	-	Shepard	**Velvick (468.1)**	**Thomas (419.3)**
Shepard	Plowman (282.2)	-	Shepard	V1 (451.4)	Shepard (324.2)
Shepard	Nabal (279.8)	-	Shepard	SHSR-02 (428.4)	A10 (320.9)

In answering the three points above the top yielding rootstocks overwhelmingly come from the Guatemalan and West Indian horticultural races, e.g. 'A8', 'Nabal', 'Plowman', 'Reed', 'SHSR-02', 'V1' and 'Velvick' (Table 35). Hybrids with Mexican and Guatemalan race genes were in the second most successful group, e.g. 'A10', 'Shepard', 'SHSR-03' and 'Zutano' whilst Mexican race rootstocks were overall the least represented group in the high performance echelon, viz. 'Barr Duke', 'Parida' and 'Thomas' (Table 35). This is reaffirmed by the numerical ranking of rootstocks presented in Table 36. With respect to individual rootstock performance across all sites 'Velvick' (3.35) has lead the field followed by 'Zutano' (2.92) and 'V1' (2.5) (Table 36). However, this doesn't mean that only these three rootstocks should be considered for planting in Australia. For example, the cumulative yield from cloned 'SHSR-03' grafted to 'Hass' and grown at Hampton has been exceptional when compared with other rootstocks (both seedling and cloned) and seedling 'Reed' has outperformed the other seedling rootstocks when grown in a disease-free site (until 2011) near 'Childers' (Table 35).

Table 36 Scored performances of the three highest yielding rootstocks across all experimental sites in the rootstock project. Scores have been corrected to reflect the number of times each rootstock appeared across all experimental sites.

Rootstock	**Rootstock type**		**Total score**	**Rootstock**	**Rootstock type**		**Total score**
	Seedling	**Cloned**			**Seedling**	**Cloned**	
A8	0.20	0.67	0.87	Shepard	0	2.00	2.00
A10	0	1.20	1.20	SHSR-02	0.71	-	0.71
Barr Duke	0.50	0	0.50	SHSR-03	0.20	1.67	1.87
Nabal	0.05	0.25	0.75	Thomas	0	1.00	1.00
Parida	0.05	0	0.05	**V1**	**1.00**	**1.50**	**2.50**
Plowman	1.00	0	1.00	**Velvick**	**2.75**	**0.60**	**3.35**
Reed	0.43	0	0.43	**Zutano**	**1.67**	**1.25**	**2.92**

Many highly developed tree and vine fruit crops, e.g. apples, citrus, table grapes have developed genetically uniform rootstocks that are vegetatively propagated for their production systems. Providing the rootstocks chosen enhance crop production it is logical that genetic uniformity should improve total production measured as tonnes produced per hectare of planted land. It was with this expectation that seedling vs. cloned avocado rootstocks studies were set up in this project. Five experiments compared seedling rootstocks with clonally propagated rootstocks of the same variety and a total of 26 pairs were matched across the experimental sites (Tables 6, 13, 20, 27 and 33). When comparing cumulative yield over the duration of the project (5-6 years yield data depending on site) there were no significant differences measured between 16 of the paired rootstocks. There were significant differences ($P \leq 0.05$) for cumulative yield between 10 of the rootstock pairs but of these seven pairs favoured the seedling rootstock and three pairs favoured the cloned rootstock. When rootstock yield variance was analysed between the seedling/cloned pairs (Tables 7, 14, 21, 28 and 34) in most cases there was no significant difference thereby challenging the preconceived concept that cloned rootstocks would increase uniformity between trees. Hence, the results from this project across the rootstocks chosen for research, strongly favour seedling superiority with respect to yield performance over the longer term. Selection of seed for this study was rigorous with material being sourced from maternal trees that were unlikely to be out-crossed with other varieties thus limiting genetic diversity to that contained in the parent tree. The potential for out-crossing to change seedling performance is demonstrated in the results of Smith *et al*. (2011) who found when 'Hass' was grafted to two 'Velvick' seedling lines where the maternal trees had difference out-crossing opportunities yield was significantly different, viz. Table 37 compare 'Velvick^{L}' with 'Velvick^{A}' seedling. The significance of this result should be checked with molecular studies to determine the extent of genetic variance among seedling lines of the same variety from sources with different out-crossing opportunities since this may significantly change the management of seed production for nursery use. For example, it may demonstrate that there are significant commercial benefits to be gained from producing seed for nursery use in isolation from out-crossing opportunities during flowering.

Table 37 Average health and yield of 'Hass' avocado trees grafted to different rootstocks and grown at Childers. Tree health was rated on the 0-10 scale where 0 = healthy and 10 = dead. Data in columns followed by different superscript letters are significantly different ($P \leq 0.05$) as tested by ANOVA. From Smith *et al.* (2011).

Rootstock	Tree health (4 years)	Tree health (4.5 years)	Cumulative yield (kg.tree^{-1})	Cumulative fruit number/tree
Velvick^{L} seedling	3.8^{bcd}	3.0^{bcd}	80.0^{a}	329^{a}
Latas™ cloned	2.7^{cd}	2.5^{cd}	70.4^{ab}	268^{ab}
A8 seedling	3.9^{bcd}	4.1^{abc}	68.2^{ab}	289^{ab}
Dusa™ cloned	2.4^{d}	1.2^{d}	64.7^{ab}	240^{abc}
A10 seedling	4.3^{bc}	4.2^{abc}	56.9^{abc}	250^{abc}
Velvick^{A} seedling	5.1^{ab}	4.9^{ab}	46.3^{bcd}	191^{bcd}
Velvick^{SHS} cloned	4.9^{b}	3.8^{bc}	35.2^{cd}	144^{cd}
Reed seedling	6.7^{a}	6.0^{a}	23.9^{d}	97^{d}

Despite the overall underperformance of cloned rootstocks there were four exceptions where a cloned rootstock was the highest yielding (although not significantly different to all rootstocks) in the experimental pool of varieties (both seedling and cloned). At Pemberton the cloned 'Zutano' rootstock grafted to 'Hass' produced 36% more fruit over the five year cropping cycle compared with cloned 'A10' which was the next highest yielding rootstock at this site but was not significantly different ($P \leq 0.05$). Cloned 'SHSR-03' grafted to 'Hass' was the highest yielding rootstock over the six-year cropping cycle at Hampton but was not significantly different to seedling 'A10', seedling 'Nabal', seedling and cloned 'Velvick' and seedling and cloned 'Zutano'. At Childers, cloned 'V1' grafted to 'Hass' was the highest yielding rootstock (499.5 kg.tree^{-1}) at this site but was not significantly different to seedling 'Velvick' (456.4 kg.tree^{-1}). 'V1' is a seedling selection of 'Velvick' which has not been offered for sale hence it would be eligible for Plant Breeders Rights however, it was not exceptional as a seedling and is quite difficult to commercially clone although with further propagation research this may be overcome.

6. High-yielding Rootstocks Identified from Experimental Sites

6.1 Introduction

Genetic variability within a population of avocado seedlings is usually high due to a flowering dichogamy that favours out-crossing (Bergh, 1975). Thomas (1997) reported large cumulative yield differences over a six-year fruiting period between 'Hass' avocado trees grafted to seedling rootstocks of unknown origin. In this study each of the seedling rootstocks selected were sourced from a maternal parent growing in comparative isolation thus reducing the opportunity for out-crossing to occur. However, each sexually produced seed has a unique recombination of genes potentially changing its performance to others from the same maternal source. Larger genetic differences will occur between seedlings of different genotypic heritage.

6.2 Materials and Methods

Seedling rootstock yield over five to six cropping cycles from experimental sites at Pemberton (WA), Hampton (QLD), Childers (QLD) and Walkamin (QLD) were reviewed following the conclusion of data collection. A total of 610 individual seedlings from 11 varietal populations grafted to either 'Hass' or 'Shepard scions were assessed by the following parameters:

1. To qualify for selection within the 10 tree rootstock population at each experimental site the yield of the individual rootstock had to produce at least 120% more fruit than the mean of the 10 replications.
2. To further qualify for selection the individual rootstock had to produce at least 170% of the mean yield of the total seedling rootstock population at the experimental site.

6.3 Results and Discussion

The highest producing rootstocks at each site conforming to the selection criteria are identified in Tables 38 to 43 below.

At Pemberton, two rootstocks were identified as potential elite yielding lines. These were 'A10' and 'Toro Canyon' seedlings (Table 38). It is of interest that both rootstocks have Mexican race genes; 'A10' is thought to be a Guatemalan x Mexican race hybrid whilst 'Toro Canyon' is a straight Mexican race variety. 'Zutano' is a Mexican race variety and when propagated as a clone at this site was the highest producing rootstock compared with other cloned rootstocks in the experiment. Pemberton is the coldest experimental site in this program and Mexican race lines are known for their greater cold tolerance when compared to Guatemalan and West Indian race material. Hence it may not be coincidental that the highest yielding individuals at this site come from a gene pool of higher cold tolerance.

Table 38 Potential high producing rootstocks in the Pemberton, WA seedling rootstock/Hass experiment. Annual yield is measured in $kg.tree^{-1}$. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 80 trees in the experiment.

Rootstock*	Production year					Totals $kg.tree^{-1}$	% Rootstock mean yield	% Experiment mean yield
	2008	2009	2010	2011	2012			
A10/R6	64.8	1.2	71.3	98.8	39.8	275.8	202.8	195.9
Toro Can/R6**	56.2	1.9	74.2	133.7	68.7	334.6	230.6	237.6

* R followed by a number identifies the tree in the associated replication position of the experiment.
** Since this project has correlated poor postharvest fruit quality with Mexican race rootstocks it may not be appropriate to recover 'Toro Canyon' material.

Using the selection criteria three potential high yielding lines were identified at Hampton (Table 39): 'Nabal', 'Plowman' and 'Velvick'. Of these, 'Velvick' is of the greatest interest since this line has been amongst the highest yields at other experimental sites of the project.

Table 39 Potential high producing rootstocks in the Hampton, QLD seedling rootstock/Hass experiment. Annual yield is measured in $kg.tree^{-1}$. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 110 trees in the experiment.

Rootstock*	Production year						Totals $kg.tree^{-1}$	% Rootstock mean yield	% Experiment mean yield
	2007	2008	2009	2010	2011	2012			
Nabal/R4	5.1	93.0	103.2	69.2	116.1	55.1	441.7	160.1	173.0
Plowman/R10	3.1	66.9	83.0	97.4	133.8	54.2	438.3	181.9	173.0
Velvick/R2**	0.3	58.0	67.1	148.7	55.0	153.8	482.9	155.7	190.6

* R followed by a number identifies the tree in the associated replication position of the experiment.
** The 'Velvick' parent tree is difficult to clone and is not commercially suited for this type of propagation. Similar difficulties may be found with its seedling progeny.

At the Childers site the 'V1' rootstock grafted to 'Hass' was identified as being potentially high yielding (Table 40). As a cloned rootstock 'V1' produced the highest yield of all rootstocks at this site.

Table 40 Potential high producing rootstocks near Childers, QLD seedling rootstock/Hass experiment. Annual yield is measured in $kg.tree^{-1}$. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 110 trees in the experiment.

Rootstock*	Production year						Totals $kg.tree^{-1}$	% Rootstock mean yield	% Experiment mean yield
	2007	2008	2009	2010	2011	2012			
V1/R5*	14.9	65.1	70.8	71.1	128.8	282.2	632.9	171.9	173.0

* R followed by a number identifies the tree in the associated replication position of the experiment.
** The 'V1' parent tree is difficult to clone and is not commercially suited for this type of propagation. Similar difficulties may be found with its seedling progeny.

Seedling 'Plowman' grafted to 'Shepard' growing at the Childers site also met the selection criteria for above average yielding rootstocks (Table 41). 'Shepard' production overall at this site was less than a similar experiment at Walkamin which has a more favourable climate for this variety.

Table 41 Potential high producing rootstocks near Childers, central QLD seedling rootstock/Shepard experiment. Annual yield is measured in $kg.tree^{-1}$. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 110 trees in the experiment.

Rootstock*	Production year						Totals $kg.tree^{-1}$	% Rootstock mean yield	% Experiment mean yield
	2007	2008	2009	2010	2011	2012			
Plowman/R9	4.7	0.0	54.6	174.5	69.6	101.5	404.8	141.1	172.2

* R followed by a number identifies the tree in the associated replication position of the experiment.

The 'Hass' experiment at Walkamin produced the largest number of rootstocks with the potential for above average yields (Table 42). During its establishment phase this site was affected by Cyclone Larry and kangaroo damage to trees which resulted in greater variability between trees that may have led to the larger population of out-performing rootstocks. Careful examination of individual trees should be undertaken before rootstock recovery attempts are made.

Table 42 Potential high producing rootstocks in the Walkamin, QLD seedling rootstock/Hass experiment. Annual yield is measured in kg.tree^{-1}. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 100 trees in the experiment.

Rootstock*	Production year						Totals kg.tree^{-1}	% Rootstock mean yield	% Experiment mean yield
	2007	2008	2009	2010	2011	2012			
Barr Duke/R2**	6.7	36.7	57.4	134.7	134.5	177.9	547.8	149.4	177.0
Barr Duke/R9	2.9	25.5	60.4	137.9	164.0	249.1	639.7	174.5	206.7
Rigato/R2	7.7	47.3	70.6	138.7	131.4	243.2	638.8	173.1	206.5
Rigato/R3	4.1	38.6	62.6	121.6	149.6	240.5	616.9	167.2	199.4
Velvick/R2***	0	38.3	28.8	115.5	113.3	240.9	536.8	137.7	173.5
Velvick/R3	4.6	24.3	42.9	156.4	139.4	207.9	575.5	147.6	186.0
Zutano/R10	0	5.2	72.3	99.4	173.2	253.3	603.3	184.3	190.0

* R followed by a number identifies the tree in the associated replication position of the experiment.
** Since this project has correlated poor postharvest fruit quality with Mexican race rootstocks it may not be appropriate to recover 'Barr Duke' material.
*** The 'Velvick' parent tree is difficult to clone and is not commercially suited for this type of propagation. Similar difficulties may be found with its seedling progeny.

The 'Shepard' grafted to seedling rootstocks resulted in six rootstocks with above average yield over the six years data was collected (Table 43). Rootstocks in this group include 'A8', 'SHSR-02', 'Velvick' (x2), and 'V1' (x2). Individual 'SHSR-02' and 'Velvick' rootstocks have been identified at some of the other experimental sites suggesting that the gene pools of these seedlings may have a higher number of individuals with above average yield potential.

Table 43 Potential high producing rootstocks in the Walkamin, QLD seedling rootstock/Shepard experiment. Annual yield is measured in kg.tree^{-1}. Comparative yield of the listed trees has been calculated as a percentage of the mean yield of the ten trees in each rootstock group and the percentage of the mean yield of the 100 trees in the experiment.

Rootstock*	Production year						Totals kg.tree^{-1}	% Rootstock mean yield	% Experiment mean yield
	2007	2008	2009	2010	2011	2012			
A8/R5	4.4	15.6	92.6	3.2	115.4	313.2	544.3	239.5	211.0
SHSR-02/R2	4.8	5.8	61.0	3.5	152.8	237.6	465.5	138.4	180.4
Velvick/R4**	0.9	33.6	45.8	3.2	130.6	242.8	456.8	126.8	177.1
Velvick/R5	9.2	35.1	7.2	3.0	115.4	313.2	483.1	134.1	187.3
V1/R2***	1.6	12.2	84.6	3.2	142.7	211.5	455.7	134.5	176.6
V1/R7	1.1	38.3	51.8	3.2	149.4	285.7	529.4	156.2	205.2

* R followed by a number identifies the tree in the associated replication position of the experiment.
** The 'Velvick' parent tree is difficult to clone and is not commercially suited for this type of propagation. Similar difficulties may be found with its seedling progeny.
*** The 'V1' parent tree is difficult to clone and is not commercially suited for this type of propagation. Similar difficulties may be found with its seedling progeny.

For the most part the "elite" trees identified in Tables 38-43 have shown either a consistent increase in production or a mild alternate bearing trend over the 5-6 years of recorded data. This is in contrast to most other trees in the experimental population that have already developed a significant alternate bearing pattern (data not shown) despite all things being equal with respect to management at each site. This pattern supports the previous data of Thomas (1997) who demonstrated that over a 6 year period some individual ‘Hass’ trees grafted to a seedling rootstock population out-performed their peers by maintaining consistent high yields without reverting to alternate bearing suggesting that in some trees there is a genetic influence on yield stronger than environmental and management factors.

7. Phytophthora Tolerance, Tree Growth and Yield Data from the "Elite" Rootstock Recovery Program

7.1 Introduction

The "elite" rootstock component of this project has focussed on identifying, recovering and further evaluating rootstocks in the field that showed extraordinarily high levels of resistance to Phytophthora root rot (PRR) compared with the population of surrounding trees. Additionally, rootstocks selected for evaluation within the project and established in replant sites have also been evaluated for their resistance to PRR and where appropriate have been further tested. In the "elite" rootstock component of this project the only significant resistance to PRR was found in "SHSR-04" rootstock which was recovered from an orchard in South Kolan (near Bundaberg) and its PRR resistance in an infested soil has been well documented (Smith *et al.*, 2010). This report adds additional information on the yield performance of 'SHSR-04' growing in a Phytophthora-free soil in SE Queensland. The rootstock trial at Walkamin was established in a Phytophthora-infested soil and the seedling rootstock 'SHSR-02' indicated an above average level of PRR resistance in the early years of growth. A population of 'SHSR-02' seedling rootstocks grafted to 'Hass' scions was planted in the PRR-infested site at Duranbah along with a population of 'A10'/'Velvick' seedling hybrid rootstocks and disease resistance monitored. Initially six rootstocks were selected from this population (five 'SHSR-02' seedlings and one 'A10/'Velvick' seedling) for recovery and further testing. After the extremely wet summer of 2011 this has been reduced to one 'SHSR-02' seedling know known as 'SHSR-07' and the 'A10'/'Velvick' seedling known as 'SHSR-08'. These two lines have been cloned and a population of 10 trees of each rootstock will be planted in May 2013 at the Duranbah PRR-infested site where they will be compared to 'SHSR-04', 'SS3-1' (from Spain) and 'Dusa' (from South Africa).

7.2 Materials and Methods

To evaluate the yield performance of 'SHSR-04' 10 trees of this rootstock were clonally propagated together with 10 trees of Velvick each as a seedling or cloned rootstock giving a total of 30 trees. The trees were planted in February 2006 in a Phytophthora-free site at Hampton in SE Queensland using a randomised block design. Growth measurements (height plus canopy diameter) were recorded from 2009 to enable the calculation of Yield Efficiency (kg of fruit/m^3 of canopy diameter) once trees began cropping (approximately 3 years from planting). Yield data was first recorded in 2010 which was the first crop the trees had set and carried to maturity. Tree yields were again recorded in 2011. Statistical analyses were performed by Genstat 11 for Windows (VSN International Ltd., UK). Analysis of variance used the 'General Analysis of Variance' model, with rootstocks as treatment structure.

7.3 Results and Discussion

Yield and yield efficiency results are reported in Table 44 below. There were no significant differences between rootstocks in either yield or yield efficiency in 2010 however in 2011 yield and yield efficiency of the 'Velvick' seedling rootstock was significantly ($P \leq 0.05$) greater than either the cloned 'Velvick' or 'SHSR-04' rootstocks. The crop across the whole orchard was low in 2012 due to inclement climatic conditions during flowering and fruit set in the preceding 2011 spring and there were no significant differences between rootstock yields or yield efficiencies (Table 44).

When comparisons are made with the seedling and cloned 'Velvick' rootstocks in this experiment against the same rootstocks planted at Hampton in 2005 it is noted that the 'Velvick' seedling rootstock outperformed the 'Velvick' cloned rootstock in the early years of the experiment but after five fruiting cycles there was no significant difference between the two rootstocks (see above). It is currently too early to predict the comparative yield performance of 'SHSR-04' in a Phytophthora-free site. However it is possible that as a clone it is also slow to reach its full potential and may catch the performance of the seedling 'Velvick' in future years. However, there is no doubt that when grown in PRR infested soils 'SHSR-04' will outperform most other rootstocks currently used by Australian avocado growers.

Table 44 Yield, yield efficiency (YE) and cumulative yield of the 'SHSR-04' cloned rootstock in comparison with seedling and cloned rootstocks of Velvick growing in a Phytophthora root rot-free site at Hampton in SE Queensland. Values in columns followed by different letters are significantly different ($P \leq 0.05$).

Rootstock[1]	**Yield ($kg.tree^{-1}$)**			**YE ($kg.m^3$)**			**Cumulative Yield ($kg.tree^{-1}$)**
	2010	**2011**	**2012**	**2010**	**2011**	**2012**	
SHSR-04[C]	6.8	30.6[b]	3.6	0.46	1.63[b]	0.61	41.0[b]
Velvick[S]	5.3	61.2[a]	10.1	0.36	3.21[a]	0.93	76.6[a]
Velvick[C]	7.3	32.7[b]	1.8	0.42	1.84[b]	0.32	41.8[b]
LSD ($P \leq 0.05$)	**ns**[2]	**21.4**	**ns**	**ns**	**1.23**	**ns**	**29.7**

[1] C = cloned rootstock and S = seedling rootstock.

[2] ns = non significant ($P > 0.05$)

8. Evaluation of Overseas (Spanish) Rootstocks

8.1 Introduction

At the V World Avocado Congress held in Spain Ms Luisa Gallo-Llobert presented data on the *Phytophthora cinnamomi* resistance of three avocado rootstocks ('Gema', 'Maoz' and 'SS3-1') that she had evaluated in the Canary Islands. Subsequently these rootstocks were imported to Australia where they have been cloned, grafted to Hass and evaluated at Tolga (North Queensland) in a replant site heavily infested with *Phytophthora cinnamomi*. Results from this rootstock evaluation are presented below.

8.2 Materials and Methods

Ten clones of the rootstocks 'Gema', 'Maoz', 'SHSR-04' and 'SS3-1' were prepared and grafted to 'Hass' along with ten seedling rootstocks of 'Reed'. 'SHSR-04' was included because of its known high level of resistance to *Phytophthora cinnamomi* while seedling 'Reed' rootstocks were included because of their documented high susceptibility to *Phytophthora cinnamomi* (Smith *et al*., 2010). The trees were planted in March 2007 in land that had previously grown avocados that had declined due to Phytophthora root rot to a point where they were no longer commercially productive. Prior to planting the land had been cleared and root-raked to remove as many roots from the previous orchard as possible. The site was cover-cropped with oats through the 2006 winter and sorghum through the 2006/07 summer. Gypsum was incorporated into the soil at the rate of 5 $t.ha^{-1}$ immediately prior to planting.

To allow establishment of trees each site was treated with Ridomil Gold 25G® at 100 $g.m^{-2}$ at planting and again three months later. Trees were drenched in their nursery bags with potassium phosphonate at 1.5 $g.l^{-1}$ 24 hours before planting and subsequently bark-painted with a 20% solution of potassium phosphonate (pH 7.2) every 6-8 weeks for the first year after establishing the experiment. One year after planting all chemical Phytophthora control management was withdrawn from the trees.

Nutrition and irrigation were managed at the site according to recommended industry practices as detailed by Newett *et al*. (1997).

Growth measurements, tree height and trunk girth immediately below the graft union were made 24 and 36 months after planting. Tree health was assessed using a rating scale of 0-10, where 0 = healthy and 10 = dead, at 18, 24, 36 and 42 months after planting. In February 2010 trees in the experiment were damaged with winds from Cyclone Yasi with many of the weaker trees blown over hence the trial was terminated at this time.

The trees were planted in a 5 x 10 randomised plot design and statistical analyses were by performed by Genstat 11 for Windows (VSN International Ltd., UK). Analysis of variance used the 'General Analysis of Variance' model, with rootstocks as treatment structure.

8.3 Results and Discussion

All trees established well growing strongly over the first year and were in relatively good health 18 months after planting (Tables 45 and 46). Two years (24 months) after planting 'Gema', 'SHSR-04' and 'SS3-1' had made similar growth with tree height and trunk girths significant greater than 'Maoz' and 'Reed' trees (Table 45). When tree health was rated 18 months after planting (Table 46) 'SHSR-04' and 'SS3-1' rootstocks were significantly ($P \leq 0.05$) better than 'Reed'. At 24 months after planting 'SHSR-04' had the best health rating (2.5) but not significantly better than 'SS3-1', or 'Gema'.

Three years (36 months) after planting, the trees grafted to 'SHSR-04' rootstocks were significantly taller than trees grafted to the other rootstocks while 'SHSR-04', 'Gema' and 'SS3-1' trees had the largest girth circumference. Over time the health rating of all trees deteriorated but at different rates with 'SHSR-04' having the best rating (5.7) 42 months after planting but not significantly better than 'SS3-1'.

Table 45 The growth of 'Hass' trees grown on five different rootstocks planted in soils infested with *Phytophthora cinnamomi* at Tolga in North Queensland. Tree growth was assessed by measuring tree height and trunk girth immediately below the graft union 24 and 36 months after planting. Mean values within columns followed by the same letter are not significantly different ($P \leq 0.05$).

Rootstock	Origin	Type	24 months		36 months	
			Height (cm)	Girth (mm)	Height (cm)	Girth (mm)
Gema	Spain	Clone	162.8^{a}	112.6^{a}	177.2^{b}	116.8^{a}
Maoz	Spain	Clone	78.3^{b}	79.8^{b}	86.1^{c}	87.2^{b}
Reed	USA	Seedling	89.5^{b}	83.2^{b}	98.7^{c}	89.4^{b}
SHSR-04	Australia	Clone	172.5^{a}	116.8^{a}	241.2^{a}	121.6^{a}
SS3-1	Spain	Clone	157.2^{a}	104.5^{a}	196.5^{b}	113.1^{a}
LSD P ≤ 0.05			**57.8**	**19.7**	**42.8**	**21.2**

Table 46 The health rating of 'Hass' trees grown on five different rootstocks planted in soils infested with *Phytophthora cinnamomi* at Tolga in North Queensland. Tree health was assessed using a rating scale of 0-10, where 0 = healthy and 10 = dead, at 18, 24, 36 and 42 months after planting. Mean values within columns followed by the same letter are not significantly different ($P \leq 0.05$).

Rootstock	Origin	Type	18 months	24 months	36 months	42 months
Gema	Spain	Clone	0.9^{ab}	4.6^{abc}	7.9^{b}	9.1^{b}
Maoz	Spain	Clone	1.1^{ab}	5.0^{bc}	8.3^{bc}	8.9^{b}
Reed	USA	Seedling	2.2^{b}	6.9^{c}	8.9^{c}	9.6^{b}
SHSR-04	Australia	Clone	0.3^{a}	2.5^{a}	5.2^{a}	5.7^{a}
SS3-1	Spain	Clone	0.2^{a}	3.2^{ab}	7.1^{ab}	7.3^{a}
LSD P≤ 0.05			**1.7**	**3.6**	**1.7**	**1.6**

The Phytophthora root rot tolerance of 'Gema' and 'Maoz' documented in the Canary Islands has not compared favourably with the locally selected rootstock 'SHSR-04' however 'SS3-1' has produced a credible result and is worthy of further research. It is intended to include 'SS3'-1 in a new evaluation trial to be planted in *Phytophthora cinnamomi* infested soils at Duranbah, northern NSW in May 2013. The disappointing results from 'Gema' and 'Maoz' may be due to strong environmental differences between the Canary Islands (dry Mediterranean) compared with North Queensland (summer-wet subtropical) and further work on these two lines is not recommended.

9. Riverland Rootstock Experiment

9.1 Introduction

At the commencement of the Rootstock Improvement project in 2002 much of southern Australia was in the grips of a drought with avocado growers in the Murray River irrigation district in survival mode using radical practices to reduce the risk of losing their orchards. This was a prolonged drought lasting around 10 years and at the time of planting regional rootstock experiments across Australia a site was not procurable in the Murray River basin. Changed rainfall patterns in 2011 saw strong flows in the Murray River and interest was re-kindled from the Riverland avocado growers with a decision made to plant a rootstock trial in the region albeit nine years after the beginning of the project.

9.2 Materials and methods

A site was chosen on the property of Thiel Orchards, Waikerie, South Australia (contact Kym Thiel; mobile 0417 800 937). The avocado production regions of California, Chile and Israel have Mediterranean climates with warm to hot dry summers and cool wet winters. Spring temperature conditions can be variable but are generally cool. Fruit set is enhanced by strategically planting polliniser varieties within orchards. The Australian Riverland extending across the tri-states of Victoria, New South Wales and South Australia has similar climatic conditions but traditionally orchards have been planted without pollinisers. In designing this rootstock trial 'Edranol' pollinisers have been incorporated into the planting design to demonstrate the effect of cross-pollination opportunities on the regularity and intensity of fruit set. Following advice from growers no pure Mexican race material was chosen for testing at this site due to past experience with high salinity in irrigation water (Mexican race varieties have the greatest susceptibility to salinity). Nine seedling rootstocks were chosen for this experiment and are detailed in Table 47 below.

Table 47 Seedling rootstocks used in the Riverland avocado rootstock experiment planted at Waikerie on the 3rd October 2012. All rootstocks were propagated to 'Hass'. Ten replicates of each rootstock were planted in a randomised block design. Edranol pollinisers were inter-planted in a pattern to give equal exposure to each rootstock line.

Rootstock	Horticultural race	Comments
AA1	Guatemalan	An Anderson's nursery rootstock currently untested in the rootstock project.
A8	Guatemalan	An Anderson's nursery rootstock with good performance at some sites in the rootstock project.
A10	Guatemalan/Mexican	An Anderson's nursery rootstock with good performance at some sites in the rootstock project.
Ashdot	West Indian	A Birdwood nursery rootstock (from Israel) with dwarfing characteristics and high yield efficiency.
Reed	Guatemalan	Reed is used extensively as a rootstock in Western Australia. Good production at some sites in the rootstock project.
SHSR-02	Guatemalan	Consistently amongst the top yield rootstocks at sites across the rootstock project. Has good resistance to Phytophthora root rot.
TT	West Indian	An unknown rootstock with strong West Indian characteristics. Should have good salt tolerance.
Velvick	West Indian/Guatemalan	Currently the most widely used rootstock in Australia. Consistently amongst the top yield rootstocks at sites across the rootstock project.
Zutano	Guatemalan/Mexican	Currently the main rootstock used in the Riverland and New Zealand. Good performance at most some sites used in the rootstock project.

10. Affect of Rootstocks on Postharvest Performance of Fruit

10.1 Introduction

Postharvest disease and physiological storage disorders represent a major constraint to the supply of high quality avocados to markets within Australia and worldwide. Preliminary research conducted before this project indicated that rootstocks can influence fruit quality parameters such as the severity of postharvest disease and disorders, and these differences can be related to levels of nutrients in the skin of fruit. To confirm these findings, fruit quality was extensively evaluated on a wide range of rootstock/scion combinations and in a diversity of growing locations, as part of the "Rootstock Improvement for the Australian Avocado Industry" project. A selection of both seedling and clonally propagated rootstocks was evaluated at two sites (Childers QLD and Walkamin QLD), while only clonal rootstocks were assessed at another two sites (Pemberton WA and Hampton QLD). Selected rootstocks grafted to either "Hass" or "Shepard" scions were evaluated at Walkamin, whereas rootstocks grafted to "Hass" were used for evaluations at the other three sites. After harvest and transport, fruit samples were either immediately ripened at 23°C ('non-stored' fruit) or cold-stored for 4 weeks at 5°C and then ripened at 20°C ('stored' fruit).

10.2 Materials and methods

Avocado fruit were harvested at commercial maturity for quality assessment from four trial sites across Australia (Table 48):

At Childers, fruit from 'Hass' trees grafted to a selection of 11 rootstocks (six clonal and five seedlings) were evaluated, with ten individual tree replications for each rootstock.

At Hampton, Pemberton and Walkamin, fruit from 'Hass' trees grafted to a selection of six clonal rootstocks were evaluated at each site, with six individual tree replications for each rootstock.

At Walkamin, fruit from Shepard trees grafted to a selection of 11 rootstocks (six clonal and five seedling ones) were evaluated, with ten individual tree replications for each rootstock.

A list of the rootstocks selected at each site and the dates of each harvest are shown in Table 48.

Approximately 45 fruit/tree were harvested (by hand or using picking poles) at each site, placed directly into trays (about 20 fruit per tray), and transported to the laboratory. Fruit arrived within 24 hours of picking for Childers and Hampton 'Hass' fruit, and within 72 hours of picking for Pemberton 'Hass' fruit and Walkamin 'Shepard' or 'Hass' fruit (which were consigned to Brisbane by refrigerated (approximately 7°C) road freight. Fruit to be sampled for dry matter, nutrients and biochemical analysis however, were consigned to Brisbane by air freight and arrived within 24 hours of harvest.

Fungicides were not applied to any of the fruit after harvest. All fruit were weighed on arrival at the laboratory for inclusion in yield data.

From each sample of 45 fruit/tree, 20 fruit were transferred to a ripening room at 23°C and 65% relative humidity (DAFF laboratories at Indooroopilly or Dutton Park, Ecosciences Precinct) for assessment of fruit shelf life (days to ripe) and postharvest disease. These conditions were used to maximise disease expression. At the eating ripe stage (as judged by fruit firmness), 'Hass' fruit were peeled and examined for anthracnose (caused by *Colletotrichum gloeosporioides*) and stem-end rot (caused by a range of fungi including *Colletotrichum gloeosporioides*, anamorphs of *Botryosphaeria* spp., *Lasiodiplodia theobromae* and *Phomopsis perseae*). 'Shepard' fruit were assessed for anthracnose externally without peeling, and stem-end rot was assessed by cutting through the peel and flesh to see the extent of infection. In both cultivars, anthracnose (body rots) severity was assessed as the percentage of fruit flesh surface area affected, and stem-end rot severity assessed as the percentage of fruit flesh volume affected. The incidence of anthracnose and stem-end rot was then calculated as the percentage of fruit affected by either disease in relation to the total number of fruit per replication. In each replication, the percentage of fruit with 5% or less anthracnose severity and no stem-end rot was considered marketable. The cause of stem-end rot lesions was determined by isolation of affected tissues onto potato dextrose agar amended with streptomycin, incubation of culture plates, and identification of the resultant fungal colonies.

The remaining 25 fruit/tree were sent to DAFF laboratories at Nambour. Twenty fruit per tree were held at 5°C for four weeks, then ripened at 20°C until eating ripe (based on fruit firmness), with no ethylene treatment. The days to ripe at 20°C were recorded for each fruit. Skin colour of each fruit was visually assessed on a 1 to 6 (green to black) scale (for 'Hass'), and the severity of discrete patches on the skin assessed as percentage of skin surface area affected (for Shepard) using the 'International Avocado Quality Manual' (White *et al.*, 2009). Fruit were then cut in halves, peeled, and the severity of flesh diseases and internal disorders assessed (as percentage of flesh volume affected) using the same manual. In each replication, the percentage of fruit with 10% or less of all flesh defects combined was considered sound. Flesh diseases were described based on the location of the disease on the fruit, for example stem-end rots or body rots. Fruit with both typical and unusual disease lesions were sent to the Indooroopilly laboratories for organism identification. The incidence of both rots and internal disorders were determined as above.

The remaining five fruit per tree were sampled for % flesh dry matter (DM), skin mineral analysis and fruit biochemical analysis:
Fruit DM was determined by taking a core of flesh (using the Hofshi plugger) from each of the five fruit, which were diced and mixed to provide one composite sample of about 20 g per replicate. Samples were weighed before and after drying at 65°C until constant weights were obtained (about three days).

Skin samples were taken from the same five fruit, oven-dried at 60°C to constant weight, ground and sent to a commercial laboratory (SGS Agritech, Toowoomba) to determine the concentrations of N, Ca, Mg, and K (the minerals most commonly associated with fruit quality after harvest) using standard certified techniques.

For all trials conducted during 2008, as well as the Walkamin Shepard trial in 2009, analysis of phenolic levels (a biochemical marker for disease resistance) in fruit skin was undertaken at harvest, as well as at the "sprung" (first detectable fruit ripening) and "eating-ripe" stages. In all subsequent trials, samples for phenolic analysis were only taken at harvest, due to the lack of treatment differences seen in the results. For all trials skin samples were only taken from fruit on trees grafted to the clonal rootstocks (five replicate trees of the six clonal rootstocks). Strips of fruit skin (approximately 1g from a composite sample of skin peeled from five fruit) were frozen at -80°C for later analysis. Phenolic acid contents were determined by using the Folin-Ciocalteau reagent on samples extracted with 50% v/v methanol, and compared against a gallic acid standard curve.

Enzyme analyses were conducted in trials which commenced after mid 2009. Two enzymes known to be involved in plant defense reactions, peroxidase and catalase, were assayed in the flesh of fruit sampled at harvest time. As per phenolic analysis, samples were only taken from fruit on trees grafted to the clonal rootstocks (five replicate trees for each of the six clonal rootstocks). Small sections of avocado flesh were taken from each of five fruit per rootstock and pooled together. The sample was ground to a fine powder in liquid nitrogen, then in sodium phosphate buffer to prevent degradation of the enzymes. Cell debris was removed through centrifugation and the supernatant was used for the assays. The extract was diluted, a substrate specific to the enzyme was added, and the degradation of the substrate was measured over time to obtain the enzyme activity rate. Each assay was replicated five times and the average was taken. Protein levels were determined for each sample and the enzyme rate per milligram of protein calculated.

Statistical analyses were performed by Genstat 11 for Windows (VSN International Ltd., UK). Analysis of variance used the 'General Analysis of Variance' model, with rootstocks as treatment structure and tree divided by fruit as block structure. The protected least significant difference (LSD) procedure at $P = 0.05$ was used to test for differences between treatment means. The relationships between tree yield/yield efficiency, fruit nutrients and fruit quality attributes were established using correlation analysis on the means for each tree. The significance of the correlations was determined by linear regression analysis ($P = 0.05$), and the strength by the correlation coefficient (r). Analysis of the variability between rootstocks of common origin was made by using Genstat to calculate the statistical variances (or the measure of spread or variation of individual units about the mean) for each pair of rootstocks based on the averages per tree. Bartlett's test was then used to compare the two variances of the pair of rootstocks and determine if the differences between them were significant for each tree or fruit characteristic.

Table 48 Harvest locations and clonal (C)/seedling (S) rootstock selections used with 'Hass' or 'Shepard' scions for fruit quality assessments.

Trial location	**Childers QLD**	**Hampton QLD**	**Pemberton WA**	**Walkamin QLD**	**Walkamin QLD**
Coordinates	25.1° S (Lat.) 152.2° E (Long.)	27.2° S (Lat.) 152.0° E (Long.)	34.3° S (Lat.) 116.0° E (Long.)	17.1° S (Lat.) 145.3° E (Long.)	17.1° S (Lat.) 145.3° E (Long.)
Harvest dates	27/6/08 4/6/09 19/5/10	17/7/08 3/8/09 12/7/10	18/11/08 1/12/10 22/11/12	4/5/10 3/5/11 23/4/12	16/2/09 8/3/10 7/2/11
Scion	Hass	Hass	Hass	Hass	Shepard
Rootstock	C[1]-A10 C-Duke 7 C-Nabal C- SHSR-03 C-Velvick C-Zutano S[2] -A10 S-Nabal S-SHSR-02 S- SHSR-03 S-Velvick	C-Zutano/C-A10[3] C-Duke 7 C-Hass C-Reed C-SHSR-03 C-Velvick	C-A10 C-Barr Duke C-Duke 7 C-Reed C-Velvick C-Zutano	C-A8 C-A10 C-Duke 7 C-Reed C-Velvick C-Zutano	C-A10 C-Duke 7[4] C-Shepard C-SHSR-03 C-Thomas C-Velvick S-A10 S-Duke 7 S-SHSR-02 S-SHSR-03 S-Velvick

1 C = clonal
2 S = seedling
3 C-Zutano was used in 2008; C-A10 was used in 2009 & 2010
4 C-Duke 7 not available in 2009

10.3 Results

10.3.1 Childers QLD ('Hass') 2008

Fruit postharvest quality

There were no significant effects of rootstock on days to eating-ripe, side anthracnose severity/incidence, stem-end anthracnose severity/incidence, stem-end rot severity/incidence or % marketable fruit at the Childers site (Table 49).

The predominant causal agent of stem-end rot at the Childers site in 2008 was *Colletotrichum* sp. (causing approximately 56% of lesions). Other causal agents were *Botryosphaeria* spp./*Lasiodiplodia theobromae* (26%), *Cladosporium* sp. (6%), *Fusarium* sp. (4%), *Alternaria* sp. (2%) and *Pestalotiopsis* sp. (2%).

Fruit post-storage quality

Rootstocks did not significantly affect fruit ripening after removal from cold storage (days to ripe) or fruit skin colour at ripe (Table 50).

At eating ripe, the severity of diffuse discolouration was affected by rootstocks, with a two-fold difference between the fruit with the lowest severity (those from trees on clonal 'Velvick' rootstock) and the highest (those from trees on clonal 'Zutano' rootstock). In contrast, there were no significant differences between rootstocks for severity of body rots, stem-end rots, or vascular leaching at eating ripe.

There were significant differences between rootstocks for the % of sound fruit at eating ripe (those with a severity rating of 10% or less of the flesh affected by all defects combined), with fruit from trees on clonal 'Velvick' and clonal 'A10' rootstocks having the highest % of sound fruit. Overall, the severity of flesh defects after cold storage and ripening was high, resulting in a very low % of sound fruit. The main causes for the loss of saleability were diffuse discolouration, followed by vascular leaching and body rots.

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

There were some significant differences among rootstocks in relation to fruit flesh dry matter (DM) at harvest (Table 51). Seedling 'SHSR-02' and seedling 'SHSR-03' had the highest DM and clonal Nabal had the lowest DM. With the exception of clonal 'Velvick', most of the clonal rootstocks had lower fruit DM values than the seedling rootstocks.

Skin N levels were significantly affected by rootstock, with clonal rootstocks generally displaying higher N values than seedling rootstocks (Table 51). A similar trend was seen for Mg and to a lesser extent for K. Conversely, Ca+Mg/K ratios were generally lower in the clonal rootstocks compared to the seedling rootstocks, except for clonal 'Velvick' and clonal 'Zutano' which had high ratios of Ca+Mg/K. Seedling 'A10', 'Nabal' and 'SHSR-02' also had high ratios of Ca+Mg/K. There were no significant effects of rootstock on skin Ca levels or N/Ca ratios at the Childers site.

Phenolic levels at harvest were significantly affected by rootstocks, with clonal 'Duke 7' showing higher skin phenolic levels than clonal 'Nabal', 'SHSR-03', 'Velvick' and 'Zutano' (Table 51). Phenolic levels at the sprung and eating-ripe stages were not significantly affected by rootstock.

Correlations

In fruit ripened at 23°C without a cool storage period, positive correlations (based on averages per tree) were found between anthracnose severity and skin N levels, as well as between skin N/Ca ratios and flesh DM (Table 52). A negative correlation was found between anthracnose severity and yield per tree.

In fruit that had been cold stored and then ripened, there were positive correlations between the severity of diffuse discolouration at eating ripe and the ratios of (Mg+K)/Ca and N/Ca in fruit skin (Table 52).

Table 49 Childers 2008: Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
S-A10	9.1	2.8	38	1.0	15	0.7	7	78
S-SHSR-03	9.2	8.4	41	1.1	11	1.4	10	72
C-A10	9.3	7.2	42	0.6	8	0.8	11	71
C-SHSR-03	9.3	8.7	44	0.9	5	2.1	14	69
C-Velvick	9.8	11.7	57	1.1	9	0.9	9	66
C- Nabal	9.0	12.0	56	0.9	11	0.6	10	64
S-Nabal	9.4	10.8	46	1.7	14	1.2	12	63
S-SHSR-02	9.0	13.5	58	1.6	14	0.3	8	60
S-Velvick	9.3	11.3	56	1.8	15	1.3	10	60
C-Zutano	9.2	13.8	56	1.5	13	1.1	8	60
C-Duke 7	9.2	13.3	68	2.2	18	1.4	11	54
P	***ns***[5]	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 200 fruit per rootstock

Table 50 Childers 2008: Effects of clonal (C) and seedling (S) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' avocado fruit held at 5.5°C for 5 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discolouration	Vascular leaching	
C-Velvick	7.6	4.5	8.8	1.1	23 [d]	8.5	25 [a]
C-A10	7.6	4.4	9.0	0.7	30 [cd]	11.2	18 [ab]
S-Nabal	6.9	4.5	8.3	0.8	34 [bcd]	8.0	10 [bc]
S-SHSR-03	7.0	4.5	8.8	0.7	38 [abc]	9.9	9 [bc]
S-A10	7.2	4.4	6.2	1.1	39 [abc]	8.0	8 [c]
C-Zutano	7.1	4.6	8.7	0.3	48 [a]	13.8	8 [c]
C-SHSR-03	7.5	4.5	7.9	0.6	45 [ab]	13.3	7 [c]
C-Duke7	7.2	4.5	9.0	1.0	39 [abc]	13.2	7 [c]
C-Nabal	7.1	4.4	6.7	0.6	45 [ab]	12.1	4 [c]
S-Velvick	7.4	4.5	10.5	1.0	44 [ab]	8.9	4 [c]
S-SHSR-02	7.1	4.5	9.8	1.2	44 [ab]	9.2	3 [c]
P	*ns*[3]	*ns*	*ns*	*ns*	*0.006*	*ns*	*<0.001*

1 Rootstocks listed in descending order of % of sound fruit
2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all flesh defects combined
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 200 fruit per rootstock

Table 51 Childers 2008: Effects of clonal (C) and seedling (S) rootstocks on fruit flesh dry matter (%), and on fruit skin minerals (% dry weight) and phenolics (gallic acid equivalent/g fresh weight) concentrations in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics concentration (gallic acid equivalents/ g fresh weight)		
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio	Harvest	Sprung	Eating-ripe
C-A10	29.1 cde	1.08 abcd	0.037	0.091 abc	1.34 ab	30	0.097 d	15.9 ab	28.3	13.9
C-Duke 7	29.1 cde	1.12 ab	0.034	0.092 ab	1.36 a	35	0.094 d	18.3 a	30.3	18.2
C-Nabal	28.4 e	1.15 a	0.037	0.093 a	1.39 a	32	0.096 d	13.0 bc	25.7	17.5
C-SHSR-03	29.5 cd	1.10 abc	0.035	0.091 abc	1.31 abc	33	0.098 cd	11.0 c	26.0	13.1
C-Velvick	29.9 abc	1.05 bcde	0.038	0.085 bcd	1.05 def	29	0.120 a	13.9 bc	33.9	19.5
C-Zutano	28.8 de	1.06 abcde	0.034	0.089 abcd	1.18 bcde	32	0.106 abcd	12.9 bc	23.3	20.0
S-A10	29.8 abcd	0.98 de	0.038	0.084 cd	1.08 def	27	0.114 ab	ND[2]	ND	ND
S-Nabal	29.5 bcd	0.96 e	0.034	0.081 d	1.01 ef	29	0.116 a	ND	ND	ND
S-SHSR-02	30.4 ab	1.00 cde	0.033	0.081 d	1.03 ef	32	0.113 abc	ND	ND	ND
S-SHSR-03	30.7 a	0.98 de	0.033	0.081 d	1.17 cde	31	0.100 bcd	ND	ND	ND
S-Velvick	30.0 abc	1.01 cde	0.031	0.085 bcd	1.19 bcd	34	0.010 bcd	ND	ND	ND
P	***<0.001***	***0.001***	***ns[3]***	***0.003***	***<0.001***	***ns***	***0.005***	***0.026***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ND = not done (only clonal rootstocks analysed for phenolics)
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for phenolics (25 fruit per rootstock)

Table 52 Childers 2008: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose severity	N	<0.001	0.32	+
Anthracnose severity	N/Ca	<0.001	0.30	+
Anthracnose severity	Dry matter	0.011	0.23	+
Anthracnose severity	Tree yield	0.029	0.19	-
Fruit held at 5oC for 5 weeks and then ripened at 20oC.				
Diffuse discolouration	K	0.001	0.41	+
Tree Yield	K	0.001	0.39	-
Vascular leaching	K	0.001	0.38	-
Tree yield	Diffuse discolouration	0.001	0.35	-
Vascular leaching	N	0.001	0.35	-
Diffuse discolouration	N	0.001	0.34	-
Diffuse discolouration	Ca	0.001	0.33	-
Tree yield	Dry matter	0.001	0.32	-
Body rot	stem-end rot	0.001	0.32	+
Dry matter	Body rot	0.002	0.27	+
Stem-end rot	Ca	0.004	0.27	-
Tree yield	% sound fruit	0.004	0.27	+
% sound fruit	N	0.006	0.26	-
% sound fruit	K	0.006	0.26	-
Tree yield	Vascular leaching	0.008	0.25	-

10.3.2 Childers QLD ('Hass') 2009

Fruit postharvest quality

Fruit from 'Hass' trees grafted to clonal 'Velvick' and seedling 'Nabal' had the lowest incidence of anthracnose, while those fruit from clonal 'Zutano' and seedling 'SHSR-02' had the highest anthracnose incidence (Table 53). Fruit from trees grafted to clonal 'A10' and seedling 'Nabal' had the highest % marketable fruit, whereas those from clonal 'Zutano' and seedling 'SHSR-02' had the lowest % marketable fruit. There were no significant effects of rootstock on days to eating-ripe, anthracnose severity or stem-end rot severity/incidence at the Childers site in 2009 (Table 53).

The predominant causal agents of stem-end rot at the Childers site in 2009 were *Colletotrichum* sp. (causing approximately 48% of lesions) and *Lasiodiplodia theobromae/Botryosphaeria* spp. (causing approximately 46% of lesions). Other causal agents were *Pestalotiopsis* sp. (3%), *Alternaria* sp. (2%) and *Fusarium* sp. (1%).

Fruit post-storage quality

Rootstocks significantly affected fruit ripening after removal from cold storage (days to ripe), although differences were less than one day (Table 54). Similarly, fruit skin colour at ripe was significantly affected by rootstocks, but differences were small.

At eating ripe, the severity of body rots, stem-end rots, and diffuse discolouration was affected by rootstocks. Diffuse discolouration and rots were generally the main defects, but overall severity was low. As a result, the % of sound fruit (those with a severity rating of 10% or less of the flesh affected by all defects combined) was above 90% for most rootstocks. However, fruit from trees on clonal 'Zutano', clonal 'SHSR-03' and clonal 'Velvick' rootstocks had lower % of sound fruit than fruit on most seedling rootstocks (except seedling 'Velvick') and on clonal 'Duke 7' and clonal 'A10' rootstocks.

Fruit flesh dry matter, skin minerals and fruit biochemical markers

There were some significant differences among rootstocks in relation to fruit flesh dry matter (DM) at harvest (Table 55). Fruit from trees on seedling 'Nabal' and seedling 'Velvick' had the lowest flesh DM.

Skin N concentrations were significantly affected by rootstock, with fruit from trees on clonal 'Zutano' and seedling 'SHSR-02' having significantly higher N concentrations than fruit from trees on clonal 'A10', clonal 'Duke 7' and clonal 'Nabal' (Table 55). Fruit from trees on clonal 'Zutano' and clonal 'Velvick' had lower fruit Ca concentrations than fruit from trees on all of the seedling rootstocks. Fruit from trees on clonal Zutano also had a significantly higher N/Ca ratio then fruit from trees on all rootstocks except for clonal 'Velvick', clonal 'SHSR-03' and clonal 'Duke 7'. There were no significant rootstock effects on fruit skin Mg or K concentrations, or on ratios of Ca+Mg/K. There were also no effects on concentrations of phenolics, catalase or peroxidase at the Childers site (Table 55).

Correlations

In fruit that had been ripened at 23°C, significant positive correlations were seen between anthracnose incidence and skin N levels, as well as between stem-end rot incidence and skin N/Ca ratios (Table 56). Both yield and yield efficiency had a significant negative correlation with stem-end rot incidence, which at this site was caused predominantly by the anthracnose pathogen (*Colletotrichum gloeosporioides*) and *Lasiodiplodia theobromae.* Significant negative correlations were also found between anthracnose incidence and skin phenolics, as well as between stem-end rot incidence and skin Ca levels (Table 56).

In fruit that had been cold-stored and then ripened, positive correlations were found between stem-end rot and days to ripe, between the % of sound fruit and tree yield or yield efficiency, between tree yield and skin K, and between dry matter and vascular browning or the % of sound fruit (Table 56). Negative correlations were found between tree yield and body rot or dry matter or skin K, and between yield efficiency and body rot (Table 56).

Table 53 Childers 2009: Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
S-A10	10.4	18.2	48 cd	5.0	15	74 a
S-Nabal	10.7	7.8	47 d	2.7	15	71 ab
S-SHSR-03	10.8	10.7	51 cd	2.3	14	59 abc
C-Velvick	10.1	11.4	47 d	5.2	23	58 abc
C-A10	10.8	8.7	52 cd	3.9	24	58 abc
S-Velvick	10.7	12.8	65 abc	2.4	15	56 abc
C-Duke 7	10.3	11.8	59 abcd	5.2	23	54 bcd
C-Nabal	10.6	18.8	58 abcd	4.8	22	53 cd
C- SHSR-03	10.4	13.4	53 bcd	4.2	27	51 cd
S-SHSR-02	10.5	18.4	69 ab	2.2	16	49 cd
C-Zutano	9.8	22.7	74 a	3.9	23	36 d
P	***ns***[5]	***ns***	***0.019***	***ns***	***ns***	***0.013***

1 Rootstocks listed in descending order of % marketable fruit. 2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease. 3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment. 4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot. 5 ns = not significant (P > 0.05). Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference. Values in table are means of 200 fruit per rootstock

Table 54 Childers 2009: Effects of clonal (C) and seedling (S) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discolour.	Vascular leaching	
S-A10	8.7 abcd	5.0 ab	0.7 c	0.5 c	0.6 cd	0.1	94 a
C-Duke7	8.4 bcd	4.8 abc	1.1 bc	0.9 bc	0.4 d	0.2	94 a
S-SHSR-02	8.1 d	4.9 ab	0.7 c	0.3 c	0.7 cd	0.4	94 a
C-A10	8.8 abc	4.8 bc	0.6 c	0.8 c	1.2 bcd	0.1	92 a
S-Nabal	8.6 abcd	5.0 a	0.9 bc	0.5 c	0.9 bcd	0.3	92 a
S-Velvick	8.1 d	4.9 ab	1.1 bc	0.4 c	1.7 abcd	0.1	90 ab
C-Nabal	9.0 a	4.7 c	1.8 abc	1.8 ab	0.9 bcd	0.1	88 ab
C-Velvick	8.2 cd	4.6 c	1.7 abc	1.1 bc	2.0 abc	0.7	82 bc
C-SHSR-03	9.0 a	4.8 abc	2.2 ab	2.0 a	2.4 ab	0.7	81 bc
C-Zutano	8.2 cd	4.9 ab	2.9 a	1.1 bc	2.8 a	0.9	77 c
P	***0.004***	***0.019***	***0.039***	***0.003***	***0.022***	***ns***[3]	***0.003***

1 Rootstocks listed in descending order of % of sound fruit. 2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all flesh defects combined. 3 ns = not significant (P > 0.05). Means within columns followed by the same letter are not significantly different (P > 0.05) as tested by least significant difference. Values in table are means of 200 fruit per rootstock.

Table 55 Childers 2009: Effects of clonal (C) and seedling (S) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	**Fruit flesh dry matter at harvest (%)**	**Fruit skin minerals concentration at harvest (% dry weight)**						**Fruit skin phenolics (gallic acid equivalents / g fresh weight)**	**Fruit flesh catalase (U/ug protein)**	**Fruit flesh peroxidase (U/ug protein)**
		N	**Ca**	**Mg**	**K**	**N/Ca ratio**	**Ca+Mg/ K ratio**			
C-A10	27.1 ^{abc}	0.77 ^{d}	0.031 ^{bcde}	0.077	1.13	26.7 ^{cd}	0.098	25.9	3.9	12.2
C-Duke 7	27.8 ^{a}	0.85 ^{bcd}	0.029 ^{bcde}	0.076	1.03	31.9 ^{abcd}	0.125	23.9	3.3	10.1
C-Nabal	27.4 ^{ab}	0.78 ^{cd}	0.028 ^{de}	0.079	1.14	29.5 ^{bcd}	0.096	23.6	4.1	11.0
C-SHSR-03	27.8 ^{a}	0.88 ^{abc}	0.029 ^{cde}	0.078	1.06	32.5 ^{abc}	0.103	22.6	3.7	11.3
C-Velvick	27.9 ^{a}	0.91 ^{ab}	0.027 ^{e}	0.087	1.29	35.8 ^{ab}	0.091	20.9	4.3	9.8
C-Zutano	27.6 ^{a}	0.98 ^{a}	0.026 ^{e}	0.082	1.18	39.9 ^{a}	0.096	20.6	4.1	9.8
S-A10	26.3 ^{bc}	0.89 ^{ab}	0.038 ^{a}	0.082	1.01	24.2 ^{d}	0.119	ND[2]	ND	ND
S-Nabal	26.1 ^{c}	0.92 ^{ab}	0.034 ^{abcd}	0.082	1.07	28.8 ^{bcd}	0.109	ND	ND	ND
S-SHSR-02	26.9 ^{abc}	0.98 ^{a}	0.036 ^{ab}	0.084	1.05	28.0 ^{bcd}	0.115	ND	ND	ND
S-SHSR-03	27.5 ^{a}	0.95 ^{ab}	0.038 ^{a}	0.086	1.13	27.0 ^{cd}	0.112	ND	ND	ND
S-Velvick	26.2 ^{c}	0.97 ^{ab}	0.036 ^{abc}	0.086	1.07	29.1 ^{bcd}	0.114	ND	ND	ND
P	***0.006***		***<0.001***	***ns***[3]	***ns***	***0.016***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ND = not done (only clonal rootstocks analysed for phenolics and enzymes)
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 56 Childers 2009: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose incidence	Phenolics	0.012	0.42	-
Stem-end rot incidence	Total yield	<0.001	0.38	-
Stem-end rot incidence	Yield efficiency	<0.001	0.36	-
Stem-end rot incidence	Ca	0.005	0.27	-
Stem-end rot incidence	N/Ca	0.011	0.25	+
Anthracnose incidence	N	0.028	0.21	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C				
Stem-end rot	Days to Ripe	0.001	0.53	+
Tree yield	Dry matter	<.001	0.39	-
Tree yield	Body rot	0.001	0.34	-
% sound fruit	Tree yield	<.001	0.34	+
Dry matter	Body Rot	<.001	0.33	+
% sound fruit	Yield efficiency	<.001	0.32	+
Dry matter	Vascular leaching	0.002	0.27	+
Tree yield	K	0.003	0.27	-
Yield efficiency	Body Rot	0.003	0.26	-
% sound fruit	Dry matter	0.005	0.25	-

10.3.3 Childers QLD ('Hass') 2010

Fruit postharvest quality

The severity of anthracnose and stem-end rot was generally low in fruit harvested from this trial, and there were no significant differences between any of the treatments (i.e. rootstock) (Table 57). There were also no treatment differences with respect to the incidence of anthracnose and stem-end rot, fruit marketability or days to eating-ripe.

Lasiodiplodia theobromae was the predominant cause of stem-end rot in this trial, causing approximately 67% of lesions. *Colletotrichum gloeosporioides* was responsible for the remaining 33% of stem-end rot lesions.

Fruit post-storage quality

Rootstocks did not significantly affect fruit ripening after removal from cold storage (days to ripe), fruit skin colour, or the severity of body rots, stem-end rots, diffuse discolouration, and vascular leaching at eating ripe (Table 58). Overall fruit quality was very good, with little incidence of flesh rots or internal disorders. As a result, the percentage of sound fruit (those with a severity rating of 10% or less of the flesh affected by all defects combined) was above 88% for all rootstocks and the differences among rootstocks were not significant (Table 58).

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

There were some significant differences among rootstocks in relation to fruit flesh dry matter (DM) at harvest (Table 59). Fruit from trees on clonal 'SHSR-03', clonal 'A10' and seedling 'SHSR-02' had the highest flesh DM, whereas fruit from trees on clonal 'Zutano' had the lowest flesh DM.

Skin N concentrations were significantly affected by rootstock, with fruit from trees on clonal SHSR-03 having significantly higher N concentrations than fruit from all other treatments, except for seedling 'A10' and seedling 'SHSR-03' (Table 59). Fruit from trees on clonal Velvick had lowest fruit N concentrations. The highest fruit Ca concentrations and ratios of Ca+Mg/K were seen in fruit from trees on clonal 'A10' and the lowest in fruit from trees on seedling 'SHSR-02'. There were no significant rootstock effects on fruit skin Mg or K concentrations, or on ratios of N/Ca. There were also no rootstock effects on concentrations of phenolics, catalase or peroxidase at the Childers site (Table 59).

Correlations

In fruit which had been ripened at 23°C, there were significant negative correlations between tree yield and stem-end rot incidence, yield efficiency and anthracnose incidence, Ca and anthracnose/stem-end rot incidence, and Ca+Mg/K and anthracnose incidence (Table 60). Tree yield, yield efficiency and Ca all correlated positively with fruit marketability.

In ripe fruit that had been cold stored and then ripened, higher % of sound fruit was generally correlated with fruit that ripened quicker, had more green on the skin at ripe, a higher skin K concentration, and were from trees with higher yield (Table 60). Higher yield was also correlated with less flesh diffuse discolouration and body rots at eating ripe.

Table 57 Childers 2010 - Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
C-Velvick	11.9	0.8	16	1.2	7	91
C-A10	12.0	0.6	15	1.7	8	90
S-Velvick	11.9	1.0	19	1.7	8	89
C-Zutano	11.9	0.4	12	2.5	10	89
C-Nabal	11.9	0.9	19	2.7	10	88
C- SHSR-03	11.9	1.5	18	2.1	8	88
S-SHSR-03	11.9	0.5	11	2.1	12	87
C-Duke 7	11.8	2.7	21	2.4	11	84
S-Nabal	11.9	0.2	10	3.3	15	83
S-A10	11.9	1.5	24	2.4	16	79
S-SHSR-02	11.8	1.4	20	3.9	18	79
P	*ns*[5]	*ns*	*ns*	*ns*	*ns*	*ns*

1 Rootstocks listed in descending order of % marketable fruit. 2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease. 3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment. 4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot. 5 ns = not significant (P>0.05). Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference. Values in table are means of 200 fruit per rootstock

Table 58 Childers 2010 - Effects of clonal (C) and seedling (S) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripen at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discol.	Vascular leaching	
C-Zutano	8.2	5.0	0.2	0.2	0.4	0.1	99
C-Duke 7	8.6	5.0	0.1	0.2	0.7	0.0	98
S-SHSR-02	8.7	5.1	0.3	0.7	0.9	0.1	95
C-Nabal	8.8	5.0	0.7	0.6	0.9	0.0	95
S-SHSR-03	8.9	5.0	0.3	0.7	0.9	0.1	94
S-Nabal	8.8	4.9	0.2	0.8	0.8	0.0	93
C-A10	9.4	5.0	0.3	0.7	1.3	0.1	93
C-Velvick	8.6	5.0	0.2	1.0	0.9	0.0	92
S-Velvick	8.6	5.1	0.5	0.7	0.9	0.1	92
S-A10	9.3	5.0	0.6	1.0	1.4	0.0	91
C-SHSR-03	9.0	5.0	0.5	1.0	1.9	0.2	88
P	*ns*[3]	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

1 Rootstocks listed in descending order of % sound fruit. 2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined. 3 ns = not significant (P > 0.05). Means within columns followed by the same letter are not significantly different (P > 0.05) as tested by least significant difference. Values in table are means of 200 fruit per rootstock.

Table 59 Childers 2010 - Effects of clonal (C) and seedling (S) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	25.3 a	0.88 bc	0.101 a	0.115	1.29	9.4	0.167 a	20.2	1.77	8.85
C-Duke 7	25.2 ab	0.88 bc	0.072 cd	0.110	1.43	12.8	0.130 bc	20.1	1.72	9.36
C-Nabal	24.7 abc	0.81 bc	0.083 bc	0.114	1.46	9.8	0.137 bc	18.1	1.08	4.94
C-SHSR-03	25.4 a	1.16 a	0.088 ab	0.116	1.41	14.4	0.149 ab	16.7	1.43	7.17
C-Velvick	24.7 abc	0.78 c	0.088 ab	0.112	1.41	9.0	0.144 bc	19.9	1.52	5.87
C-Zutano	24.3 c	0.95 bc	0.074 bcd	0.111	1.41	13.6	0.133 bc	17.4	1.69	10.51
S-A10	24.9 abc	0.99 ab	0.081 bcd	0.109	1.36	12.7	0.140 bc	ND[2]	ND	ND
S-Nabal	24.3 bc	0.86 bc	0.071 cd	0.113	1.38	12.3	0.134 bc	ND	ND	ND
S-SHSR-02	25.3 a	0.89 bc	0.067 d	0.106	1.39	13.2	0.126 c	ND	ND	ND
S-SHSR-03	24.7 abc	0.99 ab	0.089 ab	0.111	1.39	11.7	0.145 bc	ND	ND	ND
S-Velvick	24.3 bc	0.87 bc	0.078 bcd	0.112	1.36	11.9	0.140 bc	ND	ND	ND
P	***0.045***		***0.001***	***ns[3]***	***ns***	***ns***	***0.019***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ND = not done (only clonal rootstocks analysed for phenolics and enzymes)
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 60 Childers 2010: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Tree yield	Stem-end rot incidence	0.002	0.30	-
Tree yield	% Marketable fruit	0.003	0.28	+
Yield efficiency	Anthracnose incidence	0.011	0.24	-
Ca+Mg/K	Anthracnose incidence	0.015	0.23	-
Ca	% Marketable fruit	0.022	0.22	+
Yield efficiency	% Marketable fruit	0.023	0.22	+
Ca	Anthracnose incidence	0.020	0.22	-
Ca	Stem-end rot incidence	0.044	0.19	-
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
% of sound fruit	Days to ripe	<.001	0.53	-
Dry matter	Skin colour	0.003	0.26	+
Ca	Days to ripe	0.005	0.25	+
K	Days to ripe	0.005	0.25	+
Tree yield	Body rot	0.006	0.25	-
Tree yield	Diffuse discolouration	0.006	0.25	-
Dry matter	Diffuse discolouration	0.005	0.25	+
% of sound fruit	Skin colour	0.007	0.24	-
% of sound fruit	Tree yield	0.009	0.23	+
% of sound fruit	K	0.011	0.22	-

10.3.4 Hampton QLD ('Hass') 2008

Fruit postharvest quality

Rootstock significantly affected the severity and incidence of side anthracnose, with fruit from trees on clonal 'Hass' showing significantly higher anthracnose severity than those on clonal Velvick, 'Zutano', 'SHSR-03' and 'Duke 7' (Table 61). Clonal 'Reed' also had significantly higher anthracnose severity than clonal 'Velvick', 'SHSR-03' and 'Duke 7'. The incidence of side anthracnose was similarly affected by rootstock, with clonal 'Hass' showing significantly higher anthracnose incidence than clonal 'Velvick', 'SHSR-03' and 'Duke 7'. Fruit marketability was highest in clonal 'SHSR-03', 'Duke 7' and 'Velvick', and lowest in clonal 'Hass'. Days to eating-ripe were greater in clonal 'Velvick' and 'SHSR-03' than clonal 'Zutano', 'Reed' and 'Hass'. There were no significant effects of rootstock on stem-end anthracnose and stem-end rot severity or incidence.

The predominant causal agent of stem-end rot at the Hampton site in 2008 was *Colletotrichum* sp. (causing approximately 75% of lesions). Other causal agents were *Botryosphaeria* spp. (15%), *Phomopsis* sp. (4%), *Fusarium* sp. (4%) and *Alternaria* sp. (1%).

Fruit post-storage quality

Rootstocks significantly affected fruit ripening after removal from cold storage, with a difference of about one day between the fruit that took longest to ripen (from trees on clonal 'Velvick' and 'SHSR-03' rootstocks) and the least time to ripen (from trees on clonal 'Hass' rootstock) (Table 62). There were no significant differences between rootstocks for skin colour at ripe, severity of flesh diseases and internal disorders, or % of sound fruit at eating ripe. Overall, the severity of flesh defects after cold storage and ripening was very high, resulting in most fruit having more than 10% of the flesh affected by defects for all rootstocks. The main causes for the loss of saleability were diffuse discolouration, followed by vascular leaching and body rots.

Fruit flesh dry matter, skin minerals and fruit biochemical markers

Flesh DM was significantly higher in fruit from trees on clonal 'Hass' than those on clonal 'Duke 7', 'SHSR-03' and 'Zutano' (Table 63).

There were no significant effects of rootstocks on skin N levels, although the probability level ($P = 0.051$) was very close to being significant (Table 63). The highest skin N levels were seen in fruit from trees on clonal 'Hass' and 'Zutano'. The highest skin Mg levels were seen in clonal 'SHSR-03', and the lowest were seen in clonal 'Velvick'. Clonal 'Reed' had significantly higher skin K levels than clonal 'Velvick', 'Zutano' and 'SHSR-03'. Clonal 'SHSR-03' had a significantly higher skin Ca+Mg/K ratio than clonal 'Duke 7', 'Hass' and 'Reed'. There were no significant rootstock effects on skin Ca or N/Ca ratios.

There were no significant effects of rootstocks on skin phenolic levels, although the probability level ($P=0.055$) was very close to being significant (Table 63). As for Childers, fruit from trees on clonal 'Duke 7' showed the highest value for skin phenolics.

Correlations

In fruit which had been ripened at 23°C, positive correlations were found between anthracnose severity and skin N/Ca ratios, and also between stem-end rot severity and skin N/Ca ratios (Table 64), noting that *Colletotrichum* sp. was the predominant cause of stem-end rot in this trial. A negative correlation was once again found between anthracnose severity and yield per tree.

In ripe fruit that had been cold stored and then ripened, there were also some positive correlations between the severity of body rots and diffuse discolouration, and body rots and vascular leaching (Table 64). Higher yielding trees were correlated with less skin Mg and higher % of sound fruit.

Table 61 Hampton 2008: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
C-SHSR-03	11.1 [a]	10.1 [c]	65 [c]	0.8	15	0.3	6	72 [a]
C-Duke 7	10.7 [ab]	8.9 [c]	66 [c]	1.9	17	1.7	8	57 [ab]
C-Velvick	11.1 [a]	8.4 [c]	70 [bc]	1.0	18	0.7	6	54 [ab]
C-Zutano	10.6 [bc]	17.0 [bc]	78 [abc]	1.9	21	0.6	6	47 [b]
C-Reed	10.4 [bc]	27.3 [ab]	84 [ab]	2.1	18	0.6	6	38 [bc]
C-Hass	10.1 [c]	34.6 [a]	87 [a]	2.5	24	1.6	14	24 [c]
P	***0.001***	***0.001***	***0.044***	***ns[5]***	***ns***	***ns***	***ns***	***0.001***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 1200 fruit per rootstock

Table 62 Hampton 2008: Effects of clonal (C) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5.5°C for 5 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discolouration	Vascular leaching	
C-Velvick	5.7 [a]	5.0	12	0.8	37	14	2
C-Zutano	5.1 [bc]	4.9	11	0.5	43	11	1
C-Duke 7	5.6 [ab]	5.2	12	0.2	41	17	0
C-Hass	4.7 [c]	5.5	16	0.3	56	7	0
C-Reed	5.0 [c]	5.0	12	0.5	48	12	0
C-SHSR-03	5.7 [a]	4.9	13	0.6	43	14	0
P	***0.002***	***ns*[3]**	***ns***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % of sound fruit
2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 200 fruit per rootstock

Table 63 Hampton 2008: Effects of clonal (C) rootstocks on fruit flesh dry matter (%), and on fruit skin minerals (% dry weight) and phenolics (gallic acid equivalent/g fresh weight) concentrations in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics concentration (gallic acid equivalents/ g fresh weight)		
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio	Harvest	Sprung	Eating-ripe
C-Duke 7	27.9 [b]	0.94	0.025	0.090 [ab]	1.12 [ab]	39	0.104 [b]	31.1	20.5	25.8
C-Hass	29.8 [a]	1.07	0.023	0.083 [bc]	1.09 [ab]	47	0.099 [b]	19.8	23.4	24.1
C-Reed	28.5 [ab]	0.93	0.028	0.090 [ab]	1.25 [a]	35	0.097 [b]	26.4	20.2	20.9
C-SHSR-03	27.7 [b]	0.96	0.028	0.093 [ab]	1.00 [b]	36	0.127 [a]	29.5	20.5	25.2
C-Velvick	28.4 [ab]	0.90	0.028	0.083 [c]	0.98 [b]	34	0.115 [ab]	28.7	32.6	23.5
C-Zutano	26.1 [c]	1.01	0.028	0.083 [cb]	0.98 [b]	37	0.115 [ab]	25.0	25.7	25.9
P	***0.002***	***ns[2] (0.051)***	***ns***	***0.016***	***0.036***	***ns***	***0.046***	***ns (0.055)***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for phenolics (25 fruit per rootstock)

Table 64 Hampton 2008: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose severity	N/Ca	0.011	0.39	+
Stem end rot severity	N/Ca	0.013	0.38	+
Anthracnose severity	Tree yield	0.044	0.30	-
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Body rot	Diffuse discolouration	0.001	0.62	+
Body rot	Vascular leaching	0.001	0.50	-
Tree Yield	Mg	0.019	0.39	-
Tree yield	% sound fruit	0.047	0.32	+

10.3.5 Hampton QLD (Hass) 2009

Fruit postharvest quality

At the Hampton site there were no significant rootstock effects on the incidence and severity of anthracnose or stem-end rot, or on % marketable fruit (Table 65). Fruit from trees on clonal 'A10', clonal 'SHSR-03' and clonal 'Velvick' took significantly longer to ripen than those from trees on clonal 'Reed' and clonal 'Hass'.

Fruit post-storage quality

Rootstocks significantly affected fruit ripening after removal from cold storage, with a difference of almost two days between the fruit that took longest to ripen (from trees on clonal 'A10' rootstock) and the shortest time to ripen (from trees on clonal 'Reed' rootstock) (Table 66). There were no significant differences among rootstocks for skin colour at ripe.

Rootstocks significantly affected the severity of stem-end rots (but not body rots) and the internal disorders diffuse discolouration and vascular browning at eating ripe. Fruit from trees on clonal Hass and 'Reed' rootstocks had the lowest severity of stem-end rots but the highest severity of diffuse discoloration. Overall, the severity of flesh defects (both rots and internal disorders) after cold storage and ripening was very high, resulting in most fruit having more than 10% of the flesh affected by defects for all rootstocks. As a result, the percentage of sound fruit was not higher than 1% for any rootstock. The main causes for the loss of saleability were diffuse discolouration and body rots, followed by vascular leaching and stem-end rots.

Fruit flesh dry matter, skin minerals and fruit biochemical markers

There were no significant effects of rootstock on flesh DM or fruit biochemical's (phenolics, catalase and peroxidase) (Table 67). K levels were significantly higher in fruit from trees on cloned 'Reed' than in fruit from trees on cloned 'A10' and cloned 'SHSR-03'. Fruit from trees on cloned 'Reed' and cloned 'Hass' rootstocks also had significantly lower Ca+Mg/K ratios than fruit from trees on clonal 'A10' and clonal 'SHSR-03'. There were no rootstock effects on skin N, Ca or Mg levels, or on N/Ca ratios.

Correlations

In fruit ripened at 23°C, positive correlations were found between anthracnose incidence and skin N/Ca ratios, as well as between anthracnose incidence and flesh catalase levels (Table 68). Negative correlations were found between anthracnose incidence and skin Ca as well as between stem-end rot incidence and skin Mg.

In ripe fruit that had been cold stored and then ripened, fruit that ripened quicker was correlated with less stem-end rot, more severe diffuse discolouration and higher skin K concentration (Table 67). Fruit from trees with higher yield or yield efficiency was correlated with less severe diffuse discolouration. Higher skin Ca concentration was correlated with less severe diffuse discolouration and vascular leaching. Higher skin K concentration was correlated with less severe stem-end rot and more severe diffuse discolouration.

Table 65 Hampton 2009: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
C-Velvick	11.1 a	35.2	77	3.2	25	31
C-Duke 7	10.4 ab	36.8	87	1.3	16	29
C-SHSR-03	11.0 a	30.9	88	1.7	21	28
C-Hass	9.6 b	54.0	85	1.5	19	26
C-A10	10.9 a	31.3	78	5.4	31	22
C-Reed	9.6 b	52.5	95	2.9	26	13
P	*0.019*	*ns*[5]	*ns*	*ns*	*ns*	*ns*

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference. Values in table are means of 120 fruit per rootstock

Table 66 Hampton 2009: Effects of clonal (C) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discol.	Vascular leaching	
C-A10	9.7 a	5.6	19.0	9.1 a	12.9 b	13.3 bc	1
C-Hass	6.9 b	5.4	19.9	1.9 c	27.2 a	16.3 ab	1
C-Velvick	9.0 a	5.4	16.0	6.9 ab	13.4 b	15.0 ab	1
C-Duke 7	7.5 b	5.4	17.8	3.4 bc	19.4 b	18.1 a	0
C-Reed	6.8 b	5.5	22.2	2.6 c	30.9 a	11.8 c	0
C-SHSR-03	9.1 a	5.6	20.8	6.4 ab	13.9 b	13.9 bc	0
P	*<.001*	*ns* [3]	*ns*	*0.002*	*<0.001*	*0.005*	*ns*

1 Rootstocks listed in descending order of % of sound fruit
2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference. Values in table are means of 120 fruit per rootstock

Table 67 Hampton 2009: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	29.5	1.02	0.038	0.097	1.19 [bc]	28.0	0.115 [a]	21.7	6.0	14.4
C-Duke 7	28.6	0.92	0.032	0.102	1.27 [abc]	29.4	0.105 [ab]	22.7	6.2	12.7
C-Hass	30.0	0.98	0.027	0.090	1.35 [ab]	41.4	0.088 [b]	21.6	7.2	13.2
C-Reed	31.2	0.97	0.030	0.097	1.41 [a]	35.3	0.091 [b]	22.5	7.1	12.7
C- SHSR-03	28.7	0.77	0.037	0.095	1.15 [c]	22.9	0.116 [a]	21.6	6.4	12.5
C-Velvick	29.3	1.00	0.032	0.092	1.28 [abc]	31.7	0.098 [ab]	21.5	6.4	13.4
P	*ns*[2]	*ns*	*ns*	*ns*	*0.046*	*ns*	*0.022*	*ns*	*ns*	*ns*

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 68 Hampton 2009: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose incidence	N/Ca	0.007	0.44	+
Anthracnose incidence	Ca	0.014	0.41	-
Stem-end rot incidence	Mg	0.025	0.37	-
Anthracnose incidence	Flesh catalase	0.050	0.35	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Days to Ripe	Stem-end rot	0.001	0.90	+
Days to Ripe	Diffuse discolouration	0.001	0.84	-
Diffuse discolouration	K	0.001	0.61	+
Days to Ripe	K	0.001	0.58	-
Stem-end rot	K	0.001	0.56	-
Days to Ripe	Ca	0.001	0.53	+
Tree yield	Diffuse discolouration	0.005	0.43	-
Diffuse discolouration	Ca	0.024	0.34	-
Yield efficiency	Diffuse discolouration	0.026	0.34	-
Vascular leaching	Ca	0.046	0.29	-

10.3.6 Hampton QLD (Hass) 2010

Fruit postharvest quality

At the Hampton site there were some very marked rootstock effects on the incidence and severity of anthracnose and on % marketable fruit (Table 69). Fruit from trees on clonal 'Duke 7', 'Reed' and 'Hass' had a very high incidence and severity of anthracnose compared to fruit from trees clonal 'SHSR-03', 'A10' and 'Velvick'. Fruit marketability values reflected these differences in anthracnose.

Levels of stem-end rot were very low in this trial and there were no significant differences among treatments (Table 69). The predominant causal agent of stem-end rot at the Hampton site in 2010 was *Colletotrichum* sp. (causing approximately 63% of lesions). Other causal agents were *Botryosphaeria* spp. (21%), *Fusarium* sp. (11%) and *Acremonium* sp. (1%).

There were also no differences in the 'days to eating-ripe' for any of the treatments.

Fruit post-storage quality

Rootstocks significantly affected fruit ripening (days to ripe) after removal from cold storage, with a difference of 1.5 day between the fruit that took longest to ripen (from trees on clonal 'SHSR-03' rootstock) and the shortest time to ripen (from trees on clonal 'Duke-7' rootstock) (Table 70). There were no significant differences among rootstocks for skin colour at eating ripe.

Fruit from trees on clonal rootstocks 'A10', 'Velvick' and seedling 'SHSR-03' generally had less internal disorders (mainly diffuse discolouration and vascular leaching) after cold storage than fruit from trees on the other rootstocks (especially clonal 'Reed') (Table 70). As a result, the percentage of sound fruit was higher in fruit from trees on clonal 'A10' and 'Velvick' rootstocks than fruit from trees on clonal 'Duke 7' and 'Reed' rootstocks (Table 70).

Rootstocks did not significantly affect the severity of body rots and the overall incidence was very low (Table 70). Stem-end rots were non-existent across all rootstocks (data not shown).

Fruit flesh dry matter, skin minerals and fruit biochemical markers

The highest N and lowest Ca levels were seen in fruit which also had the highest anthracnose levels i.e. those from trees on clonal 'Reed', 'Duke 7' and 'Hass' (Table 71). Not surprisingly, N/Ca and Ca+Mg/K ratios in fruit reflected these findings.

There were no significant effects of rootstock on flesh DM, skin phenolics or flesh catalase at the Hampton site in 2010 (Table 71). Flesh peroxidase levels were affected by rootstock however, with fruit from trees on clonal 'Velvick' showing significantly lower peroxidase levels than fruit from trees on clonal 'Duke 7', 'Hass' and 'Reed'.

Correlations

In fruit ripened at 23°C, there were significant negative correlations between Ca and anthracnose/stem-end rot incidence, between Ca+Mg/K and anthracnose incidence, and between N or N/Ca and fruit marketability (Table 72). Ca and Ca+Mg/K correlated positively with fruit marketability, as did N and N/Ca with anthracnose incidence. There were no significant correlations between tree yield/yield efficiency and disease at Hampton in 2010.

In ripe fruit that had been cold stored, there were significant correlations between the severity of flesh defects (mainly diffuse discolouration and vascular leaching), skin minerals concentrations/ratios, yield, dry matter, days to ripe, and the % of sound fruit and (Table 72). Higher percentages of sound fruit were generally correlated with fruit that had more skin Ca, less skin K, higher Ca+Mg/K ratio, lower N/Ca ratio, were smaller, were from trees with higher yield, and took longer to ripe (Table 72).

Table 69 Hampton 2010: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence[3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
C-SHSR-03	8.9	11.8 c	39.0 c	0.01	1.0	75.0 a
C-A10	8.8	16.6 bc	47.5 bc	0.02	0.8	73.1 a
C-Velvick	8.9	9.3 c	47.3 bc	0.10	2.0	70.2 ab
C-Hass	8.6	38.6 ab	75.2 ab	0.21	2.0	37.4 c
C-Duke 7	8.2	44.0 a	78.4 ab	0.10	1.7	37.2 bc
C-Reed	8.5	43.0 a	81.0 a	0.12	6.0	29.0 c
P	***ns***[5]	***0.016***	***0.022***	***ns***	***ns***	***0.005***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot
5 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 70 Hampton 2010: Effects of clonal (C) rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)			% of sound fruit[2]
			Body rots	Diffuse discol.	Vascular leaching	
C-A10	5.5 ab	4.2	0.1	7.9 b	7.4 c	67 a
C-Velvick	5.5 ab	3.9	0.2	8.0 b	9.4 c	67 a
C-SHSR-03	5.8 a	4.1	0.1	8.3 b	9.9 bc	55 ab
C-Hass	5.0 bc	3.8	0.1	19.8 ab	16.5 ab	33 bc
C-Duke 7	4.3 c	3.6	0.3	17.5 ab	12.5 abc	30 bc
C-Reed	5.0 bc	4.2	0.9	28.1 a	17.6 a	24 c
P	***0.005***	***ns***[3]	***ns***	***0.047***	***0.023***	***0.030***

1 Rootstocks listed in descending order of % sound fruit
2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P > 0.05$) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 71 Hampton 2010: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	32.5	1.22 b	0.064 a	0.118	1.59	20.6 c	0.120 a	24.3	2.7	9.91 abc
C-Duke 7	38.3	1.33 ab	0.037 bc	0.107	1.97	38.2 ab	0.073 b	20.7	5.69	12.21 a
C-Hass	32.4	1.43 a	0.044 bc	0.110	1.70	28.3 bc	0.092 ab	19.8	4.54	11.06 ab
C-Reed	34.3	1.32 ab	0.030 c	0.080	1.76	45.8 a	0.068 b	19.3	4.21	10.96 ab
C- SHSR-03	36.8	1.24 b	0.056 ab	0.112	1.47	23.8 bc	0.116 a	24.5	3.84	8.79 bc
C-Velvick	29.8	1.20 b	0.056 ab	0.116	1.55	21.7 c	0.117 a	20.5	4.61	8.60 c
P	***ns[2]***	***0.022***	***0.011***	***ns***	***ns***	***0.004***	***0.011***	***ns***	***ns***	***0.035***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 72 Hampton 2010: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
N	% Marketable fruit	<0.001	0.79	-
N	Anthracnose incidence	<0.001	0.71	+
N/Ca	% Marketable fruit	<0.001	0.69	-
N/Ca	Anthracnose incidence	<0.001	0.62	+
(Ca+Mg)/K	% Marketable fruit	0.001	0.60	+
(Ca+Mg)/K	Anthracnose incidence	0.002	0.57	-
Ca	% Marketable fruit	0.002	0.57	+
Ca	Anthracnose incidence	0.007	0.51	-
Ca	Stem-end rot incidence	0.05	0.38	-
N/Ca	Stem-end rot incidence	0.044	0.39	+
Fruit held at 5oC for 5 weeks and then ripened at 20oC				
% sound fruit	(Ca+Mg)/K	<.001	0.74	+
% sound fruit	Days to ripe	<.001	0.74	+
(Ca+Mg)/K	Vascular leaching	<.001	0.69	-
(Ca+Mg)/K	Days to ripe	<.001	0.69	+
(Ca+Mg)/K	Diffuse discolouration	<.001	0.68	-
% sound fruit	Fruit weight	<.001	0.67	-
Tree yield	Days to ripe	<.001	0.66	+
% sound fruit	K	<.001	0.65	-
Diffuse disc.	K	<.001	0.65	+
Fruit weight	Vascular leaching	<.001	0.61	+
Days to ripe	Diffuse discolouration	<.001	0.60	-
Tree yield	K	<.001	0.60	-
Days to ripe	K	<.001	0.58	-
Tree yield	(Ca+Mg)/K	0.001	0.56	+
% sound fruit	Tree yield	0.002	0.54	+
% sound fruit	N/Ca	0.003	0.52	-
Ca	Diffuse discolouration	0.003	0.51	-
% sound fruit	Ca	0.007	0.47	+
Mg	Vascular leaching	0.008	0.46	-
N/Ca	Vascular leaching	0.008	0.46	+

10.3.7 Pemberton WA (Hass) 2008

Fruit postharvest quality

The severity and incidence of side anthracnose and the % marketable fruit were significantly affected by rootstock at the Pemberton site (Table 73). Fruit from trees on clonal 'A10', 'Reed' and 'Velvick' had a significantly lower severity of side anthracnose and a significantly higher % of marketable fruit than those on clonal 'Zutano' and 'Barr Duke'. Similarly clonal 'A10', 'Velvick' and 'Reed' had a significantly lower incidence of side anthracnose than clonal 'Barr Duke'. There were no significant effects of rootstock on days to eating-ripe or stem-end anthracnose and stem-end rot severity/incidence.

The predominant causal agent of stem-end rot at the Pemberton site in 2008 was *Colletotrichum gloeosporioides* (causing approximately 75% of lesions). Other causal agents were *Fusarium* sp. (20%), *Colletotrichum acutatum* (8%), *Pestalotiopsis* sp. (7%), *Phomopsis* sp. (1%) and *Macrophomina* sp. (1%).

Fruit post-storage quality

Rootstocks did not significantly affect days to ripe or fruit skin colour at ripe (Table 74). The severity of body rots was significantly affected by rootstocks at eating ripe, with higher severity for fruit from trees on clonal 'Barr Duke' compared to all other rootstocks. There were no significant differences between rootstocks for severity of stem-end rots, diffuse discolouration and vascular leaching, or % of sound fruit at eating ripe. The main causes for the loss of saleability were diffuse discolouration, followed by vascular leaching, body rots, and stem-end rots.

Fruit flesh dry matter, skin minerals and fruit biochemical markers

There were no significant rootstock effects on fruit DM at harvest (Table 75).

Skin N levels were significantly higher in fruit from trees on clonal 'Barr Duke' and 'Zutano' than those on clonal 'A10' or 'Velvick' (Table 75). Clonal 'Velvick' had significantly higher skin Ca levels than all other rootstocks. Clonal 'A10' had significantly higher skin Ca levels than clonal 'Reed'. Skin N/Ca ratios were highest in clonal 'Barr Duke' and 'Reed' and lowest in clonal 'Velvick' and 'A10'. Clonal 'Velvick', 'A10' and 'Zutano' had a higher skin Ca+Mg/K ratio than clonal 'Reed'. There were no significant rootstock effects on skin Mg and K levels, flesh DM or skin

There were no significant rootstock effects on fruit skin phenolic levels (75).

Correlations

In fruit ripened at 23°C, a positive correlation was found between anthracnose severity and skin N levels (Table 76).

In ripe fruit that had been cold stored, a negative correlation was found between stem-end rot severity and skin N, and a positive one between dry matter % and vascular leaching severity (Table 76).

Table 73 Pemberton 2008: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% of flesh surface area)	Incidence [3] (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	Severity (% of flesh volume)	Incidence (% fruit affected)	
C-A10	15.9	1.1 d	28 c	1.1	5	0.5	2	93 a
C-Reed	15.8	2.0 d	43 bc	0.7	4	0.1	4	90 a
C-Velvick	15.8	2.7 cd	30 c	3.0	7	0.6	8	81 ab
C-Duke 7	15.7	7.5 bc	59 ab	1.0	10	0.4	6	71 bc
C-Zutano	15.4	10.8 ab	61 ab	1.7	12	0.1	2	66 c
C-Barr Duke	15.3	13.5 a	73 a	2.7	11	0.4	3	50 d
P	***ns***[5]	***<0.001***	***<0.001***	***ns***	***ns***	***ns***	***ns***	***<0.001***

1 Rootstocks listed in descending order of % of sound fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with a severity rating of 5% or less for anthracnose and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 1200 fruit per rootstock

Table 74 Pemberton 2008: Effects of clonal rootstocks on days to ripe, skin colour (1-6), severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 5 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[3]
			Body rots	Stem-end rots	Diffuse discol.	Vascular leaching	
C-Zutano	9.0	5.2	1.4 b	3.2	5.7	1.4	56
C-Duke 7	8.7	5.3	4.9 b	3.5	6.1	2.8	53
C-Reed	8.6	5.1	3.6 b	3.9	8.6	3.3	45
C-Velvick	9.3	5.2	3.4 b	3.9	5.4	2.4	43
C-A10	9.9	5.2	3.8 b	6.6	4.5	2.9	34
C-Barr Duke	8.7	5.3	8.7 a	6.0	8.4	4.1	27
P	***ns***[3]	***ns***	***0.013***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % of sound fruit

2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined

3 ns = not significant (P > 0.05)

Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Values in table are means of 1200 fruit per rootstock

Table 75 Pemberton 2008: Effects of clonal (C) rootstocks on fruit flesh dry matter (%), and on fruit skin minerals (% dry weight) and phenolics (gallic acid equivalent/g fresh weight) concentrations in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics concentration (gallic acid equivalents/ g fresh weight)		
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio	Harvest	Sprung	Eating-ripe
C-A10	27.8	0.87 [c]	0.087 [b]	0.120	0.97	10.7 [bc]	0.217 [ab]	38.2	34.5	34.5
C-Barr Duke	25.9	0.97 [a]	0.070 [bc]	0.117	0.98	14.3 [a]	0.192 [bc]	31.4	29.8	34.4
C-Duke 7	25.5	0.95 [ab]	0.073 [bc]	0.113	0.99	13.2 [ab]	0.190 [bc]	29.5	31.3	34.6
C-Reed	27.1	0.93 [abc]	0.064 [c]	0.112	1.01	14.8 [a]	0.175 [c]	27.5	29.6	36.3
C-Velvick	25.3	0.87 [bc]	0.106 [a]	0.114	0.97	8.6 [c]	0.230 [a]	31.6	32.1	33.9
C-Zutano	25.3	0.97 [a]	0.080 [bc]	0.118	0.90	12.4 [ab]	0.220 [ab]	24.8	34.0	28.2
P	***ns*[2]**	***0.041***	***0.003***	***ns***	***ns***	***0.003***	***0.03***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for phenolics (25 fruit per rootstock)

Table 76 Pemberton 2008: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose severity	N	0.013	0.39	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Stem-end rot	N	0.013	0.42	-
Dry matter	Vascular leaching	0.036	0.35	+

10.3.8 Pemberton WA (Hass) 2010

Fruit postharvest quality

There were no significant rootstock effects on the severity or incidence of anthracnose in 'Hass' fruit harvested at the Pemberton site (Table 77), although fruit from trees on clonal 'Barr Duke' did have much higher anthracnose levels than fruit from trees on all other rootstocks (as was seen in the most recent Pemberton harvest of 2008). Correspondingly, fruit from trees on clonal 'Barr Duke' had a significantly lower marketability percentage than those from trees on other rootstocks. Levels of stem-end rot were very low and there were no significant differences among treatments. It was interesting to note however that *Colletotrichum fioriniae (*previously known as *Colletotrichum acutatum*) caused approximately 27% of stem-end rot lesions at this site. Of the remaining stem-end rot lesions, approximately 60% were caused by *C. gloeosporioides*, 7% by *Fusarium* sp., 3% by *Aspergillus* sp. and 3% by undetermined pathogens.

Fruit post-storage quality

Rootstocks significantly affected days to ripe and skin colour at ripe in fruit that had been cold stored, although the differences were small (Table 78). In contrast, there was considerably less flesh diffuse discolouration (which resulted in higher percentage of sound fruit) in fruit from trees on clonal 'Zutano', 'Duke 7' and 'Reed' compared to fruit from trees on clonal 'Velvick' (Table 78). Except for fruit from tress on clonal 'Velvick', overall quality was high. There were no rootstock effects on flesh rots or vascular leaching at eating ripe (Table 78).

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

At the Pemberton site there were no significant rootstock effects on flesh DM or fruit biochemical's (phenolics, catalase and peroxidase) in 'Hass' fruit (Table 79). Fruit from trees on 'Barr Duke' had the lowest Ca concentration and Ca+Mg/K ratio of all the rootstocks, and the highest K concentration and N/Ca ratio. Fruit from these trees also had the highest fruit N concentration, although this wasn't statistically significant. Fruit from trees on clonal 'Velvick' and clonal 'A10' had the highest fruit Ca concentrations and Ca+Mg/K ratios.

Correlations

In fruit ripened at 23°C, there were positive correlations between anthracnose/stem-end rot incidence and skin N or N/Ca ratios, as well as between % marketable fruit and skin Ca or Ca+Mg/Ca ratios (Table 80). There were negative correlations between anthracnose incidence and skin Ca, Ca+Mg/K ratios or tree yield, between stem-end rot incidence and skin Ca or Ca+Mg/K ratios, and between % marketable fruit and skin N, Ca or N/Ca ratios.

In fruit that had been cold stored, there were some correlations between the severity of flesh defects at eating ripe and skin minerals concentrations/ratios, skin colour and days to ripe (Table 80). A higher percentage of sound fruit was correlated with fruit that ripened quicker and had less skin Ca, but the correlations were relatively weak.

Table 77 Pemberton 2010 - Effects of clonal (C) rootstocks on days to eating-ripe, fruit flesh dry matter, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-A10	17.4	1.9	41.7	0.4	8.3	82.5 a
C-Duke 7	15.9	4.0	44.2	1.3	10.8	80.0 a
C-Velvick	16.3	3.7	47.2	1.0	10.9	77.2 a
C-Zutano	16.9	5.1	45.0	0.5	9.2	76.7 a
C-Reed	16.7	4.3	41.7	1.4	12.5	75.0 a
C-Barr Duke	15.4	9.5	68.9	1.1	14.7	51.1 b
P	***ns[5]***	***ns***	***ns***	***ns***	***ns***	***0.003***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 78 Pemberton 2010 - Effects of clonal rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rot	Stem-end rot	Diffuse discol.	Vascular leaching	
C-Zutano	5.9 abc	5.3 a	0.3	0.4	0.2 b	0.2	96 a
C-Duke 7	5.7 bc	5.2 a	0.1	0.6	0.5 b	0.2	94 a
C-Reed	6.2 a	5.4 a	0.7	0.3	1.0 b	0.1	94 a
C-Barr Duke	5.5 c	4.9 b	0.8	0.7	0.2 b	1.4	89 a
C-A 10	6.2 ab	5.3 a	0.7	0.3	4.3 ab	0.2	82 ab
C-Velvick	6.2 ab	5.4 a	1.0	0.5	7.4 a	1.2	69 b
P	***0.026***	***0.012***	***ns[3]***	***ns***	***0.025***	***ns***	***0.010***

1 Rootstocks listed in descending order of % sound fruit
2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 79 Pemberton 2010 - Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	29.5	1.00	0.110 a	0.127	1.27 bc	9.6 b	0.190 a	29.5	1.97	10.0
C-Barr Duke	28.8	1.15	0.060 c	0.115	1.73 a	22.2 a	0.103 c	28.8	3.33	5.4
C-Duke 7	28.1	1.05	0.075 bc	0.117	1.46 ab	14.5 b	0.139 bc	28.0	5.67	12.6
C-Reed	28.4	1.08	0.085 b	0.117	1.17 c	13.8 b	0.176 ab	28.4	3.74	13.9
C- Velvick	29.2	0.97	0.113 a	0.113	1.21 bc	8.9 b	0.194 a	29.2	2.21	11.7
C-Zutano	28.7	1.00	0.090 ab	0.125	1.25 bc	11.7 b	0.178 ab	28.7	2.55	11.9
P	***ns***[2]	***ns***	***<0.001***	***ns***	***0.002***	***0.015***	***0.002***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 80 Pemberton 2010: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
(Ca+Mg)/K	Anthracnose incidence	<0.001	0.75	-
(Ca+Mg)/K	% Marketable fruit	<0.001	0.67	+
N	% Marketable fruit	<0.001	0.64	-
N/Ca	% Marketable fruit	<0.001	0.61	-
Ca	% Marketable fruit	<0.001	0.58	+
Ca	Anthracnose incidence	<0.001	0.53	-
N/Ca	Stem-end rot incidence	0.001	0.52	+
N	Anthracnose incidence	0.002	0.5	+
N/Ca	Anthracnose incidence	0.003	0.48	+
Ca	Stem-end rot incidence	0.013	0.41	-
(Ca+Mg)/K	Stem-end rot incidence	0.014	0.41	-
N	Stem-end rot incidence	0.014	0.41	+
Tree yield	Anthracnose incidence	0.049	0.33	-
Fruit held at 5°C for 5 weeks and then ripened at 20°C				
Ca	Diffuse discolouration	<.001	0.58	+
N/Ca	Skin colour	<.001	0.56	-
N	Skin colour	0.001	0.49	-
(Ca+Mg)/K	Stem-end rot	0.002	0.48	-
K	Stem-end rot	0.002	0.48	+
Ca	Days to ripe	0.003	0.46	+
N	Stem-end rot	0.004	0.44	+
N/Ca	Vascular leaching	0.005	0.43	+
Ca	Stem-end rot	0.008	0.41	-
(Ca+Mg)/K	Diffuse discolouration	0.013	0.38	+
% of sound fruit	Ca	0.017	0.36	-
% of sound fruit	Days to ripe	0.017	0.36	-
Diffuse discolouration	N	0.019	0.36	-
K	Skin colour	0.024	0.34	-
(Ca+Mg)/K	Days to ripe	0.025	0.34	+
N	Vascular leaching	0.026	0.34	+
N/Ca	Stem-end rot	0.028	0.33	+
Ca	Skin colour	0.039	0.30	+

10.3.9 Pemberton WA (Hass) 2012

Fruit postharvest quality

'Hass' fruit harvested at the Pemberton site from trees on clonal 'Barr Duke' in 2012 had a significantly higher severity of anthracnose than fruit from trees on all other rootstocks (Table 81), and also had the highest incidence of anthracnose. Fruit from trees on clonal 'Duke 7' also performed quite poorly in terms of anthracnose. Fruit from trees on clonal 'A10' had the highest severity of stem-end rot but the lowest levels of anthracnose (Table 81). Fruit from trees on clonal 'Barr Duke' and 'Duke 7' had the lower % marketability and shortest ripening time compared to other rootstocks.

*Colletotrichum fioriniae (*previously known as *Colletotrichum acutatum*) caused approximately 91% of stem-end rot lesions at this site. Of the remaining stem-end rot lesions, approximately 6% were caused by *C. gloeosporioides*, 3% by *Fusarium* sp. and 1% by *Cladosporium* sp..

Fruit post-storage quality

Rootstocks significantly affected days to ripe and skin colour at ripe in fruit that had been cold stored, with fruit from trees on clonal 'Barr Duke' and 'Duke 7' showing the lowest skin colour ratings at the ripe stage and the shortest days to ripe (Table 82). There were no rootstock effects on the severity of body rot, stem-end rot or diffuse discolouration, although fruit from trees on clonal 'Barr Duke' and 'Duke 7' had the highest severity of vascular browning. Correspondingly, these fruit had the lowest % of sound fruit (Table 82).

Fruit flesh dry matter, skin minerals and fruit biochemical markers

At the Pemberton site in 2012, there were a number of significant rootstock effects on flesh DM, fruit skin nutrient levels and fruit biochemical's (phenolics, catalase and peroxidase) (Table 83). Fruit from trees on clonal 'Reed' had the lowest flesh DM, and those from trees on clonal 'A10', 'Barr Duke' and 'Zutano' had the highest DM. Fruit from trees on clonal 'Barr Duke' and 'Duke 7' had the highest skin K and N levels, as well as the lowest Ca+Mg/K ratios and the highest flesh catalase levels (Table 83). Peroxidase levels were also very high in fruit from trees on clonal 'Duke 7', 'A10' and 'Barr Duke'.

Correlations

In fruit ripened at 23°C, there were positive correlations between % marketable fruit and tree yield/yield efficiency/skin Ca+Mg/Ca ratios and skin phenolics (Table 84). There were also positive correlations between skin Ca+Mg/Ca ratios and tree yield/yield efficiency. Tree yield and yield efficiency negatively correlated with anthracnose incidence and severity.

In fruit that had been cold stored, fruit that ripened quicker were correlated less skin Ca and N, lower dry matter with there were significant correlations between skin minerals and days to ripe (Table 84). A higher % of sound fruit was correlated with less skin N and a lower skin N/Ca ratio, with fruit with less vascular browning was correlated with less N, more Ca and a higher (Ca+Mg)/K ratio (Table 84).

Table 81 Pemberton 2012: Effects of clonal (C) rootstocks on days to eating-ripe, fruit flesh dry matter, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-Reed	16.2 b	5.9 cd	47.5 cd	8.1 b	32.5	61.7 a
C-Velvick	16.0 b	3.5 d	42.5 cd	10.2 ab	34.2	57.5 a
C-A10	16.7 a	2.2 d	32.5 d	15.2 a	40.0	54.2 a
C-Zutano	15.4 c	9.0 c	54.2 bc	5.6 b	35.0	50.8 ab
C-Duke 7	14.8 d	16.8 b	71.7 ab	10.2 ab	55.0	31.7 b
C-Barr Duke	14.9 d	22.2 a	80.8 a	8.5 b	46.7	30.8 b
P	***<0.001***	***<0.001***	***<0.001***	***0.016***	***ns[5]***	***0.016***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot
5 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 82 Pemberton 2012: Effects of clonal rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' avocado fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rot	Stem-end rot	Diffuse discolour.	Vascular browning	
C-Velvick	4.3 b	5.0 a	0.1	0.8	0.3	2.1 c	94 a
C-A10	4.8 a	5.0 a	0.2	1.7	0.3	2.3 c	92 ab
C-Zutano	4.4 ab	4.9 a	0.3	1.4	0.2	3.4 bc	89 ab
C-Reed	4.3 b	4.9 a	0.2	1.8	0.6	3.6 bc	87 abc
C-Duke 7	4.2 b	4.7 b	0.6	2.7	0.3	7.5 ab	78 bc
C-Barr Duke	4.1 b	4.7 b	0.8	3.5	0.5	9.3 a	73 c
P	***0.029***	***<0.001***	***ns[3]***	***ns***	***ns***	***0.013***	***0.029***

1 Rootstocks listed in descending order of % sound fruit
2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant ($P > 0.05$)
Skin colour based on visual rating scale (1=green; 6=black).
Means in columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by LSD
Values in table are means of 120 fruit per rootstock (from six trees per rootstock)

Table 83 Pemberton 2012: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	29.8 [a]	1.05 [bc]	0.082	0.107	1.225 [b]	13.8	0.155 [a]	34.5 [b]	4.20 [c]	10.97
C-Barr Duke	28.9 [a]	1.13 [a]	0.058	0.110	1.502 [a]	20.1	0.113 [c]	37.1 [b]	13.23 [a]	17.55
C-Duke 7	28.4 [ab]	1.10 [ab]	0.067	0.117	1.507 [a]	16.6	0.123 [bc]	38.2 [b]	7.78 [b]	12.66
C-Reed	26.6 [b]	1.05 [bc]	0.075	0.112	1.280 [b]	14.6	0.147 [ab]	59.4 [a]	7.69 [bc]	12.68
C- Velvick	28.4 [ab]	0.98 [c]	0.075	0.105	1.362 [ab]	14.5	0.133 [abc]	55.6 [a]	8.17 [bc]	12.45
C-Zutano	28.9 [a]	1.03 [bc]	0.072	0.115	1.36 [ab]	15.2	0.140 [abc]	36.4 [b]	7.21 [bc]	5.97
P	***0.042***	***0.003***	***ns***	***ns***	***0.01***	***ns***	***0.035***	***<0.001***	***0.02***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 84 Pemberton 2012: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P-value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
K	Tree yield	<0.001	0.71	-
K	Yield efficiency	<0.001	0.60	-
% Marketable fruit	Mg	0.015	0.49	-
% Marketable fruit	N/Ca	0.051	0.48	-
Anthracnose incidence	Tree yield	0.002	0.48	-
(Ca+Mg)/K	Tree yield	0.003	0.46	+
Anthracnose severity	Tree yield	0.008	0.41	-
Anthracnose incidence	Yield efficiency	0.007	0.41	-
% Marketable fruit	Yield efficiency	0.011	0.39	+
% Marketable fruit	(Ca+Mg)/K	0.029	0.37	+
Mg	Yield efficiency	0.025	0.34	-
% Marketable fruit	Phenolics	0.051	0.33	+
(Ca+Mg)/K	Yield efficiency	0.028	0.33	+
% Marketable fruit	Tree yield	0.05	0.29	+
N	Yield efficiency	0.046	0.29	-
% Marketable fruit	K	0.002	0.29	-
% Marketable fruit	N	0.001	0.28	-
Anthracnose severity	Yield efficiency	0.059	0.27	-
Stem-end rot incidence	Yield efficiency	0.069	0.26	-
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Days to ripe	Ca	<0.001	0.56	+
Vascular browning	N	0.002	0.47	+
Days to ripe	(Ca+Mg)/K	0.003	0.46	+
Days to ripe	N/Ca	0.003	0.46	-
Vascular browning	(Ca+Mg)/K	0.001	0.42	-
Vascular browning	Ca	0.006	0.42	-
% sound fruit	N	0.014	0.38	-
Days to ripe	K	0.018	0.36	-
Days to ripe	Mg	0.019	0.36	-
% sound fruit	N/Ca	0.029	0.33	-
Stem-end rot	N/Ca	0.036	0.31	+

10.3.10 Walkamin QLD (Hass) 2010

Fruit postharvest quality

There were no significant rootstock effects on the severity or incidence of anthracnose or stem-end rot, or on the % marketable fruit in 'Hass' fruit harvested at the Walkamin site in 2010 (Table 85). Fruit from trees on clonal 'A8' and clonal 'A10' rootstocks took significantly longer to ripen at 23°C than fruit from trees on clonal 'Velvick' and clonal 'Duke 7' rootstocks.

The predominant causal agent of stem-end rot in 'Hass' fruit at the Walkamin site in 2010 was *Colletotrichum* sp., causing approximately 84% of lesions. *Fusarium* sp. caused the remaining 16% of stem-end rot lesions.

Fruit post-storage quality

Rootstocks significantly affected days to ripe, with a difference of almost two days between the fruit that took longest to ripen (from trees on clonal 'Reed' rootstock) and the shortest time to ripen (from trees on clonal 'Duke 7' rootstock) (Table 86). There were no significant differences between rootstocks for skin colour at ripe (data not shown). The average skin colour at ripe across all treatments was 5.5.

There were no significant differences between rootstocks for severity of body rots, stem-end rots, diffuse discolouration, vascular leaching, or the % of sound fruit at eating ripe. The main causes for the lower % of sound fruit were body rots, followed by stem-end rots and diffuse discolouration, but overall severity of flesh defects was low, resulting in high % of sound fruit across all rootstocks.

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

At the Walkamin site in 2010 there were no significant rootstock effects on flesh DM, skin nutrients or biochemical markers in Hass fruit (Table 87).

Correlations

In fruit ripened at 23°C, there were positive correlations between anthracnose incidence and skin N, skin Mg, skin K, skin N/Ca and flesh catalase (Table 88). All of these parameters also positively correlated with stem-end rot incidence, except for skin N. There were negative correlations between anthracnose/stem-end rot incidence and skin Ca/skin Ca+Mg/Ca ratios. Tree yield also negatively correlated with anthracnose incidence.

In fruit that had been cold stored, fruit with less body rots were correlated with more skin Ca, less skin K, a higher skin (Ca+Mg)/K ratio, and a lower skin N/Ca ratio (Table 88). Fruit from higher yielding trees were correlated with less body rot, less diffuse discolouration, and a higher % of sound fruit (Table 88).

Table 85 Walkamin 2010: Effects of clonal (C) rootstocks on days to eating-ripe, fruit flesh dry matter, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Fruit flesh dry matter at harvest (%)	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
			Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-Velvick	13.1 [bc]	28.8	11.1	51	0.4	7	66
C-A8	14.7 [a]	28.4	16.7	59	0.8	18	57
C-Reed	14.1 [abc]	27.3	17.4	53	2.8	21	55
C-A10	14.5 [a]	26.6	17.8	66	2.6	21	53
C-Zutano	14.4 [ab]	27.3	21.5	67	1.5	16	48
C-Duke 7	12.9 [c]	28.7	27.3	73	1.3	14	42
P	***0.034***	***ns***[5]	***ns***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area or flesh volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot
5 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference

Table 86 Walkamin 2010: Effects of clonal rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and % of sound 'Hass' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Severity (% of flesh volume affected)				% of sound fruit[2]
		Body rots	Stem-end rots	Diffuse discolouration	Vascular leaching	
C-A10	8.1 [bc]	0.8	0.2	0.4	0.0	96
C-A8	8.8 [ab]	2.8	1.7	1.0	0.1	86
C-Reed	9.4 [a]	2.7	1.2	1.2	0.2	86
C-Zutano	8.5 [b]	4.4	1.1	0.6	0.1	85
C-Velvick	8.3 [bc]	6.2	0.7	2.2	0.1	76
C-Duke 7	7.5 [c]	8.5	1.4	1.9	0.3	72
P	***0.003***	***ns***[3]	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % of sound fruit
2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant ($P > 0.05$)
Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference
Values in table are means of 120 fruit per rootstock

Table 87 Walkamin 2010: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A8	28.4	1.17	0.057	0.093	1.27	21.6	0.120	19.78	5.70	11.87
C-A10	26.6	1.15	0.062	0.096	1.43	18.8	0.111	20.73	5.42	11.97
C-Duke 7	28.7	1.13	0.063	0.096	1.55	20.0	0.107	21.10	5.06	9.17
C-Reed	27.3	1.10	0.065	0.089	1.33	18.2	0.119	20.97	4.18	7.56
C- Velvick	27.8	1.18	0.061	0.094	1.52	20.3	0.103	18.92	4.91	11.67
C-Zutano	27.3	1.08	0.056	0.092	1.42	20.8	0.107	21.28	5.79	13.17
P	***ns***[2]	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 88 Walkamin in 2010: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose incidence	Skin (Ca+Mg)/K	<0.001	0.57	-
Anthracnose incidence	Skin Ca	0.0014	0.53	-
Anthracnose incidence	Skin N/Ca	0.0026	0.51	+
Anthracnose incidence	Skin N	0.0105	0.44	+
Anthracnose incidence	Flesh peroxidase	0.0281	0.38	-
Fruit held at 5oC for 5 weeks and then ripened at 20°C.				
Body rot	(Ca+Mg)/K	<.001	0.53	-
Body rot	K	<.001	0.52	+
Days to ripe	K	0.001	0.51	-
Tree yield	Body rot	0.002	0.49	-
Days to ripe	(Ca+Mg)/K	0.003	0.47	+
Tree yield	Diffuse discolouration	0.01	0.40	-
Body rot	N/Ca	0.011	0.39	+
Tree yield	% sound fruit	0.011	0.39	+
% sound fruit	(Ca+Mg)/K	0.015	0.38	+
Yield efficiency	(Ca+Mg):K	0.015	0.38	+
Body rot	Ca	0.018	0.36	-
Days to ripe	N	0.018	0.36	-
Tree yield	Dry matter	0.018	0.36	-
Days to ripe	N/Ca	0.02	0.36	-
Yield efficiency	K	0.021	0.35	-
Body rot	N	0.029	0.33	+
Yield	(Ca+Mg)/K	0.037	0.31	+

10.3.11 Walkamin QLD (Hass) 2011

Fruit postharvest quality

At the Walkamin field site in 2011, there were no significant rootstock effects on fruit ripening time, anthracnose incidence and severity, stem-end rot severity, or marketability of 'Hass' avocado fruit ripened at 23°C without a cold storage period (Table 89). Fruit from trees on cloned 'Velvick' and 'Duke 7' rootstocks however did have a significantly higher incidence of stem-end rot than those from trees on cloned 'Reed'. Stem-end rot was caused predominantly by *Lasiodiplodia theobromae/Botryosphaeria* spp (47%) and *Colletotrichum* sp. (43%) in this trial. A range of other pathogens also caused stem-end rot including *Fusarium* sp. (5%) *Phomopsis* sp. (3%), *Pestalotiopsis* sp. (1%) and *Cladosporium* sp. (1%).

Fruit post-storage quality

Fruit from trees on clonal 'Velvick' and 'Duke 7' rootstocks ripened quicker than fruit from trees on the other rootstocks, although the differences were less than a day (Table 90). At eating ripe, the percentage of sound fruit (those with a 10% or less of the flesh affected by all defects combined) was higher in fruit from trees on clonal 'A8', 'A10', and 'Reed' compared to fruit from trees on clonal 'Velvick' and 'Duke 7' rootstocks (Table 90). The main causes of quality loss were body rots, diffuse discolouration and vascular leaching. Rootstock effects on stem-end rots were not significant (Table 90).

Fruit dry matter, skin minerals and biochemical markers

There were no significant effects of rootstock on flesh dry matter, skin N, skin Ca, skin Mg, N/Ca ratio, (Ca+Mg)/K ratio or skin phenolics in 'Hass' avocado fruit at the Walkamin field site in 2011 (Table 91). Fruit from trees on clonal 'Velvick' had significantly higher skin K levels than those from trees on clonal 'A10' and clonal 'Zutano'.

Correlations

The only significant correlations found in fruit ripened at 23°C were those between stem-end rot incidence and skin K (positive correlation) and those between fruit marketability and skin K (negative correlation) (Table 92).

In fruit that had been cold stored, a higher percentage of sound fruit was correlated with fruit that ripened quicker and had less skin K and N (Table 92). Fruit that ripened quicker was also correlated with less severe diffuse discolouration and body rots. Fruit with less severe diffuse discolouration, vascular leaching and body rots were correlated to less skin K and N and more skin Ca. Fruit from trees with higher yield or yield efficiency were correlated with less body rots and diffuse discolouration. There were also some correlations between days to ripe and skin K, N, and Ca (Table 92). However, in general the correlations were relatively weak (r values between 0.30-0.55).

Table 89 Walkamin 2011: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-A10	15.5	11.1	60.8	6.8	28.1 [abc]	57.7
C-A8	15.0	13.9	64.7	5.2	21.6 [bc]	55.7
C-Zutano	15.0	21.0	69.5	5.3	29.4 [abc]	46.9
C-Reed	13.8	24.6	68.5	3.5	17.8 [c]	39.8
C-Velvick	13.6	24.6	75.9	12.0	46.2 [a]	27.0
C-Duke 7	12.8	33.3	86.0	5.2	39.5 [ab]	25.9
P	***ns***[5]	***ns***	***ns***	***ns***	***0.03***	***ns***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area/volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Table 90 Walkamin 2011: Effects of clonal rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and the % of sound 'Hass' avocado fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Severity (% of flesh volume affected)				% sound fruit[2]
		Body rot	Stem-end rot	Diffuse discolouration	Vascular leaching	
A8	6.7 [a]	0.8 [d]	0.1	3.1 [b]	0.9 [b]	93 [a]
A10	6.8 [a]	3.3 [cd]	0.0	2.4 [b]	2.8 [b]	86 [a]
Reed	6.7 [a]	3.8 [bc]	0.1	2.8 [b]	2.3 [b]	84 [a]
Zutano	6.9 [a]	2.9 [cd]	0.3	3.0 [b]	2.7 [b]	81 [ab]
Velvick	6.1 [b]	6.5 [ab]	0.3	5.0 [b]	3.2 [b]	60 [bc]
Duke 7	6.3 [b]	7.8 [a]	0.4	11.0 [a]	6.6 [a]	47 [c]
P	***<.001***	***<.001***	***ns***[3]	***<.001***	***0.002***	***0.002***

1 Rootstocks listed in descending order of % sound fruit.
2 Sound fruit = fruit with 10% or less of flesh volume affected by all flesh defects combined.
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference.
Values in table are means of 96 fruit per rootstock.

Table 91 Walkamin 2011: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	**Ca**	**Mg**	**K**	**N/Ca ratio**	**Ca+Mg/K ratio**			
C-A8	27.11	1.03	0.042	0.095	1.37 abc	28.8	0.103	19.78	2.95	10.63
C-A10	26.66	1.03	0.042	0.093	1.34 bc	24.9	0.105	20.73	3.21	12.00
C-Duke 7	27.89	1.12	0.033	0.093	1.50 ab	34.2	0.088	21.10	4.31	10.76
C-Reed	27.54	1.12	0.040	0.097	1.60 ab	30.6	0.086	20.97	2.87	8.50
C- Velvick	27.43	1.07	0.032	0.093	1.63 a	34.0	0.078	18.92	3.75	10.14
C-Zutano	26.93	1.00	0.032	0.090	1.20 c	34.4	0.102	21.28	3.08	10.30
P	***ns*[2]**	***ns***	***ns***	***ns***	***0.018***	***ns***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 92 Walkamin in 2011: Significant correlations between various parameters in 'Hass' avocado fruit harvested from

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Stem-end rot incidence	K	0.017	0.36	+
% Marketable fruit	K	0.013	0.38	-
Fruit held at 5oC for 5 weeks and then ripened at 20°C.				
Diffuse discolouration	Days to ripe	<.001	0.55	-
% of sound fruit	Days to ripe	<.001	0.53	+
Days to ripe	K	0.002	0.48	-
% of sound fruit	K	0.003	0.47	-
Days to ripe	N	0.004	0.45	-
Vascular leaching	N	0.006	0.43	+
% of sound fruit	N	0.006	0.43	-
Body Rot	K	0.007	0.42	+
Body rot	Days to ripe	0.009	0.41	-
Vascular leaching	K	0.010	0.40	+
Diffuse discolouration	K	0.012	0.39	+
Diffuse discolouration	N	0.012	0.39	+
Body Rot	N	0.016	0.37	+
Diffuse discolouration	Ca	0.017	0.37	-
Days to ripe	Ca	0.018	0.36	+
Vascular leaching	Ca	0.027	0.34	-
Body Rot	Yield efficiency	0.038	0.31	-
Diffuse discolouration	Tree yield	0.046	0.30	-

10.3.12 Walkamin QLD (Hass) 2012

Fruit postharvest quality

At the Walkamin field site in 2012, there were no significant rootstock effects on fruit ripening time, anthracnose incidence and severity, or stem-end rot severity in 'Hass' avocado fruit ripened at 23°C without a cold storage period (Table 93). Fruit from trees on clonal 'Duke 7' however did have a significantly higher incidence of stem-end rot and lower % marketability than those from trees on all rootstocks except for clonal 'Velvick' (Table 93).

Stem-end rot was caused by *Lasiodiplodia theobromae/Botryosphaeria* spp (33%), *Colletotrichum* sp. (29%) and *Fusarium* sp. (27%) in this trial.

Fruit post-storage quality

After removal from storage at 5°C for four weeks, rootstocks did not significantly affect fruit ripening (days to ripe at 20°C), fruit skin colour, nor the severity of body rots and diffuse discolouration at eating ripe (Table 94). Likewise the severity of stem-end rots or other internal disorders (vascular browning, vascular leaching, seed cavity browning, and tissue breakdown) at eating ripe (data not shown). Overall fruit quality was excellent, with little incidence of flesh diseases or internal disorders. As a result, the percentage of sound fruit (those with a severity rating of 10% or less of the flesh affected by all flesh defects combined) was very high and not significantly affected by rootstocks (Table 94).

Fruit dry matter, skin minerals and biochemical markers

There were no significant effects of rootstock on flesh dry matter, skin nutrients or skin phenolic levels in 'Hass' avocado fruit at the Walkamin field site in 2012 (Table 95). Fruit from trees on clonal 'Duke 7' did however have significantly higher catalase and peroxidase levels than those from trees on all rootstocks except for clonal 'A10' (Table 95).

Correlations

In fruit ripened at 23°C, there were positive correlations between anthracnose incidence/severity and skin N, skin N/Ca, skin K, flesh DM and flesh catalase levels (Table 96). There were negative correlations between anthracnose incidence/severity and skin Ca, skin Ca+Mg/Ca ratios, skin phenolics, and days to eating-ripe. Anthracnose severity and stem-end rot incidence/severity negatively correlated with % marketability, as did anthracnose incidence with flesh peroxidase levels (Table 96).

In fruit that had been cold stored, fruit that ripened quicker were correlated with those with less diffuse discolouration, less skin Ca and K, and lower yield (Table 96). Fruit from high yielding trees were correlated with fruit with lower % DM, less diffuse discolouration and less body rot (Table 96).

Table 93 Walkamin 2012: Effects of clonal (C) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Hass' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-A10	17.4	1.11	15.0	0.61	6.7 [bc]	90.8 [a]
C-Zutano	17.0	2.95	28.3	0.67	4.2 [c]	87.5 [ab]
C-Reed	16.7	2.34	26.7	1.38	9.2 [bc]	83.3 [ab]
C-A8	17.1	3.68	22.5	0.65	5.8 [bc]	83.3 [ab]
C-Velvick	16.3	8.16	34.2	1.23	15.8 [ab]	70.8 [bc]
C-Duke 7	17.0	6.34	49.2	3.36	24.2 [a]	60.0 [c]
P	***ns*[5]**	***ns***	***ns***	***ns***	***0.006***	***0.012***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area/volume affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot
5 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Table 94 Walkamin 2012: Effects of clonal rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and the % of sound 'Hass' avocado fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Skin colour (1-6)	Severity (% of flesh volume affected)		% sound fruit[2]
			Body rot (%)	Diffuse discolour. (%)	
A8	7.5	5.2	0.0	0.0	100
Zutano	7.7	5.2	0.2	0.0	99
A10	7.6	5.4	0.7	0.0	98
Duke-7	7.5	5.2	1.0	0.0	97
Velvick	7.2	5.3	1.6	0.1	95
Reed	*7.6*	5.4	1.4	0.3	92
P	***ns*[3]**	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % sound fruit
2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant (P > 0.05)
Skin colour based on visual rating scale (1 = green; 6=black).
Means in columns without letters are not significantly different (P ≤ 0.05) as tested by LSD.
Values in table are means of 120 fruit per rootstock (from six trees per rootstock)

Table 95 Walkamin 2012: Effects of clonal (C) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Hass' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A8	25.7	1.07	0.058	0.087	1.19	18.5	0.123	22.61	3.89 [cd]	18.13 [a]
C-A10	24.8	1.10	0.072	0.090	1.30	15.8	0.128	23.65	3.72 [d]	16.57 [ab]
C-Duke 7	24.5	1.23	0.053	0.088	1.35	24.4	0.107	19.79	4.24 [abc]	15.64 [b]
C-Reed	25.5	1.05	0.067	0.083	1.33	17.5	0.119	22.71	4.52 [ab]	18.13 [a]
C- Velvick	26.1	1.20	0.062	0.083	1.55	21.0	0.096	17.49	4.86 [a]	17.83 [a]
C-Zutano	24.9	1.03	0.065	0.082	1.28	16.3	0.117	20.41	4.00 [bcd]	17.14 [ab]
P	***ns*[2]**	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***0.003***	***0.026***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 96 Walkamin in 2012: Significant correlations between various parameters in 'Hass' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose incidence	Phenolics	0.0121	0.42	-
Stem-end rot incidence	Tree yield	<0.001	0.38	-
Stem-end rot incidence	Yield efficiency	<0.001	0.36	-
Stem-end rot incidence	Ca	0.0048	0.27	-
Stem-end rot incidence	N/Ca	0.011	0.25	+
Anthracnose incidence	N	0.0279	0.21	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C				
Days to ripe	Diffuse discolouration	<.001	0.50	+
Yield efficiency	Dry matter	<.001	0.30	-
Tree yield	Dry matter	<.001	0.30	-
Fruit weight	(Ca+Mg)/K	0.003	0.27	-
Tree yield	Days to ripe	0.003	0.27	-
Days to ripe	Ca	0.005	0.25	+
Days to ripe	K	0.005	0.25	+
Tree yield	Body rot	0.006	0.25	-
Tree yield	Diffuse discolouration	0.006	0.25	-
Dry matter	Diffuse discolouration	0.005	0.25	+

10.3.13 Walkamin QLD (‘Shepard’) 2009

Fruit postharvest quality

Side anthracnose levels were very high in ‘Shepard’ fruit at Walkamin, but there were no significant rootstock effects on anthracnose severity (Table 97). For the incidence of side anthracnose however, fruit from trees on seedling ‘A10’, clonal ‘A10’, seedling ‘SHSR-03’ and seedling ‘Duke 7’ showed the lowest values for anthracnose incidence, and those on clonal Thomas showed the highest values. There were no significant rootstock effects on stem-end rot incidence or severity, which was caused predominantly (65%) by the anthracnose pathogen (*Colletotrichum* sp.) in this trial. Other causal agents of stem-end rot in this trial were *Lasiodiplodia theobromae* (18%), *Pestalotiopsis* sp. (6%), *Fusarium* sp. (6%), *Cladosporium* sp. (3%) and *Phomopsis* sp. (3%). There were also no significant rootstock effects on % marketable fruit. Seedling ‘Velvick’ fruit took significantly longer to ripen than clonal ‘A10’, seedling ‘SHSR-03’, clonal ‘SHSR-03’ and seedling ‘SHSR-02’ fruit (Table 97).

Fruit post-storage quality

Rootstocks did not significantly affect days to ripen or the percentage of fruit skin blackening (an indication of chilling injury) at ripe (Table 98). The ratings for skin blackening were consistently high for all rootstocks, suggesting that the storage temperature of 5^oC, without any pre-conditioning treatment at higher temperatures, may have been too low for ‘Shepard’ fruit.

The severity of body rots and vascular leaching was significantly affected by rootstocks, with lower severity for fruit from trees on seedling ‘Duke 7’ and higher for fruit from trees on clonal ‘Thomas’ for both defects (Table 98). There were no significant differences between rootstocks for severity of stem-end rots and diffuse discolouration. The % of sound fruit at eating ripe was affected by rootstocks, mainly as a result of the rootstock differences in body rots and vascular leaching, which were major causes of the reduced % of sound fruit, together with diffuse discolouration. In general, fruit from trees on seedling rootstocks had the highest % of sound fruit compared to the fruit from trees on clonal rootstocks.

Fruit flesh dry matter, skin minerals and fruit biochemical markers

There were no significant effects of rootstocks on flesh DM at harvest at the Walkamin site (Table 99). Skin N levels were highest in fruit from trees on seedling and clonal ‘Velvick’, clonal ‘Thomas’, clonal ‘Shepard’ and clonal ‘SHSR-03’, and lowest in fruit from trees on seedling and clonal ‘A10’, seedling ‘Duke 7’ and seedling ‘SHSR-03’ (Table 99). Rootstock effects on skin N/Ca ratios showed a similar pattern. Clonal ‘Shepard’, ‘Velvick’ and ‘Thomas’ and seedling ‘Duke 7’ and ‘Velvick’ showed the highest skin Mg levels, with clonal and seedling ‘A10’ and clonal ‘SHSR-03’ showing the lowest levels. Seedling ‘Velvick’ and all clonal rootstocks except for ‘A10’ showed the highest skin K levels, and the highest skin Ca+Mg/K ratios were seen in clonal and seedling ‘A10’, seedling ‘Duke 7’ and seedling ‘SHSR-03’. There were no significant effects of rootstocks on fruit skin phenolics (Table 99).

Correlations

In fruit ripened at 23°C, positive correlations were found between anthracnose severity and: skin N levels, skin N/Ca ratios, anthracnose incidence and flesh DM (Table 100). A positive correlation was also found between stem-end rot severity and skin N levels. A negative correlation was found between stem-end rot severity and skin phenolic levels at harvest. It should be noted that at this site, values for stem-end rot included stem-end anthracnose, and that most of the stem-end rot (65%) was in fact stem-end anthracnose.

In ripe fruit that had been cold stored, the % of sound fruit was negatively correlated with skin N, Mg and K concentrations, and positively correlated with skin Ca concentration tree yield (Table 100). The severity of diffuse discolouration and body rot was negatively correlated with skin K and N concentrations. Tree yield was negatively correlated with skin K concentration and the severity of body rot. The severity of black skin was positively correlated with skin N (Table 100).

Table 97 Walkamin 2009: Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Shepard' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot[5]		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% fruit surface area)	Incidence (% fruit affected)	
C-A10	13.4 ab	25.2	79 bcd	0.5	12	49
S-A10	13.0 abcd	31.2	75 d	1.0	17	48
S-SHSR-03	13.3 ab	32.0	77 cd	0.7	16	47
S-Duke 7	13.1 abcd	29.2	78 cd	0.9	19	43
C-Shepard	12.8 bcd	34.4	88 abc	0.8	19	40
C-SHSR-03	13.2 abc	31.4	92 ab	1.2	17	37
C-Velvick	12.9 abcd	38.7	89 abc	0.8	20	36
S-SHSR-02	13.4 a	38.5	85 abcd	1.4	28	34
S-Velvick	12.6 d	40.0	90 abc	1.4	25	33
C-Thomas	12.6 cd	46.3	95 a	1.6	25	24
P	***0.043***	***ns[6]***	***0.025***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤ 5% anthracnose severity and no stem-end rot; 5 Includes stem-end anthracnose in this trial ; 6 ns = not significant (P > 0.05); Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Table 98 Walkamin 2009: Effects of clonal (C) and seedling (S) rootstocks on days to ripe, % of skin with blackening, severity of flesh defects (% of flesh volume affected), and % of sound 'Shepard' fruit held at 5°C for 5 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe	Skin blackening (%)	Severity (% of flesh volume affected)				% of sound fruit[2]
			Body rots	Stem-end rots	Diffuse discol.	Vascular leaching	
S-Duke 7	6.1	71	5.0 c	0.7	2.8	0.6 d	72 a
S-SHSR-03	6.9	71	5.8 bc	0.6	4.8	1.8 cd	61 ab
S-SHSR-02	6.8	76	8.2 bc	1.1	4.6	2.3 bcd	53 abc
S-Velvick	6.4	75	7.5 bc	0.9	4.6	2.3 bcd	49 bcd
S-A10	7.2	69	7.3 bc	0.7	7.5	1.8 cd	49 bcd
C-Velvick	6.7	74	7.5 bc	0.5	7.2	3.6 abc	48 bcd
C-A10	6.7	76	7.3 bc	0.5	5.5	3.1 abcd	46 bcd
C-SHSR-03	6.8	82	9.1 ab	1.4	4.4	5.8 a	37 cd
C-Shepard	6.9	73	8.8 abc	0.7	7.1	4.9 ab	31 cd
C-Thomas	6.4	82	12.6 a	0.7	8.8	5.3 a	28 d
P	***ns[3]***	***ns***	***0.029***	***ns***	***ns***	***0.003***	***0.005***

1 Rootstocks listed in descending order of % of sound fruit
2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 200 fruit per rootstock

Table 99 Walkamin 2009: Effects of clonal (C) and seedling (S) rootstocks on fruit flesh dry matter (%), and on fruit skin minerals (% dry weight) and phenolics (gallic acid equivalent/g fresh weight) concentrations in 'Shepard' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics concentration (gallic acid equivalents/ g fresh weight)		
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio	Harvest	Sprung	Eating-ripe
C-A10	23.2	1.04 c	0.105	0.095 cd	1.63 cde	10.1 bc	0.123 abc	14.1	17.6	ND
C-Shepard	24.4	1.14 abc	0.086	0.106 ab	1.99 a	13.6 a	0.098 d	12.5	16.6	ND
C- SHSR-03	22.1	1.10 abc	0.092	0.091 d	1.82 abcd	12.2 abc	0.101 cd	9.8	15.9	ND
C-Velvick	25.7	1.12 abc	0.097	0.104 abc	1.97 a	11.9 abc	0.107 bcd	12.2	15.9	ND
C-Thomas	24.1	1.20 ab	0.100	0.108 a	1.94 ab	12.3 ab	0.109 bcd	9.8	14.6	ND
S-A10	24.3	1.05 c	0.097	0.093 cd	1.56 de	11.2 abc	0.126 ab	ND[2]	ND	ND
S-Duke 7	23.4	1.06 c	0.110	0.096 abcd	1.52 e	10.4 bc	0.141 a	ND	ND	ND
S-SHSR-02	24.3	1.10 bc	0.094	0.096 bcd	1.68 bcde	11.9 abc	0.116 bcd	ND	ND	ND
S-SHSR-03	23.5	1.05 c	0.113	0.094 bcd	1.55 de	9.8 c	0.139 a	ND	ND	ND
S-Velvick	24.8	1.22 a	0.094	0.106 ab	1.87 abc	13.5 a	0.108 bcd	ND	ND	ND
P	***ns*[3] *(0.058)***	***0.039***	***ns (0.065)***	***0.023***	***0.001***	***0.045***	***<0.001***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order

2 ND=not done (only clonal rootstocks analysed for phenolics; eating-ripe phenolics sample not taken due to high disease levels)

3 ns = not significant (P > 0.05)

Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference

Values in table are means of 50 fruit per rootstock except for phenolics (25 fruit per rootstock)

Table 100 Walkamin 2009: Significant correlations between various parameters in 'Shepard' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23°C				
Anthracnose severity	Dry matter	<0.001	0.47	+
Stem-end rot severity	Phenolics (at harvest)	0.016	0.45	-
Anthracnose severity	Skin N	0.001	0.38	+
Anthracnose severity	Skin N/Ca	0.009	0.25	+
Stem-end rot severity	Skin N	0.012	0.24	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Diffuse discolouration	K	0.004	0.43	-
Body Rot	K	0.005	0.42	-
% sound fruit	K	0.005	0.42	-
Body Rot	N	0.009	0.39	-
% Black skin	N	0.011	0.38	+
Diffuse discolouration	Mg	0.011	0.38	-
Tree Yield	K	0.013	0.36	-
% sound fruit	N	0.019	0.34	-
Dry Matter	N	0.016	0.34	+
% sound fruit	Mg	0.029	0.32	-
Diffuse discolouration	N	0.037	0.30	-
Tree yield	% sound fruit	0.039	0.30	+
Tree yield	Body rot	0.042	0.29	-

10.3.14 Walkamin QLD ('Shepard') 2010

Fruit postharvest quality

Fruit harvested from 'Shepard' trees grafted to clonal 'Thomas' rootstock had a significantly higher severity of stem-end rot than fruit from trees on all other rootstocks, except for clonal 'SHSR-03' (Table 101). Stem-end rot was caused predominantly (84%) by the anthracnose pathogen (*Colletotrichum* sp.) in this trial. Other causal agents of stem-end rot in this trial were *Phomopsis* sp. (5%) *Lasiodiplodia theobromae* (4%), *Fusarium* sp. (4%) and *Cladosporium* sp. (2%).

There were no significant rootstock effects on anthracnose severity/incidence, stem-end rot incidence and % marketable fruit.

Fruit from trees on clonal 'A10', seedling 'Velvick' and seedling 'SHSR-03' fruit took significantly longer to ripen than fruit from trees on clonal 'Duke 7', seedling 'Duke 7' and clonal 'Shepard' (Table 101).

Fruit post-storage quality

Rootstocks significantly affected days to ripe of 'Shepard' fruit, with differences of up to 1.3 days between the fruit that took longest to ripen (from trees on clonal 'A10' rootstock) and the shortest time to ripen (from trees on clonal 'Duke 7' rootstock) (Table 102).

There were no significant differences among rootstocks for percentage of discrete patches on the skin of ripe 'Shepard' fruit (an indication of chilling damage, data not shown). The average severity of discrete patches across all rootstocks was 26% of skin surface area affected.
There were no significant differences among rootstocks for severity of body rots, stem-end rots, diffuse discolouration, vascular leaching, or % of sound fruit at eating ripe. The main causes for the reduced % of sound fruit were body rots and vascular leaching, followed by diffuse discolouration, but overall severity of flesh defects was very low, resulting in high percentages of sound fruit across all rootstocks.

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

There were significant rootstock effects on fruit DM at harvest (Table 103), with a difference of up to 2.6% between the more mature fruit (from trees on seedling 'A10' and 'Duke 7' rootstocks) and the less mature fruit (from trees on clonal 'Thomas' rootstock). There were also no significant rootstock effects on concentrations of biochemical markers (catalase, peroxidase and phenolics) (Table 103).

Skin Ca and Ca+Mg/K ratios were highest in fruit from trees on clonal 'Velvick', and lowest in fruit from trees on seedling 'SHSR-02' (Table 103). Correspondingly, N/Ca ratios were highest in fruit from trees on seedling 'SHSR-02' and lowest in fruit from trees on clonal 'Velvick'.

Correlations

In fruit ripened at 23°C, there were significant correlations between the incidence of anthracnose and all of the nutrients tested (Table 104). Correlations were positive for all nutrients except Ca, which as always showed a negative relationship with anthracnose. The incidence of stem-end rot in 'Shepard' fruit at this site also correlated significantly with all nutrients except N, although there was a positive correlation with N/Ca ratios in skin.

There were also significant positive correlations between flesh catalase levels and the incidence of anthracnose in fruit ripened at 23°C, and a significant negative correlation between yield and the incidence of anthracnose (Table 104).

In fruit that had been cold stored, those from high yielding trees correlated with lower dry matter, longer ripening time and higher skin K concentration (Table 104). Fruit that took longer to ripe were correlated with higher skin Ca and lower skin Mg concentration concentrations, and with higher skin (Ca+Mg)/K ratio and with lower skin N/Ca ratio. Lower severity of black skin (a type of chilling injury) was correlated with lower concentration of skin K and Mg concentrations, a higher skin (Ca+Mg)/K ratio and with lower skin N concentration.

Table 101 Walkamin 2010: Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Shepard' avocado fruit ripened at 23°C.

Rootstock[1]	Days to eating-ripe	Side anthracnose		Stem-end rot		Marketable fruit (%)[4]
		Severity[2] (% fruit surface area)	Incidence[3] (% fruit affected)	Severity (% flesh volume)	Incidence (% fruit affected)	
C-A10	14.4 [a]	8.1	62	0.9 [b]	21	69
S-Velvick	14.4 [a]	6.7	54	1.3 [b]	25	69
C-Velvick	14.1 [ab]	5.1	57	0.8 [b]	22	68
S-SHSR-03	14.6 [a]	7.1	50	1.2 [b]	28	65
C-Shepard	13.5 [bc]	11.1	64	1.0 [b]	25	59
S-SHSR-02	14.1 [ab]	9.5	63	1.3 [b]	27	58
S-Duke 7	13.7 [bc]	10.9	76	1.9 [b]	34	55
S-A10	13.9 [ab]	13.9	67	1.9 [b]	31	51
C-SHSR-03	14.0 [ab]	14.9	67	2.2 [ab]	34	51
C-Duke 7	13.0 [c]	21.4	58	1.6 [b]	24	50
C-Thomas	14.1 [ab]	18.9	86	3.4 [a]	53	35
P	***0.002***	***ns[5]***	***ns***	***0.027***	***ns***	***ns***

1 Rootstocks listed in descending order of % marketable fruit. 2 Severity = average % of ripe fruit flesh surface area affected by each disease. 3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment. 4 Marketable fruit = % of ripe fruit with ≤5% anthracnose severity and no stem-end rot. 5 ns = not significant ($P > 0.05$). Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference.

Table 102 Walkamin 2010: Effects of clonal (C) and seedling (S) rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and % of sound 'Shepard' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	Severity (% of flesh volume affected)				% of sound fruit[2]
		Body rots	Stem-end rots	Diffuse discolouration	Vascular leaching	
C-Duke7	5.7 [c]	0.6	0.1	0.1	0.4	99
S-SHSR-03	6.8 [ab]	0.3	0.0	0.0	0.5	99
S-Duke7	6.3 [b]	0.6	0.0	0.2	0.5	98
S-SHSR-02	6.5 [ab]	0.8	0.1	0.1	1.2	96
C-Thomas	6.6 [ab]	1.1	0.1	0.2	0.6	95
C-A10	7.0 [a]	1.0	0.2	0.3	0.9	95
S-A10	6.6 [ab]	0.6	0.2	0.8	0.5	94
C-Velvick	6.9 [a]	0.8	0.3	0.1	1.1	93
S-Velvick	6.7 [ab]	1.0	0.1	0.0	4.7	93
C-Shepard	6.5 [ab]	0.6	0.1	0.7	1.5	92
C-SHSR-03	6.6 [ab]	0.9	0.2	1.8	4.3	84
P	***0.004***	***ns[3]***	***ns***	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % of sound fruit. 2 Sound fruit = % of ripe fruit with a severity rating of 10% or less for all defects combined. 3 ns = not significant ($P > 0.05$). Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) as tested by least significant difference. Values in table are means of 200 fruit per rootstock.

Table 103 Walkamin 2010: Effects of seedling (S) and clonal (C) rootstocks on fruit flesh dry matter, and on skin minerals and fruit biochemical markers in 'Shepard' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	24.1 abc	0.94	0.112 ab	0.0803 bc	1.38	9.16 bc	0.152 ab	12.06	5.75	13.56
C-Duke 7	23.0 cd	1.04	0.085 de	0.0898 a	1.78	12.26 abc	0.101 d	10.59	4.40	9.97
C-Shepard	23.4 abcd	0.96	0.083 de	0.0931 a	1.60	12.32 ab	0.114 cd	10.96	5.03	13.34
C-SHSR-03	23.2 bcd	0.98	0.098 bcd	0.0878 ab	1.64	10.36 bc	0.118 cd	9.70	4.61	12.22
C- Thomas	23.2 bcd	1.02	0.087 de	0.0868 ab	1.50	11.93 bc	0.118 cd	13.31	5.65	13.68
C-Velvick	23.2 bcd	0.98	0.117 a	0.0815 bc	1.34	8.93 c	0.155 a	11.21	5.54	13.31
S-A10	24.7 a	0.89	0.084 de	0.076 cde	1.43	11.41 bc	0.124 bcd	ND[3]	ND	ND
S-Duke 7	24.7 a	0.99	0.089 de	0.0747 cde	1.45	11.38 bc	0.125 bcd	ND	ND	ND
S-SHSR-02	23.9 abc	1.11	0.074 e	0.0781 cd	1.52	15.40 a	0.107 d	ND	ND	ND
S-SHSR-03	24.5 ab	0.93	0.107 abc	0.0697 e	1.28	9.17 bc	0.141 abc	ND	ND	ND
S-Velvick	22.1 d	0.98	0.091 cd	0.0714 de	1.28	10.96 bc	0.130 abcd	ND	ND	ND
P	***0.007***	***ns[2]***	***<0.001***	***<0.001***	***ns***	***0.01***	***0.006***	***ns***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
3 ND = not done (only done on clonal rootstocks)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Table 104 Walkamin 2010: Significant correlations between various parameters in 'Shepard' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23oC.				
Anthracnose incidence	N	<0.001	0.32	+
Anthracnose incidence	Ca	<0.001	0.39	-
Anthracnose incidence	Mg	<0.001	0.46	+
Anthracnose incidence	K	<0.001	0.60	+
Anthracnose incidence	N/Ca	<0.001	0.45	+
Anthracnose incidence	(Ca+Mg)/K	<0.001	0.55	-
Anthracnose incidence	Flesh catalase	0.0039	0.54	+
Anthracnose incidence	Total yield	<0.001	0.45	-
Stem-end rot incidence	Ca	0.0029	0.29	-
Stem-end rot incidence	Mg	0.0255	0.22	+
Stem-end rot incidence	K	<0.001	0.32	+
Stem-end rot incidence	N/Ca	0.0186	0.23	+
Stem-end rot incidence	(Ca+Mg)/K	<0.001	0.37	-
Stem-end rot incidence	Flesh catalase	0.0174	0.45	+
Fruit held at 5°C for 5 weeks and then ripened at 20°C.				
Tree yield	Dry matter	<.001	0.59	-
Days to ripe	(Ca+Mg)/K	<.001	0.53	+
Days to ripe	K	<.001	0.53	-
Tree yield	Days to ripe	<.001	0.50	+
Dry matter	K	<.001	0.48	+
Black skin	K	<.001	0.47	+
Days to ripe	Ca	<.001	0.46	+
Black skin	Mg	<.001	0.43	+
Tree yield	K	<.001	0.42	-
Days to ripe	N/Ca	<.001	0.41	-
Days to ripe	Mg	<.001	0.41	-
Black skin	(Ca+Mg):K	<.001	0.37	-
Black skin	N	<.001	0.32	+

10.3.15 Walkamin QLD ('Shepard') 2011

Fruit postharvest quality

Fruit harvested from 'Shepard' trees grafted to clonal 'Thomas' rootstock had a significantly higher severity of anthracnose than fruit from trees on all other rootstocks (Table 105). Fruit from trees on clonal 'Duke 7' also had a significantly higher severity of anthracnose than those from trees on all but one of the seedling rootstocks (i.e. seedling 'Duke 7'). A similar pattern was seen in regard to the incidence of anthracnose. The lowest levels of anthracnose overall were seen in fruit from trees on seedling 'Velvick', 'SHSR-03' and 'A10' (Table 105).

Fruit from trees on clonal 'Thomas' and seedling 'Duke 7' had the highest incidence of stem-end rot, while those from trees on clonal 'A10' had the lowest incidence of stem-end rot (Table 105). Stem-end rot severity was highest in fruit from trees on seedling 'SHSR-02', and lowest in those from trees on clonal 'Shepard'. Stem-end rot was caused predominantly (58%) by the anthracnose pathogen (*Colletotrichum* sp.) in this trial. A range of other pathogens caused stem-end rot including *Botryosphaeria* spp./*Lasiodiplodia theobromae* (14%), *Phomopsis* sp. (13%), *Fusarium* sp. (3%) and *Pestalotiopsis* sp. (3%).

The least marketable fruit in this trial were those from trees on clonal 'Thomas' (24%), 'clonal Duke 7' (38%) and seedling 'Duke 7' (40%) (Table 105). Fruit from trees on clonal 'A10' were the most marketable fruit (65%). Fruit from trees on clonal 'Thomas' took the shortest time to ripen (14.5 d), whereas those from trees on seedling 'A10' took the longest time to ripen (16.3 d).

Fruit post-storage quality

Rootstocks significantly affected days to ripe of the 'Shepard' fruit after cold storage, although the differences were generally one day or less (Table 106). Fruit from trees on seedling 'SHSR-03', seedling 'Velvick', seedling 'SHSR-02' and on clonal 'Velvick' rootstocks had less discrete skin patches at ripe (an indication of chilling damage) than fruit from trees on clonal 'Thomas' and 'Duke-7' rootstocks (Table 106). At eating ripe, there were no significant differences between rootstocks for severity of body rots, diffuse discolouration and vascular leaching (Table 106), or stem-end rots (data now shown). The main causes for quality loss were body rots, followed by diffuse discolouration and vascular leaching, but overall severity of flesh defects was relatively low, resulting in high percentages of sound fruit (81% and above) and no significant differences among rootstocks (Table 106).

Fruit flesh dry matter, skin minerals, and fruit biochemical markers

Fruit from trees on clonal 'Thomas' (Table 107) had the highest N, lowest Ca and highest N/Ca ratio of all rootstock treatments. Conversely, fruit from trees on seedling 'SHSR-03' had the lowest N, highest Ca and lowest N/Ca ratio. These findings correlate well with marketability data (Table 105) which shows that fruit from trees on clonal 'Thomas' were the least marketable (24%) of all treatments and those from trees on seedling 'SHSR-03' the second most marketable (63%).

There were significant rootstock effects on fruit DM at harvest (Table 107), with a difference of 2.5% between the most mature fruit (from trees on clonal 'A10') and the least mature fruit (from trees on clonal 'Thomas').

There were no significant effects of rootstock on fruit biochemical's (phenolics, catalase and peroxidase) at the Walkamin site in 2010 (Table 107).

Correlations

The incidence of anthracnose and stem-end rot in 'Shepard' avocado fruit ripened at 23°C significantly correlated with a number of measured parameters, particularly skin N (positive correlation) and skin Ca (negative correlation) (Table 108). Although not as strong, there was also a significant negative correlation between anthracnose incidence and average tree yield, and a significant positive correlation between % marketable fruit and yield efficiency (kg fruit/m^3 canopy volume).

In fruit that had been cold stored, a higher percentage of sound fruit was correlated with fruit that ripened quicker and had less discrete patches (chilling injury) on removal from storage (Table 108). There were some correlations between days to ripe and the severity of body rots or vascular leaching; between body rots and discrete patches; between yield and dry matter; and between skin K and skin

(Ca+Mg)/K ratio and the % of discrete patches (Table 108). However, the correlations were relatively weak (r values between 0.34-0.45).

Table 104 Walkamin 2011: Effects of clonal (C) and seedling (S) rootstocks on days to eating-ripe, severity (%) and incidence (%) of anthracnose and stem-end rot, and % marketable fruit in 'Shepard' fruit ripened at 23°C.

		Side anthracnose		Stem-end rot		
Rootstock[1]	**Days to eating-ripe**	**Severity[2] (% fruit surface area)**	**Incidence[3] (% fruit affected)**	**Severity (% flesh volume)**	**Incidence (% fruit affected)**	**Marketable fruit (%)[4]**
C-A10	15.92 [abc]	10.1 [bc]	60.5 [bc]	1.5 [bc]	17.0 [c]	64.8 [a]
S-SHSR-03	15.99 [abc]	5.7 [c]	56.7 [c]	2.0 [bc]	26.0 [bc]	62.9 [ab]
S-A10	16.28 [a]	6.1 [c]	59.0 [c]	1.7 [bc]	29.0 [bc]	61.0 [ab]
S-Velvick	16.02 [abc]	4.9 [c]	58.5 [c]	1.9 [bc]	36.0 [ab]	54.5 [abc]
S-SHSR-02	15.73 [abc]	7.2 [c]	63.2 [bc]	5.5 [a]	40.0 [ab]	49.4 [abc]
C-Velvick	16.12 [ab]	7.2 [c]	66.9 [bc]	2.4 [bc]	33.2 [b]	48.2 [abc]
C-SHSR-03	15.43 [abc]	10.3 [bc]	62.1 [bc]	2.1 [bc]	28.1 [bc]	47.6 [abc]
C-Shepard	15.40 [bc]	9.9 [bc]	74.5 [ab]	1.2 [c]	29.0 [bc]	45.5 [bc]
S-Duke 7	15.76 [abc]	8.2 [bc]	67.1 [bc]	3.2 [b]	50.8 [a]	39.6 [cd]
C-Duke 7	15.15 [cd]	14.3 [b]	76.2 [ab]	2.0 [bc]	37.5 [ab]	37.9 [cd]
C-Thomas	14.52 [d]	20.4 [a]	84.0 [a]	3.0 [bc]	50.0 [a]	24.0 [d]
P	***0.008***	***<0.001***	***0.009***	***0.002***	***<0.001***	***<0.001***

1 Rootstocks listed in descending order of % marketable fruit
2 Severity = average % of ripe fruit flesh surface area affected by each disease
3 Incidence = the % of ripe fruit with any level of disease in relation to the total number of fruit per treatment
4 Marketable fruit = % of ripe fruit with ≤ 5% anthracnose severity and no stem-end rot
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference

Table 105 Walkamin 2011: Effects of clonal (C) and seedling (S) rootstocks on days to ripe, severity of flesh defects (% of flesh volume affected), and % sound 'Shepard' fruit held at 5°C for 4 weeks and then ripened at 20°C with no ethylene.

Rootstock[1]	Days to ripe at 20°C	% discrete patches	Severity (% of flesh volume affected)			% sound fruit[2]
			Body rot	Diffuse discolour.	Vascular leaching	
S-Velvick	7.2 abc	24 cd	0.6	1.4	0.2	94
S-SHSR-02	6.8 cd	24 cd	2.0	0.7	0.3	91
C-Duke7	6.5 d	36 b	2.5	1.0	0.2	88
C-Velvick	7.4 ab	26 cd	1.6	1.5	1.4	88
C-SHSR-03	6.9 abcd	24 cd	1.4	2.0	1.3	87
C-A10	7.5 a	26 cd	3.2	1.8	0.6	87
S-Duke7	6.8 abcd	26 bcd	1.3	1.8	0.3	87
C-Thomas	6.8 abcd	47 a	2.2	1.3	0.2	86
C-Shepard	6.8 bcd	29 bcd	2.3	1.2	0.4	85
S-SHSR-03	7.3 abc	20 d	2.1	1.3	1.6	85
S-A10	7.3 abc	30 bc	4.6	1.5	1.9	81
P	***0.025***	***<0.001***	***ns***[3]	***ns***	***ns***	***ns***

1 Rootstocks listed in descending order of % sound fruit
2 Sound fruit = fruit with a severity rating of 10% or less for all defects combined
3 ns = not significant (P > 0.05)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 200 fruit per rootstock

Table 106 Walkamin 2011: Effects of clonal (C) and seedling (S) rootstocks on fruit flesh dry matter, fruit skin minerals and fruit biochemical markers in 'Shepard' avocado.

Rootstock[1]	Fruit flesh dry matter at harvest (%)	Fruit skin minerals concentration at harvest (% dry weight)						Fruit skin phenolics (gallic acid equivalents / g fresh weight)	Fruit flesh catalase (U/ug protein)	Fruit flesh peroxidase (U/ug protein)
		N	Ca	Mg	K	N/Ca ratio	Ca+Mg/K ratio			
C-A10	25.4 [a]	1.23 [bcd]	0.099 [abc]	0.081	1.28	13.7 [bcd]	0.145	12.0 [c]	3.49	18.04
C-Duke 7	25.0 [ab]	1.33 [ab]	0.085 [bcd]	0.090	1.49	16.1 [ab]	0.119	10.3 [c]	3.70	16.73
C-Shepard	23.7 [bcd]	1.25 [abcd]	0.081 [d]	0.087	1.36	16.0 [ab]	0.127	13.0 [bc]	3.48	14.61
C-SHSR-03	23.4 [cd]	1.26 [abcd]	0.089 [bcd]	0.082	1.30	14.5 [abc]	0.135	16.9 [ab]	3.35	16.64
C-Thomas	22.9 [d]	1.36 [a]	0.080 [d]	0.089	1.39	17.5 [a]	0.125	19.4 [a]	3.69	18.16
C-Velvick	23.6 [bcd]	1.21 [bcd]	0.100 [ab]	0.074	1.19	12.5 [cd]	0.152	20.9 [a]	3.04	15.62
S-A10	24.2 [abcd]	1.21 [bcd]	0.097 [abc]	0.082	1.24	12.8 [cd]	0.147	ND[3]	ND	ND
S-Duke 7	24.1 [abcd]	1.21 [bcd]	0.084 [cd]	0.084	1.31	14.6 [abc]	0.135	ND	ND	ND
S-SHSR-02	23.6 [bcd]	1.31 [abc]	0.081 [d]	0.089	1.36	16.5 [ab]	0.128	ND	ND	ND
S-SHSR-03	23.8 [bcd]	1.14 [d]	0.104 [a]	0.081	1.33	11.2 [d]	0.142	ND	ND	ND
S-Velvick	24.8 [abc]	1.20 [cd]	0.082 [d]	0.088	1.33	15.1 [abc]	0.132	ND	ND	ND
P	***0.035***	***0.028***	***0.003***	***ns[2]***	***ns***	***0.002***	***ns***	***<0.001***	***ns***	***ns***

1 Rootstocks listed in alphabetical order
2 ns = not significant (P > 0.05)
3 ND = not done (only clonal rootstocks analysed for phenolics and enzymes)
Means within columns followed by the same letter are not significantly different (P ≤ 0.05) as tested by least significant difference
Values in table are means of 50 fruit per rootstock except for fruit biochemical's (25 fruit per rootstock)

Table 107 Walkamin in 2011: Significant correlations between various parameters in 'Shepard' avocado fruit.

Variable 1	Variable 2	P value	r (correlation coefficient)	Relationship
Fruit ripened at 23oC.				
Anthracnose incidence	Yield	0.026	0.19	-
Anthracnose incidence	Ca	0.002	0.28	-
Anthracnose incidence	Mg	0.004	0.26	+
Anthracnose incidence	N	<0.001	0.36	+
Anthracnose incidence	N/Ca	<0.001	0.36	+
Anthracnose incidence	(Ca+Mg)/K	0.015	0.22	-
Stem-end rot incidence	Ca	<0.001	0.31	-
Stem-end rot incidence	N	0.014	0.22	+
Stem-end rot incidence	N/Ca	0.002	0.29	+
% Marketable fruit	Yield efficiency	0.038	0.18	+
% Marketable fruit	Ca	<0.001	0.35	+
% Marketable fruit	Mg	0.014	0.22	-
% Marketable fruit	N	<0.001	0.35	-
% Marketable fruit	N/Ca	<0.001	0.38	-
% Marketable fruit	(Ca+Mg)/K	0.004	0.26	+
Fruit held at 5^{o}C for 5 weeks and then ripened at 20^{o}C.				
% of sound fruit	Days to ripe	<.001	0.45	-
Body rot	Discrete patches	<.001	0.42	+
Days to ripe	Vascular leaching	<.001	0.41	+
% of sound fruit	Discrete patches	<.001	0.40	-
Body rot	Days to ripe	<.001	0.39	+
Yield	Fruit dry matter	<.001	0.35	-
K	Discrete patches	<.001	0.34	+
(Ca+Mg)/K	Discrete patches	<.001	0.34	-

10.3.16 Tree to tree variability in fruit quality and fruit minerals between seedling and clonal rootstocks

The tree to tree variances between rootstocks of common origin for fruit harvested at Childers (Hass) in 2008-10, and at Walkamin (Shepard) in 2010-11 were determined. Overall results showed little significant differences between the variances of seedling and clonal rootstocks for some key quality attributes and skin minerals in both Hass (Table 108) and Shepard (Table 109) fruit. There were some significant differences particularly for severity of diffuse discolouration in some rootstocks, but for Hass fruit, those of seedling origin had the smallest variances (an indication of less variation), and for Shepard fruit results varied depending on the rootstock.

Table 108 Childers 2008-10: Variances between Hass trees on rootstocks of common origin for some fruit quality attributes and fruit skin minerals

Rootstock	2008 - Tree variances			2009 - Tree variances			2010 - Tree variances		
	Rootstock origin		P value	Rootstock origin		P value	Rootstock origin		P value
	Seedling	Clonal		Seedling	Clonal		Seedling	Clonal	
A10									
Body rot	11	25	0.212	0.8	0.4	0.287	0.3	0.1	0.148
Diffuse discoloration	179	161	0.872	0.4	1.7	0.039	0.5	2.6	**0.025**
% sound fruit	78	217	0.142	38	51	0.660	52	157	0.117
Skin Ca	0.6	0.5	0.650	0.6	0.5	0.845	3.3	6.6	0.318
Skin N	62	211	0.081	54	334	**0.013**	832	218	0.059
Skin (Mg+K)/Ca	37	68	0.380				0	0	0.928
Nabal									
Body rot	8.0	12.2	0.537	1	4	0.111	0.2	1.8	0.003
Diffuse discoloration	267	105	0.182	1.6	0.9	0.393	0.8	0.6	0.803
% sound fruit	147	23	0.010	62	29	0.274	49	49	0.995
Skin N	109	392	0.081	107	129	0.782	71	269	0.065
Skin Ca	0.8	0.5	0.081	0.7	0.4	0.404	0.6	0.3	0.325
Skin (Mg+K)/Ca	66	114	0.427				0	0	0.936
SHSR-03									
Body rot	19	8	0.205	3	6	0.203	0.2	0.8	0.075
Diffuse discoloration	198	79	0.188	1	17	<0.001	1.3	2.6	0.330
% sound fruit	97	39	0.191	47	480	0.002	122	205	0.459
Skin Ca	0.5	0.7	0.503	0.8	0.5	0.523	3.9	7.4	0.375
Skin N	67	153	0.236	183	62	0.123	810	1480	0.396
Skin (Mg+K)/Ca	111	266	0.209				3.0	30	**0.002**
Velvick									
Body rot	14	13	0.927	2.3	3.2	0.659	0.2	0.1	0.395
Diffuse discoloration	254	183	0.631	2.3	3.8	0.486	0.8	0.9	0.979
% sound fruit	23	247	0.001	82	300	0.067	108	63	0.450
Skin Ca	0.3	0.8	0.167	25	0.5	**<0.001**	3.0	1.7	0.395
Skin N	85	44	0.345	228	77	0.120	223	575	0.185
Skin (Mg+K)/Ca	137	53	0.168				3.1	4.6	0.561

Parameters based on 10 trees (reps) per rootstock. Variances and P values determined using Genstat and Bartlett's test.

Table 109 Walkamin 2010-11: Variances between Shepard trees on rootstocks of common origin for some fruit quality attributes and fruit skin minerals

Rootstock	2010 - Tree variances			2011 - Tree variances		
	Rootstock origin		P value	Rootstock origin		P value
	Seedling	Clonal		Seedling	Clonal	
A10						
Incidence side anthracnose				204	264	0.710
Incidence stem end rot				222	296	0.678
% marketable fruit				462	620	0.667
Body rot severity	0.6	1.8	0.086	17	23	0.680
Diffuse discolouration severity	2.6	0.3	**0.006**	4	5	0.668
% sound fruit	77	64	0.784	299	190	0.510
Ca	4.9	7.6	0.529	2.7	7.2	0.156
N	1120	582	0.343	143	290	0.308
N/Ca	46	14	0.086	7	30	**0.039**
(Mg+K)/Ca	21	26	0.761	6	12	0.321
Duke 7						
Incidence side anthracnose				599	220	0.198
Incidence stem end rot				190	196	0.967
% marketable fruit				282	450	0.536
Body rot severity	0.6	0.6	0.984	3	13	0.059
Diffuse discolouration severity	0.22	0.02	**0.003**	16	1	**<0.001**
% sound fruit	12.5	3	0.076	144	110	0.727
Ca	1.9	1.8	0.928	1.8	2.0	0.876
N	210	398	0.382	236	164	0.634
N/Ca	7	5	0.807	7	15	0.296
(Mg+K)/Ca	14	3	0.061	6	1	**0.038**
SHSR-03						
Incidence side anthracnose				509	200	0.208
Incidence stem end rot				629	390	0.514
% marketable fruit				731	424	0.457
Body rot severity	0.1	0.7	**0.004**	4.1	4.4	0.902
Diffuse discolouration severity	0.01	18.6	**<0.001**	4	4	0.807
% sound fruit	5	312	**<0.001**	138	276	0.345
Ca	4.9	2.3	0.305	2.5	2.1	0.805
N	825	269	0.134	103	153	0.588
N/Ca	13	7	0.434	4	8	0.323
(Mg+K)/Ca	7	7	0.954	6	6	0.933
Velvick						
Incidence side anthracnose				223	356	0.495
Incidence stem end rot				338	168	0.311
% marketable fruit				314	359	0.843
Body rot severity	1.4	0.6	0.232	0.3	6.6	**<0.001**
Diffuse discolouration severity	0.01	0.07	**0.002**	2	5	0.177
% sound fruit	235	196	0.792	58	379	**0.010**
Ca	1.8	6.8	0.063	2.4	3.6	0.567
N	62	307	**0.026**	222	121	0.379
N/Ca	3	10	0.078	13	8	0.488
(Mg+K)/Ca	5	16	0.117	7	11	0.545

Parameters based on 10 trees (reps) per rootstock. Variances and P values determined using Genstat and Bartlett's test.

10.4 Discussion

The results presented in this report represent postharvest fruit quality evaluations conducted over three seasons at four different field sites in Australia for both 'non-stored' (e.g. ripened at 23°C following harvest and transport) or 'stored' (e.g. cold-stored for 4 weeks at 5°C and then ripened at 20°C) fruit. A selection of both seedling and clonally propagated rootstocks was evaluated at two of these sites (Childers QLD and Walkamin QLD), while only clonal rootstocks were assessed at the remaining two sites (Pemberton WA and Hampton QLD). Selected rootstocks grafted to either 'Hass' or 'Shepard' scions were evaluated at Walkamin, whereas rootstocks grafted to 'Hass' were used for evaluations at the other three sites. 'Non-stored' fruit was assessed for flesh diseases, while 'stored' fruit evaluations included both external (e.g. skin colour and skin chilling injury) and internal (flesh diseases and physiological disorders) quality.

Given the wide variation in growing environments included in this study, combined with seasonal variation at individual sites, rootstock/scion cultivar/race and propagation method, it is not surprising that there was a high degree of variation in results across the study. Despite this however, we have seen a number of trends emerge from the vast amount of data collected since 2008. These trends are discussed below in relation to the principal variables studied in this evaluation:

Growing location
In this study a number of the rootstocks were evaluated at multiple sites, and in some instances at every site (Table 1). Examples of the latter included clonal 'A10', 'Duke 7', 'Velvick' and 'Zutano'. Overall, fruit harvested from 'Hass' or 'Shepard' trees grafted to clonal 'A10' rootstock performed well at most sites in terms of fruit quality, both in relation to 'stored' and 'non-stored' fruit. Fruit from trees on clonal 'Velvick' also often performed well, but there were some instances where both fruit marketability ('non-stored' fruit) and % of sound fruit ('stored' fruit) were relatively low, such as at the Walkamin 'Hass' site in some years. Fruit from trees on clonal 'Zutano' generally performed well at the Pemberton site in relation to % of sound fruit (stored fruit), but was not a consistently good performer across all sites. Fruit quality was frequently poor in fruit from trees on clonal 'Duke 7' rootstock at all sites.

Interesting results were seen with 'Hass' fruit from trees on clonal 'Reed' rootstock which was evaluated at three sites (Hampton, Pemberton and Walkamin). Fruit from trees on clonal 'Reed' at Hampton often had poor quality compared to fruit from trees on a number of other rootstocks (particularly non-stored fruit but also stored fruit), whereas equivalent fruit at Pemberton performed much better. Results for 'Reed' at Walkamin were less conclusive due to a general lack in significant differences between rootstocks, although the rootstock did perform well in 2012 in terms of % of sound fruit (stored fruit).

As was the case for fruit from trees on clonal 'A10' rootstock, those on clonal 'SHSR-03' also tended to perform well in terms of fruit quality across several sites (although it was not evaluated at Pemberton).

Seasonal variation
While there was some variation in the performance of rootstocks from year to year at each site, generally trends could be seen in terms of the best and worst performing rootstocks. For example, at the Pemberton site, non-stored fruit from 'Hass' trees on clonal 'Barr Duke' were consistently the lowest quality in terms of postharvest disease in each of the three years in which evaluations were done, whereas equivalent fruit from trees on clonal 'A10' were always of comparatively high quality. Similarly at Hampton, non-stored fruit from 'Hass' trees on clonal 'Reed', 'Duke 7' and Hass performed poorly across the three seasons compared to non-stored fruit from 'Hass' trees on clonal 'SHSR-03', 'A10' and 'Velvick' which performed consistently well. At Walkamin, non-stored fruit from 'Shepard' trees on clonal 'Thomas' rootstock were consistently of the lowest quality across the three seasons, whereas those on clonal and seedling 'A10', seedling 'SHSR-03' and 'Velvick' generally performed well in most evaluations. In all three locations, there were similar differences between rootstocks for 'stored' fruit in only one out of three seasons, with little significant differences in the other two seasons.

Seedling vs. clonal rootstocks
A comparison of seedling and clonally propagated rootstocks was undertaken at Childers on 'Hass' trees and at Walkamin on 'Shepard' trees. In terms of % marketable fruit (non-stored) and % sound fruit

(stored) at the Childers or Walkamin sites, there was no indication that fruit from trees on either seedling or clonally propagated rootstocks performed better than the other.

There were also little differences in terms of the tree to tree variances between rootstocks of common origin for some key quality attributes and skin minerals in both locations over 2-3 seasons. Thus, the common belief that clonally propagated rootstocks would be less variable than seedling ones is not supported by the evidence provided by this study. However, a more detailed statistical analysis should be undertaken in future studies to more accurately define any possible differences.

Rootstock race

Studies conducted prior to the commencement of this project (Willingham *et al*., 2001, 2006; Marques *et al*., 2003; Anderson *et al*., 2003) provided preliminary evidence that fruit quality parameters may be influenced by the "compatibility" of rootstock and scion race. In particular, fruit from 'Hass' trees grafted to Mexican race rootstocks such as 'Duke 6' and 'Parida' were shown to have higher levels of postharvest disease, particularly anthracnose, than those grafted to Guatemalan/West Indian race rootstocks. In this project fruit from 'Hass' (Guatemalan x Mexican hybrid) and 'Shepard' (Mexican x Guatemalan hybrid) trees grafted to a range of Guatemalan, West Indian and Mexican race rootstocks were evaluated for postharvest fruit quality. Results obtained in this project on 'Hass' fruit support these previous studies in the most part, in that we frequently found fruit from 'Hass' trees on Mexican race rootstocks such as 'Barr Duke' and 'Duke 7' performed poorly in terms of fruit quality compared to those from trees on predominantly Guatemalan (e.g. 'A10', 'SHSR-03') and 'West Indian' (e.g. 'Velvick') rootstocks. However, if race compatibility is a key factor, then one might expect that fruit from 'Shepard' (Mexican) trees would perform better when the scion is grafted to a Mexican rootstock, which was not necessarily what we found. Non-stored fruit from 'Shepard' trees grafted to the Mexican rootstock 'Thomas' were consistently of the lowest quality (in terms of postharvest disease), and those from trees on clonal or seedling 'Duke 7' (Mexican) had similar levels of poor quality in the third season of 'Shepard' trials (2011).

Detailed molecular analyses should be undertaken to characterise the genetic parentage of rootstocks currently used, or under selection, in Australia.

The effect of rootstock on fruit skin nutrients

Previous studies (Willingham *et al*., 2001, 2006; Marques *et al*., 2003; Anderson *et al*., 2003) have indicated that nutrient levels (particularly N and Ca) in avocado fruit skin and leaves may be related to rootstock-mediated resistance to postharvest disease as well as other quality parameters. At each of the four sites evaluated in this project, and in each of the three seasons, fruit skin samples were taken at harvest for all of the rootstock x scion combinations evaluated and analysed for the major nutrients N, Ca, Mg and K. Although there is variation in results, it was often found that fruit from rootstock x scion combinations with the best fruit quality (in terms of disease and physiological storage disorders) had the lowest skin N levels and highest skin Ca levels. This was supported by correlation analyses which showed positive correlations between fruit quality parameters and skin N levels/skin N/Ca ratios, and negative correlations between fruit quality parameters and skin Ca levels/skin Ca+Mg/K ratios. Based upon the results obtained in this project, N/Ca ratios in the skin of unripe avocado fruit at harvest time currently constitute one the best indicators we presently have of potential fruit quality in ripe fruit.

There may be some potential for improving the performance of rootstocks which have a negative influence on fruit quality, perhaps by altering the balance of N/Ca in fruit through modified nutritional practices. This would only be worth considering though if the rootstock had other very strong, positive attributes, such as high yield.

The effect of rootstock on fruit biochemical's potentially involved in disease resistance

In the initial stages of the project, concentrations of total soluble phenolic compounds in the skin of fruit taken from all clonal rootstock x scion combinations were measured at harvest, and also in fruit starting to ripen ("sprung" fruit) and ripe fruit ("eating-ripe"). However in most cases there were no significant effects of rootstock on concentrations of phenolic compounds at the three different stages, and so future analyses were only done on fruit skin at harvest time. Throughout the project there continued to be little meaningful correlation between fruit skin phenolic concentration and postharvest fruit quality parameters. Similarly, the enzymes, catalase and peroxidase, have not to date been strong indicators of fruit disease resistance like fruit N and Ca have. Some correlations between these enzymes and disease have been found, but have not been strong or consistent.

Relationship between yield and postharvest fruit quality
Total tree yield and/or yield efficiency often correlated negatively with the incidence of postharvest disease and physiological disorders, that is, fruit from high yielding trees tended to have lower disease and disorder levels. While these correlations tended to be weaker and less frequently observed than the correlations between N/Ca and disease, they still constitute an important finding of the study and confirm other studies (Cutting and Vorster, 1991; Hofman *et al*., 2002).

11. Intellectual Property

Plant improvement research provides the opportunity to develop new genetic material that can be protected through Plant Breeder's Rights. This project has been continually recovering and testing genetic material that has the potential to improve avocado production both at the domestic and international level. Performance criteria being evaluated for rootstocks are high sustainable yields, anthracnose resistance imparted to fruit and Phytophthora root rot resistance. Success has been achieved in identifying rootstocks with commercial levels of Phytophthora root rot resistance which are reported on below:

11.1 'SHSR-04'

'SHSR-04' is the rootstock from an "escape" tree that was recovered from a 'Hass' orchard where most of the surrounding trees had succumbed to Phytophthora root rot. Genetic material of the rootstock was recovered, clonally propagated, grafted to 'Hass' and then planted in highly infested Phytophthora root rot sites for evaluation. The evaluation program clearly showed that this rootstock had useful commercial resistance (Smith *et al*., 2010, 2011) but similar to current commercially available Phytophthora root rot resistant rootstock, viz., 'Dusa' and 'Latas' from South Africa, it is not totally resistant and requires chemical support to maintain health. Potassium phosphonate is the standard industry treatment used to control Phytophthora root rot in avocados (Pegg *et al*., 1987; Whiley *et al*., 1995). Pegg (pers. Comm. 2013) has found that pineapples with genetic levels of Phytophthora root rot resistance require lower application rates of potassium phosphonate to keep them healthy. It is likely that avocado rootstocks with commercial resistance levels will also respond at lower rates of chemical protection thus reducing costs.

The equity in this rootstock lies with Mr George Green (50%), HAL (31.79%) and Sunshine Horticultural Services Pty Ltd (18.21%). It is recommended that the rootstock be commercialised for both the Australian and International avocado industries.

11.2 'SHSR-07'

The parent line of 'SHSR-07' is 'SHSR-02' which has been used as a rootstock by the Australian avocado industry since the 1960's so is ineligible for Plant Breeders Rights. Introduced into the rootstock improvement program in 2002, it was observed that 'SHSR-02' seedling rootstocks had varying levels of resistance to Phytophthora root rot when grafted to 'Hass' and grown in Phytophthora-infested soils. In 2006, 150 seedlings of 'SHSR-02' were grown, grafted to 'Hass' and planted in Phytophthora-infested soil. The trees were chemically protected for the first 12 months of establishment using Ridomil Gold G® and bark-painted potassium phosphonate (20%) + 2% Pulse®. Other standard agronomic practices were applied to ensure growth, e.g. weed control, nutrition and irrigation. Once chemical protection was withdrawn the health of the seedling population was monitored using the 0-10 scale where 0 = healthy and 10 = dead. In 2007, five promising lines were selected for rootstock recovery and the 'Hass' scions removed to allow rootstock regrowth. Following the wet summer of 2011, only one of the candidate rootstocks remained healthy, bud-wood was collected for cloning and 10 trees grafted to 'Hass' have been prepared for re-evaluation in Phytophthora-infested soil.

Trees will be planted in May 2013 and monitored by Sunshine Horticultural Services Pty Ltd (unfunded). Should this rootstock prove successful for commercialisation the equity split will be HAL (63.58%) and Sunshine Horticultural Services Pty Ltd (36.42%).

11.3 'SHSR-08'

'SHSR-08' is believed to be a hybrid between 'Velvick' and 'A10' and was identified by Mr Graham Anderson of Anderson's Nursery, Duranbah NSW. The seedling was grafted to 'Hass' and incorporated into the same program that evaluated 'SHSR-07' where the same protocols were applied. This rootstock also survived the 2011 wet season and good health, bud-wood was collected for cloning and 10 trees grafted to 'Hass' have been prepared for re-evaluation in a Phytophthora-infested soil.

Trees will be planted in May 2013 and monitored by Sunshine Horticultural Services Pty Ltd (unfunded). Should this rootstock prove successful for commercialisation the equity split will be Andersons Nursery (50%), HAL (31.79%) and Sunshine Horticultural Services Pty Ltd (18.21%).

At the conclusion of this project the only other rootstock line of interest is 'V1' however the parent tree died in the summer of 2011 and the recovery of genetic material would have to occur from cloned trees at the Childers site. This rootstock is potentially high-yielding but is difficult to clone making it less attractive for commercialisation.

12. Technology Transfer

12.1 Conferences, Field days and Publications

1. **A.W. Whiley** Presented information on Crop Phenology/Management and Rootstock results at the Burnett Avocado Growers Field Day (AV06003) on the 3rd October 2008.
2. **Ecosciences Precinct Team Members** Presented project results at four avocado study group field days (West Moreton QLD, 2008; Mareeba QLD, 2009; Comboyne NSW, 2009; Pemberton WA, 2010).
3. **E.K Dann** Conference paper. Dann, E.K., Hassan, M.K., Irving, D.E., Pegg, K.G., Smith, L.A., Dean, J.R. and Coates, L.M. (2008) Effect of variety or rootstock on biochemical defences and postharvest disease development in mango and avocado. Book of abstracts, International Conference on Biotic Plant Interactions, The University of Queensland, March 27-29, 2008.
4. **A.W. Whiley** Presented information on rootstock results including a field walk of the experiment to the South West Avocado Growers Field Day (WA) on the 25th June 2009.
5. **A.W. Whiley** Presented a paper on the results from the Rootstock project at the Australasian Avocado Conference in Cairns 23rd July 2009.
6. **A.W. Whiley** Presented a paper on avocado varieties at the Australasian Avocado Conference in Cairns 23rd July 2009.
7. **Peer reviewed paper published** Smith, L.A., Dann, E.K., Pegg, K.G., Whiley, A.W., Giblin, F.R., Doogan, V. and Kopittke, R. (2011) Field assessment of avocado rootstock selections for resistance to Phytophthora root rot. *Australasian Plant Pathology* 40 (1), 39-47.
8. **Ecosciences Precinct Team Members** Presented a paper to The Australian and New Zealand Avocado Growers Conference in Cairns, July 2009. Dann, E, Coates, L, Smith, L, Pegg, K, Dean, J and Cooke, T. (2009) Impacts of fruit disease management on quality, The Australian and New Zealand Avocado Growers Conference, Cairns, 2009.
9. **Ecosciences Precinct Team Members** Presented project results to the 8th Annual Avocado R&D Integration Workshop in Canberra, June 2010.
10. **A.W. Whiley** A field day including two Power point presentations was given to the Riverland avocado growers (Waikerie October 2010).
11. **A.W. Whiley** Presented an update of the Rootstock project to the 9th Annual Avocado R&D Integration Workshop in Brisbane, August 2011.
12. **Ecosciences Precinct Team Members** Presented project results to the 10th Annual Avocado R&D Integration Workshop in Brisbane, September 2012.
13. Research papers were presented at the 7th World Avocado Congress in Cairns (5-9th September 2011). These papers were:

    Coates, L.M., Dann, E.K., Shuey, L.S., Smith, L.A., Dean, J.R., Cooke, A.W., Pegg, K.G., Hofman, P.J., Marques, R., Stubbings, B. and Whiley, A.W. (2011). Effects of rootstock on avocado fruit quality – assessment of postharvest disease, major cations and biochemical traits. *Proceedings of the VII World Avocado Congress*, Cairns September 2011. Pp. 206-214.

    Marques, J., Hofman, P., Whiley, A., Dann, E., Coates, L., Stubbings, B., Smith, L., Dean, J., Cooke, A. (2011). Rootstocks affect quality of 'Hass' avocado fruit after storage. In *7th World Avocado Congress 2011.* pp. 625-630.

    Smith, L.A., Dann, E.K., Pegg, K.G. and Whiley, A.W. (2011). Field assessment of avocado rootstock selections for resistance to Phytophthora root rot. *Proceedings of the VII World Avocado Congress*, Cairns September 2011.

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13. References

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14. Appendix I

14.1 Site Plans of Rootstock Experiments

Anderson Site Plan

Rootstock evaluation trial
Andersons Road, Duranbah, NSW

Clonal Rootstock Experiment

R1 – 2	R4 – 6	R7 – 7
R1 – 4	R4 – 5	R7 – 2
R1 – 7	R4 – 1	R7 – 5
R1 – 1	R4 – 2	R7 – 1
R1 – 3	R4 – 7	R7 – 6
R1 – 6	R4 – 4	R7 – 3
R1 – 5	R4 – 3	R7 – 4
R2 – 7	R5 – 1	R8 – 2
R2 – 2	R5 – 4	R8 – 4
R2 – 5	R5 – 6	R8 – 7
R2 – 1	R5 – 3	R8 – 1
R2 – 6	R5 – 2	R8 – 3
R2 – 3	R5 – 7	R8 – 6
R2 – 4	R5 – 5	R8 – 5
R3 – 6	R6 – 4	R9 – 1
R3 – 1	R6 – 3	R9 – 4
R3 – 4	R6 – 6	R9 – 6
R3 – 7	R6 – 1	R9 – 3
R3 – 3	R6 – 7	R9 – 2
R3 – 5	R6 – 2	R9 – 7
R3 – 2	R6 – 5	R9 – 5
R10 – 2	R10 – 3	R10 – 4
R10 – 5	R10 – 7	R10 – 1
		R10 - 6

Clonal Rootstock Key

1. A10
2. Barr Duke
3. Duke 7
4. Hass
5. Nabal
6. Velvick
7. V1

Seedling Rootstock Experiment

R1 – 3	R4 – 9	R7 – 10	R10 – 1
R1 – 7	R4 – 4	R7 – 1	R10 – 5
R1 – 2	R4 – 1	R7 – 6	R10 – 8
R1 – 5	R4 – 5	R7 – 9	R10 – 10
R1 –8	R4 – 10	R7 – 5	R10 – 7
R1 – 10	R4 – 6	R7 – 3	R10 – 3
R1 – 1	R4 – 8	R7 – 8	R10 – 6
R1 – 9	R4 – 2	R7 – 7	R10 – 4
R1 – 4	R4 – 7	R7 – 2	R10 – 2
R1 – 6	R4 – 3	R7 – 4	R10 – 9
R2 – 10	R5 – 3	R8 – 9	
R2 – 1	R5 – 7	R8 – 4	
R2 – 6	R5 – 2	R8 – 1	
R2 – 9	R5 – 5	R8 – 5	
R2 – 5	R5 – 8	R8 – 10	
R2 – 3	R5 – 10	R8 – 6	
R2 – 8	R5 – 1	R8 – 8	
R2 – 7	R5 – 9	R8 – 2	
R2 – 2	R5 – 4	R8 – 7	
R2 – 4	R5 – 6	R8 – 3	
R3 – 9	R6 – 10	R9 – 6	
R3 – 4	R6 – 1	R9 – 3	
R3 – 1	R6 – 6	R9 – 7	
R3 – 5	R6 – 9	R9 – 2	
R3 – 10	R6 – 5	R9 – 5	
R3 – 6	R6 – 3	R9 – 8	
R3 – 8	R6 – 8	R9 – 10	
R3 – 2	R6 – 7	R9 – 1	
R3 – 7	R6 – 2	R9 – 9	
R3 - 3	R6 – 4	R9 – 4	

Seedling Rootstock Key

1. A8
2. A10
3. Barr Duke
4. Nabal
5. Parida
6. Peasley
7. Reed
8. Toro Canyon
9. SHSR-03
10. Velvick

Avonova Site Plan

Rootstock evaluation trial (planted 15th December, 2005)
Loc 5203 Stirling Track, Pemberton WA

Clonal Rootstock Experiment

South

Roadway

Forest

Orchard

R1 – 5	R4 – 9	R7 – 1
R1 – 7	R4 – 6	R7 – 5
R1 – 9	R4 – 1	R7 – 3
R1 – 1	R4 – 5	R7 - 9
R1 – 3	R4 – 4	R7 – 7
R1 – 6	R4 – 8	R7 – 2
R1 – 8	R4 – 3	R7 – 4
R1 – 2	R4 – 7	R7 – 6
R1 – 4	R4 – 2	R7 – 8
R2 – 8	R5 – 5	R8 – 7
R2 – 6	R5 – 2	R8 – 2
R2 – 2	R5 – 3	R8 – 4
R2 - 4	R5 – 7	R8 – 8
Stone	R5 – 9	R8 – 1
R2 – 5	R5 – 1	R8 – 6
R2 – 1	R5 – 4	R8 – 9
R2 – 3	R5 – 6	R8 – 3
R2 – 9	R5 – 8	R8 – 5
R3 – 6	R6 – 3	R9 – 9
R3 – 1	R6 – 8	R9 – 8
R3 – 5	R6 – 6	R9 – 6
R3 – 8	R6 – 4	R9 – 3
R3 – 9	R6 – 2	R9 – 2
R3 – 2	R6 – 5	R9 – 5
R3 – 3	R6 – 7	R9 – 7
R3 – 7	R6 – 1	R9 – 4
R3 – 4	R6 – 9	R9 – 1
R10 – 6	R10 - 7	R10 – 2
R10 – 8	R10 – 1	R10 - 9
R2 - 7	R10 – 3 VS	

Clonal rootstock key

1. A10
2. Barr Duke
3. Duke 7
4. Franceschi
5. Hass
6. Nabal
7. Reed
8. Velvick
9. Zutano

Seedling Rootstock Experiment

Avonova site plan continued…

Seedling Rootstock Experiment **South**

Clonal Rootstock Experiment

Forest

R1 – 5	R4 – 6	R7 – 1
R1 – 7	R4 – 1	R7 – 5
R1 – 1	R4 – 5	R7 – 3
R1 – 3	R4 – 4	R7 – 7
R1 – 6	R4 – 8	R7 – 2
R1 – 8	R4 – 3	R7 – 4
R1 – 2	R4 – 7	R7 – 6
R1 – 4	R4 – 2	R7 – 8
R2 – 8	R5 – 2	R8 – 7
R2 – 2	R5 – 5	R8 – 2
R2 – 6	R5 – 3	R8 – 4
R2 – 4	R5 – 7	R8 – 8
R2 – 7	R5 – 1	R8 – 1
R2 – 5	R5 – 4	R8 – 6
R2 – 1	R5 – 6	R8 – 3
R2 - 3	R5 – 8	R8 – 5
R3 – 6	R6 – 3	R9 – 1
R3 – 1	R6 – 5	R9 – 8
R3 – 5	R6 – 7	R9 – 6
R3 – 8	R6 – 4	R9 – 3
R3 – 2	R6 – 2	R9 – 2
R3 – 3	R6 – 8	R9 – 5
R3 – 7	R6 – 6	R9 – 7
R3 – 4	R6 – 1	R9 – 4
R10 – 8	R10 – 3	R10 – 2
R10 - 5	R10 – 1	R10 – 4
	R10 - 6	R10 -7

Orchard

Seedling rootstock key

1. A10
2. Duke 7
3. SHSR-02
4. Nabal
5. Plowman
6. Toro Canyon
7. Velvick
8. V1

AVOWEST Site Plan

Rootstock evaluation trial (planted January, 2005)

Carabooda Road, Wanneroo, WA

Hass Experiment

Seedling rootstock experiment

X	X	X	X	X
2	5	4	3	1
1	3	5	2	4
5	2	2	5	3
4	1	3	1	5
3	4	1	4	2
2	1	5	3	5
5	3	2	1	3
4	4	3	5	1
3	5	4	2	4
1	2	1	4	2
X	X	X	X	X

Clonal rootstock experiment

X	X	X	X
2	3	1	4
1	2	3	1
3	4	2	2
4	2	4	1
1	1	3	3
4	3	2	4
2	2	1	1
3	1	4	2
4	4	2	4
1	3	3	2
X	X	X	X

Key for seedling rootstocks

1. A10
2. Nabal
3. Plowman
4. Velvick
5. SHSR-03

Key for cloned rootstocks

1. A10
2. Nabal
3. Plowman
4. Velvick

Lavers Orchards Site Plan

Rootstock evaluation trial (planted 6th & 7th April, 2005)

Henry Hannan Drive, Walkamin, QLD

Shepard Rootstock Experiment

PACKING SHED

ROADWAY (East)

Shepard seedling rootstock

X	X	X	X
R9 – 4	R6 – 1	R6 - 6	R1 – 3
R9 – 10	R6 – 2	R6 – 9	R1 – 5
R9 – 7	R6 - 10	R6 – 3	R1 – 10
R9 – 3	R6 – 4	R6 – 8	R1 – 4
R9 – 2	R7 – 4	R6 – 5	R1 – 1
R9 – 9	R7 – 7	R7 – 7	R1 – 7
R10 – 9	R7 – 2	R5 – 10	R1 – 2
R10 – 6	R7 – 8	R5 – 3	R1 – 9
R10 – 8	R7 – 10	R5 – 4	R1 – 6
R10 – 5	R7 – 1	R5 – 7	R1 – 8
R10 – 3	R7 – 3	R5 – 8	R2 – 10
R10 – 4	R7 – 6	R5 – 9	R2 – 4
R10 – 2	R7 – 9	R5 – 1	R2 – 6
R10 – 7	R7 – 5	R5 – 6	R2 – 1
R10 –10	R8 – 2	R5 – 2	R2 – 9
R10 – 1	R8 – 6	R5 – 5	R2 – 7
X	R8 – 4	R4 – 6	R2 – 2
X	R8 – 10	R4 – 5	R2 – 5
X	R8 – 1	R4 – 9	R2 – 3
X	R8 – 5	R4 – 4	R2 – 8
X	R8 – 9	R4 – 2	R3 – 5
X	R8 – 7	R4 – 7	R3 – 9
X	R8 – 8	R4 – 3	R3 – 6
X	R8 – 3	R4 – 8	R3 – 4
X	R9 – 5	R4 – 10	R3 – 1
X	R9 – 1	R4 – 1	R3 – 8
X	R9 – 6	R3 – 10	R3 – 2
X	R9 – 8	R3 – 3	R3 – 7
X	X	X	X

Shepard cloned rootstocks

X	X	X
R9 – 5	R9 – 1	R1 – 3
R9 – 9	R9 – 6	R1 – 5
R9 – 7	R9 – 8	R1 – 9
R9 – 3	R9 – 4	R1 – 4
R9 – 2	R8 - 2	R1 – 1
R10 – 6	R8 – 6	R1 – 7
R10 – 8	R8 – 4	R1 – 2
R10 – 5	R8 – 9	R1 – 6
R10 – 3	R8 – 1	R1 – 8
R10 – 4	R8 – 5	R2 – 9
R10 – 2	R8 - 7	R2 – 4
R10 – 7	R8 – 8	R2 – 6
R10 – 9	R8 – 3	R2 – 1
R10 – 1	R7 – 4	R2 – 7
X	R7 – 7	R2 – 2
X	R7 - 2	R2 – 5
X	R7 – 8	R2 – 3
X	R7 – 9	R2 – 8
X	R7 – 1	R3 – 5
X	R7 – 3	R3 – 6
X	R7 – 6	R3 – 4
X	R7 – 5	R3 – 1
X	R6 – 2	R3 – 8
X	R6 – 9	R3 – 2
X	R6 – 4	R3 – 7
X	R6 – 1	R3 – 3
X	R6 – 6	R3 – 9

Lavers Orchard site plan continued…

Shepard rootstock trial

Key for Shepard cloned rootstock experiment

1. A10
2. Barr Duke
3. Duke 7
4. Nabal
5. Shepard
6. SHSR-03
7. Thomas
8. Velvick
9. Zutano

X	R6 – 3	R4 – 6
X	R6 – 8	R4 – 5
X	R6 – 5	R4 – 4
X	R6 – 7	R4 – 2
X	R5 – 9	R4 – 7
X	R5 – 3	R4 – 3
X	R5 – 4	R4 – 8
X	R5 – 7	R4 – 9
X	R5 – 8	R4 -1
X	R5 – 1	R5 – 6
X	R5 – 5	R5 - 2
X	X	X

Key for Shepard seedling rootstock experiment

1. A8
2. A10
3. Duke 7
4. SHSR-02
5. Nabal
6. Reed
7. SHSR-03
8. Velvick
9. V1
10. Zutano

Lavers Orchard site plan continued…

Hass rootstock experiment

Hass seedling rootstocks

10	9	8	7	6
R10 – 2	R10 – 9	R5 – 6	R5 – 5	R1 – 3
R10 – 7	R10 – 6	R5 – 2	R5 – 8	R1 – 5
R10 -10	R10 – 8	R6 – 7	R5 – 3	R1 – 10
R10 - 1	R10 – 5	R6 – 2	R5 – 4	R1 – 1
X	R10 – 4	R6 – 10	R5 – 7	R1 – 4
X	R10 – 3	R6 – 4	R5 – 10	R1 – 7
X	R9 – 10	R6 – 1	R5 – 9	R1 – 2
X	R9 – 7	R6 – 6	R5 – 1	R1 – 9
X	R9 – 3	R6 – 9	R4 – 6	R1 – 8
X	R9 – 2	R6 – 3	R4 – 5	R1 – 6
X	R9 – 5	R6 – 8	R4 – 9	R2 – 4
X	R9 – 9	R6 – 5	R4 – 4	R2 – 10
X	R9 – 1	R7 – 4	R4 – 2	R2 – 6
X	R9 – 6	R7 – 7	R4 – 3	R2 – 1
X	R9 – 8	R7 – 2	R4 – 7	R2 – 9
X	R9 – 4	R7 – 1	R4 – 8	R2 – 7
X	R8 – 3	R7 – 8	R4 10	R2 – 2
X	R8 – 8	R7 – 10	R4 – 1	R2 – 5
X	R8 – 4	R7 – 3	R3 – 8	R2 – 3
X	R8 – 10	R7 – 6	R3 – 2	R2 – 8
X	R8 – 1	R7 – 9	R3 – 7	R3 – 5
X	R8 – 5	R7 -5	R3 – 3	R3 – 9
X	R8 – 9	R8 – 2	R3 – 10	R3 – 6
X	R8 – 7	R8 – 6	R3 - 1	R3 – 4
X	X	X	X	X

Hass cloned rootstocks

5	4	3	2
R1 – 3	R6 – 7	R6 – 2	R10 – 9
R1 – 5	R5 – 6	R6 – 10	R10 – 6
R1 – 10	R5 – 2	R6 - 4	R10 – 8
R1 – 4	R5 – 5	R6 – 1	R10 – 5
R1 - 1	R5 – 8	R6 – 6	R10 – 3
R1 – 7	R5 – 3	R6 - 9	R10 – 4
R1 – 2	R5 – 4	R6 – 3	R10 – 2
R1 – 9	R5 – 7	R6 – 8	R10 – 7
R1 – 6	R5 – 10	R6 – 5	R10 -10
R1 – 8	R5 – 9	R7 – 4	R10 – 1
R2 – 10	R5 – 1	R7 – 7	R9 – 10
R2 – 4	R4 – 6	R7 – 2	R9 – 7
R2 – 6	R4 – 5	R7 – 8	R9 – 3
R2 – 1	R4 – 9	R7 – 10	R9 – 2
R2 – 9	R4 – 4	R7 – 1	R9 – 9
R2 – 7	R4 – 2	R7 – 3	R9 – 5
R2 – 2	R4 – 7	R7 – 6	R9 – 1
R2 – 5	R4 – 3	R7 – 9	R9 – 6
R2 – 3	R4 – 8	R7 – 5	R9 – 8
R2 – 8	R4 – 10	R8 – 2	R9 – 4
R3 – 5	R4 – 1	R8 – 6	R8 – 8
R3 – 9	R3 – 8	R8 – 4	R8 – 3
R3 – 6	R3 – 2	R8 – 10	X
R3 – 4	R3 – 7	R8 – 1	X
R3 – 1	R3 – 3	R8 – 5	X
X	R3 – 10	R8 – 9	X
X	X	R8 – 7	X
X	X	X	X

Key for Hass cloned rootstocks

1. A8	6. Nabal
2. A10	7. Reed
3. Barr Duke	8. Thomas
4. Duke 7	9. Velvick
5. Hass clone	10. Zutano

Key for Hass seedling rootstocks

1. A8	6. Nabal
2. A10	7. Reed
3. Barr Duke	8. Rigato
4. Duke 7	9. Velvick
5. SHSR-02	10. Zutano

Simpson Farms Site Plan

Rootstock evaluation trial (planted 18th May, 2005)

Goodwood Road, Childers, QLD

Shepard Rootstock (seedling) Experiment

ROADWAY (North-east)

Hass seedling rootstock

R6 – 11	R1 – 3
R6 – 8	R1 – 7
R6 – 1	R1 – 9
R6 – 7	R1 – 4
R6 - 5	R1 – 11
R6 – 3	R1 – 2
R6 – 6	R1 – 6
R6 – 10	R1 – 10
R6 – 2	R1 – 1
R6 – 4	R1 – 5
R6 - 9	R1 – 8
R7 – 10	R2 – 9
R7 – 1	R2 – 2
R7 – 3	R2 – 4
R7 – 11	R2 – 11
R7 – 9	R2 – 7
R7 – 5	R2 – 1
R7 – 8	R2 – 8
R7 – 2	R2 – 3
R7 – 4	R2 – 5
R7 – 6	R2 – 10
R7 – 7	R2 - 6
R8 – 3	R3 – 11
R8 – 7	R3 – 7
R8 – 9	R3 – 1
R8 – 4	R3 – 5
R8 – 11	R3 – 8
R8 – 2	R3 – 2
R8 – 6	R3 – 6
R8 – 10	R3 – 3
R8 – 1	R3 – 10
R8 – 5	R3 – 4
R8 – 8	R3 – 9

Hass clonal rootstock

R6 – 8	R1 – 3
R6 – 1	R1 – 7
R6 – 7	R1 – 9
R6 – 5	R1 – 4
R6 – 3	R1 – 2
R6 – 6	R1 – 6
R6 – 2	R1 – 1
R6 – 4	R1 – 5
R6 – 9	R1 – 8
R7 – 1	R2 – 9
R7 – 3	R2 – 2
R7 – 9	R2 – 4
R7 – 5	R2 – 7
R7 – 8	R2 – 1
R7 – 2	R2 – 8
R7 – 4	R2 – 3
R7 – 6	R2 – 5
R7 – 7	R2 – 6
R8 – 3	R3 – 7
R8 – 7	R3 – 1
R8 – 9	R3 – 5
R8 – 4	R3 – 8
R8 – 2	R3 – 2
R8 – 6	R3 – 6
R8 – 1	R3 – 3
R8 – 5	R3 – 4
R8 – 8	R3 – 9
R9 – 9	R4 – 8
R9 – 2	R4 – 1
R9 – 4	R4 – 7
R9 – 7	R4 – 5
R9 – 1	R4 – 3
R9 – 8	R4 – 6
R9 – 3	R4 – 2
R9 – 5	R4 – 4
R9 – 6	R4 – 9

Shepard seedling rootstock

R6 – 11	R1 – 3
R6 – 8	R1 – 7
R6 – 1	R1 – 9
R6 – 7	R1 – 4
R6 - 5	R1 – 11
R6 – 3	R1 – 2
R6 – 6	R1 – 6
R6 – 10	R1 – 10
R6 – 2	R1 – 1
R6 – 4	R1 – 5
R6 - 9	R1 – 8
R7 – 10	R2 – 9
R7 – 1	R2 – 2
R7 – 3	R2 – 11
R7 – 9	R2 – 4
R7 – 5	R2 – 7
R7 – 11	R2 – 1
R7 – 8	R2 – 8
R7 – 2	R2 – 3
R7 – 4	R2 – 5
R7 – 6	R2 – 10
R7 – 7	R2 – 6
R8 – 3	R3 – 7
R8 – 7	R3 – 1
R8 – 9	R3 – 5
R8 – 4	R3 – 11
R8 – 11	R3 – 8
R8 – 2	R3 – 2
R8 – 6	R3 – 6
R8 – 10	R3 – 3
R8 – 1	R3 – 10
R8 – 5	R3 – 4
R8 – 8	R3 – 9

Irrigation hydrant

Simpson Farms site plan continued…

R9 – 9	R4 – 8
R9 – 2	R4 – 1
R9 – 4	R4 – 7
R9 – 7	R4 – 5
R9 – 1	R4 – 3
R9 – 11	R4 – 6
R9 – 8	R4 – 10
R9 – 3	R4 – 2
R9 – 5	R4 – 4
R9 – 10	R4 – 11
R9 – 6	R4 – 9
R10 – 7	R5 – 10
R10 – 1	R5 – 5
R10 – 5	R5 – 3
R10 – 8	R5 – 9
R10 – 2	R5 – 1
R10 – 6	R5 – 8
R10 – 3	R5 – 11
R10 – 10	R5 – 2
R10 – 4	R5 – 4
R10 – 9	R5 – 6
R10 - 11	R5 - 7

R10 – 4	R5 – 5
R10 – 2	R5 – 3
R10 – 7	R5 – 9
R10 – 1	R5 – 1
R10 – 5	R5 – 8
R10 – 6	R5 – 2
R10 – 3	R5 – 4
R10 – 9	R5 – 6
R10 - 8	R5 – 7

R9 – 9	R4 – 11
R9 – 2	R4 – 8
R9 – 11	R4 – 1
R9 – 4	R4 – 7
R9 – 7	R4 – 5
R9 – 1	R4 – 3
R9 – 8	R4 – 6
R9 – 3	R4 – 10
R9 – 5	R4 – 2
R9 – 10	R4 – 4
R9 – 6	R4 – 9
R10 – 7	R5 – 10
R10 – 1	R5 – 5
R10 – 5	R5 – 3
R10 – 11	R5 – 9
R10 – 8	R5 – 1
R10 – 2	R5 – 11
R10 – 6	R5 – 8
R10 – 3	R5 – 2
R10 – 10	R5 – 4
R10 – 4	R5 – 6
R10 – 9	R5 - 7

Key for Shepard seedling rootstock experiment

1. A10
2. Duke 7
3. Edranol
4. SHSR-02
5. Nabal
6. Parida
7. Plowman
8. Reed
9. Shepard (cloned rootstock)
10. Toro Canyon
11. Velvick

Key for Hass cloned rootstock experiment

1. A8
2. A10
3. Duke 7
4. Nabal
5. SHSR-03
6. Thomas
7. Velvick
8. V1
9. Zutano

Hass seedling rootstock experiment

1. A8
2. A10
3. SHSR-02
4. Nabal
5. Peasley
6. Reed
7. SHSR-03
8. Toro Canyon
9. Velvick
10. Velvick/Hazard
11. V1

Burton Site Plan – Block 8

Rootstock evaluation trial (planted 20th January, 2005)

Keys Road, Hampton, QLD

East *West*

Clonal Rootstocks				Seedling Rootstocks			
Row 4	**Row 5**	**Row 6**	**Row 7**	**Row 8**	**Row 9**	**Row 10**	**Row 11**
R10 – 7	R7 – 6	R6 – 5	R1 – 4	GUARD	GUARD	GUARD	GUARD
R10 – 5	R7 – 9	R6 – 2	R1 – 9	R10 – 5	R6 – 11	R6 - 4	R1 – 2
R10 – 2	R7 – 3	R6 – 10	R1 – 6	R10 – 8	R6 – 6	R5 – 6	R1 – 7
R10 – 10	R7 – 8	R6 – 7	R1 – 2	R10 – 10	R6 – 10	R5 – 9	R1 – 3
R10 – 4	R7 – 7	R6 – 8	R1 – 5	R10 – 7	R6 – 8	R5 – 5	R1 – 1
R10 – 1	R7 – 5	R6 – 1	R1 – 3	R10 – 4	R6 – 7	R5 – 11	R1 – 9
R10 – 6	R7 – 1	R6 – 3	R1 – 7	R10 – 2	R6 – 2	R5 – 4	R1 – 5
R10 – 9	R7 – 4	R6 – 9	R1 – 1	R10 – 11	R6 – 1	R5 – 2	R1 – 10
R10 – 3	R7 – 10	R6 – 6	R1 – 8	R10 – 3	R6 – 5	R5 – 10	R1 – 4
R10 – 8	R7 – 2	R6 – 4	R1 - 10	R10 – 1	R6 – 9	R5 – 7	R1 – 6
GEM	R8 – 8	R5 – 10	R2 – 2	R10 – 9	R6 - 3	R5 – 3	R1 – 8
GEM	R8 – 2	R5 – 5	R2 - 7	R10 – 6	R7 – 11	R5 – 8	R1 – 11
GEM	R8 – 5	R5 – 9	R2 – 1	R9 – 3	R7 – 2	R5 – 1	R2 – 8
GEM	R8 – 3	R5 – 6	R2 – 10	R9 – 10	R7 – 4	R4 – 6	R2 – 4
GEM	R8 – 1	R5 – 4	R2 – 8	R9 – 7	R7 – 7	R4 - 11	R2 – 1
A3	R8 – 7	R5 – 1	R2 – 3	R9 – 11	R7 – 1	R4 – 9	R2 – 7
A3	R8 – 9	R5 – 3	R2 – 6	R9 – 8	R7 – 6	R4 – 5	R2 – 6
A3	R8 – 4	R5 – 2	R2 – 4	R9 – 5	R7 – 5	R4 – 2	R2 – 11
A3	R8 – 10	R5 – 7	R2 – 5	R9 – 2	R7 – 9	R4 – 3	R2 – 5
A3	R8 – 6	R5 – 8	R2 – 9	R9 – 4	R7 – 3	R4 – 1	R2 – 10
A3	R9 – 8	R4 – 2	R3 – 8	R9 – 6	R7 – 8	R4 – 8	R2 – 3
A3	R9 – 7	R4 – 3	R3 – 1	R9 – 9	R7 – 10	R4 – 10	R2 – 9
A3	R9 – 1	R4 – 9	R3 – 4	R9 – 1	R8 – 9	R4 – 4	R3 – 6
A3	R9 – 6	R4 – 5	R3 – 10	R8 – 7	R8 - 2	R4 – 7	R3 – 11
A3	R9 – 10	R4 – 6	R3 – 7	R8 – 4	R8 – 6	R3 – 4	R3 – 2
G1033	R9 – 3	R4 – 4	R3 – 5	R8 – 5	R8 – 3	R3 – 8	R3 – 9
G1033	R9 – 5	R4 – 7	R3 – 2	R8 – 1	R8 – 10	R3 – 3	R3 – 5
G335	R9 – 9	R4 -10	R3 – 6	GUARD	R8 – 8	R3 – 10	R3 – 7
G335	R9 – 4	R4 – 8	R3 – 9	GUARD	R8 – 11	R3 – 1	GUARD
G6 parent	R9 – 2	R4 - 1	R3 - 3	GUARD	GUARD	GUARD	GUARD

Spacing 9m x 6m

Burton site plan continued…

East *West*

Row 1	Row 2	Row 3
		A4
		A4
		A4
		A4
		A4
		A4
		A4
		A4
		A4
		A4
		G6 parent
		G3/71
		G1-66

Spacing 9m x 6m

15. Appendix II

15.1 Field assessment of avocado rootstock selections for resistance to Phytophthora root rot

L. A. Smith[A], *E. K. Dann*[B], *K. G. Pegg*[A] and *A. W. Whiley*[C]

[A] Agri-Science Queensland, Department of Employment, Economic Development and Innovation, Ecosciences Precinct, 41 Boggo Rd, Dutton Park, QLD, Australia
[B] Queensland Alliance for Agriculture and Food Innovation, University of Queensland, Ecosciences Precinct, 41 Boggo Rd, Dutton Park, QLD, Australia
[C] Sunshine Horticultural Services, 287 Dulong Rd, Nambour, 4560, QLD, Australia

Corresponding author: Elizabeth K. Dann, e.dann@uq.edu.au

Keywords: Phytophthora cinnamomi

Abstract

The use of *Phytophthora cinnamomi* (Pc) resistant rootstocks has become an increasingly useful tool in the integrated management of Phytophthora root rot (PRR) in avocado orchards. Field trials have been conducted at three locations in the eastern production areas of Australia since December 2005 in replant land with a history of PRR to assess the performance of rootstock selections. Seedling and clonally-propagated rootstocks were included from a range of currently used rootstocks as well as material selected from trees which had survived for many years despite high Pc pressure, i.e. "escape" trees. All rootstocks were grafted with 'Hass' scions.

New selections 'SHSR-02', SHSR-04', ungrafted 'Hass' (rooted cuttings from clonal propagation) and the commercially available rootstock 'Dusa™' were found to be consistently better survivors and healthier over time compared to other rootstocks including 'Reed', 'Velvick' and 'A10'. Superior health was often associated with increased tree height and trunk girth. 'Reed' was consistently highly susceptible, and had the lowest yields at a site with relatively low PRR pressure where tree health of 'Reed' only was compromised by Pc. Soil baiting and root isolations confirmed the presence and infectivity of Pc in soils at the field sites. The trials clearly demonstrated the advantage of using rootstocks able to withstand high *Pc* pressure when establishing new avocado orchards, particularly in replant land.

EVALUACIÓN DE CAMPO EN PIES DE INJERTO DE AGUACATES SELECCIONADOS PARA LA RESISTENCIA A LA PUDRICIÓN DE RAÍZ POR PHYTOPHTHORA

El uso de pies de injerto, en cultivos de aguacate, resistentes a *Phytophthora cinnamomi* (Pc) se ha convertido en una herramienta útil para el manejo integrado de la pudrición de raíz por *Phytophthora* (PRR). Para evaluar el comportamiento de los pies de injerto seleccionados, se realizaron trabajos de campo en tres lugares del Este de Australia desde 2005 en tierras

replantadas en donde se había reportado la presencia de PRR. Para ello se incluyeron pies de injerto propagados por semilla o clonados como también material seleccionado de árboles los cuales han sobrevivido muchos años a pesar de la alta presión ocasionada por Pc, por ejemplo 'escape'. Todos los pies de injerto fueron injertados con vástagos de 'Hass'.

Se encontró que nuevas variedades de 'Hass' no injertadas (esquejes enraizados por propagación clonal), 'SHSR-02' y 'SHSR-04', sobrevivieron y fueron más sanos que otros pies de injerto incluyendo 'Reed', 'Velvick' y 'A10'. La salud es asociada con el aumento de la altura y grosor del tronco del árbol. 'Reed' es altamente susceptible y el rendimiento más bajo en lugares de baja presión ocasionada por PRR en donde la salud de 'Reed' solo era comprometida por Pc. Muestras de suelo y raíces aisladas confirma la presencia e infección por Pc. Los ensayos demostraron claramente la ventaja al establecer nuevos cultivos de aguacate, especialmente en tierras replantadas, al utilizar aquellos pies de injerto que pueden soportar altas presiones ocasionadas por Pc.

Introduction

Phytophthora root rot (PRR), caused by the oomycete pathogen *Phytophthora cinnamomi* (Pc) is ubiquitous within avocado production areas in Australia and overseas, and is considered the most destructive and important disease. Its impact is currently reduced using an integrated approach including cultural (mulching, adequate drainage and optimal nutrition), chemical (potassium phosphonate) and genetic approaches (breeding and selection of resistant or tolerant rootstocks). Recent selections, identified and developed from trees which have survived for some years in the presence of Pc, have been included in field trials at three sites, known to have high Pc populations. Their growth and survival was monitored over time, since planting in late 2005 and early 2006. The majority of this work has recently been published (Smith *et al.* 2011) and the reader is referred to the publication for full details.

Materials and Methods

All details of field trials conducted to assess establishment, survival and performance of a range of rootstock material are described in a recent publication of this work, and will not be repeated in detail here. See paper by (Smith *et al.* 2011). Very briefly, 3 sites were chosen on commercial avocado orchards which had a history of severe Phytophthora root rot in trees prior to bulldozing the block. The sites were at Duranbah, northern NSW, Hampton, south-east Queensland and Childers, central Queensland. Several trees of each rootstock (with 'Hass' scions) were planted at each site. Trees were sourced from our collaborator, Dr Tony Whiley, and also from Anderson's Nursery and Birdwood Nursery. Rootstocks included those recovered from 'escape' trees, that is, those which have survived for long periods despite high *P. cinnamomi* pressure. Trees were treated with phosphonate and metalaxyl for the establishment period, to allow vigorous growth and favourable root:shoot ratio such that they had the opportunity to express resistance once Pc protection measures were discontinued. Trees were assessed regularly for canopy health, on a 0 to 10 scale (Darvas *et al.* 1984), and fruit yields (weight and pieces of fruit per tree) were collected in 2009 and 2010.

Results and discussion

Full details of this work are available in Smith et al, 2011, and for copyright reasons, will not be duplicated here. Briefly, two selections 'SHSR-02' and 'SHSR-04', as well as ungrafted 'Hass' and the commercial rootstock 'Dusa™' were significantly better survivors and were healthier over time than other rootstocks including 'Velvick' (from various sources), 'Duke 7', A8, A10, 'Reed', 'Latas™', 'Rigato' and 'Barr Duke'. 'Reed' was consistently highly susceptible and most of these trees had died within the 4 year assessment period. Superior tree health was often associated with increased tree height and trunk girths (Smith *et al.* 2011). The study demonstrated variation in establishment of trees under high disease pressure, for example at the Duranbah, NSW site (Plate 1), tree health after 2 years ranged from 2.7 to 8.5, (on a scale where 10 = dead), compared with under a lower disease pressure at the Childers QLD site 3 years after planting where tree health ranged from 0 (healthy) to 2.2. In other words, trees thrived under lower Pc pressure at Childers in the first 3 years of the trial.

More recent data on health of trees in the Childers trial, and fruit yields, is presented in Table 1 (not included in above mentioned publication). At 4 and 4.5 years after planting, the effects of Phytophthora root rot were becoming more apparent, with trees on 'Reed' rootstock scoring an average of 6.7 and 6, respectively (compared to a maximum of 2.2 in previous years). Trees on 'Reed' rootstock were significantly less healthy than all others except 'Velvick' seedling (Anderson) at both assessment times, and 'A8' and 'A10' assessed 4.5 years after planting (Table 1). The healthiest trees were on 'Dusa' and 'Latas' rootstock. Despite having the healthiest canopies, 'Dusa' and 'Latas' were not the highest yielding rootstocks in 2010, having yields of 80% and 88% those of the highest yielding rootstock 'Velvick' seedling (Simpson). 'Reed' rootstock yielded very poorly, with only 30% the weight of fruit compared to 'Velvick' seedling (Simpson). This poor performance could be due to its relative ill thrift, and known high susceptibility to PRR. Root examination, selective isolation of roots on selective media and lupin baiting for Phytophthora confirmed an extremely high population of *P. cinnamomi* at all trial sites

Rootstock selections with increased establishment and survival capability under high Phytophthora root rot (PRR) disease pressure have been identified in this project. Selections 'SHSR-02', 'SHSR-04', ungrafted 'Hass' (rooted cuttings from clonal propagation), and the commercial rootstock 'Dusa™' were significantly healthier over time than other rootstocks, including many commercially grown such as 'Reed', 'Velvick' and 'Duke 7'. There is very little evidence for the source and/or mechanisms of the observed tolerance, and further research on the G x E (genotype x environment) interactions, root regeneration capacity, biochemical and/or genetic markers (as discussed in (Smith, Dann *et al.* 2011) is necessary. Also of interest in the current study was the superior performance of ungrafted 'Hass' in one trial (results not presented here), and raises the question about whether grafting in some situations may exacerbate either root or canopy/fruit diseases, due to potential physiological stress imposed. This issue will be investigated further.

Plate 1 Rootstock trial at Duranbah, NSW, demonstrating healthy tree on 'SHSR-04' selection among less thrifty trees

Table 1 Average health and yield of trees grafted to different rootstocks in the Childers trial, established in May 2006.

Rootstock	Tree health at 4 years		Tree health at 4.5 years		Crop Weight per tree (kg)		Pieces of Fruit/tree	
Velvick seedling (Lynwood)	3.8	bcd	3.0	bcd	80.0	a	329	a
Latas™ clonal	2.7	cd	2.5	cd	70.4	ab	268	ab
A8 seedling	3.9	bcd	4.1	abc	68.2	ab	289	ab
Dusa™ clonal	2.4	d	1.2	d	64.7	ab	240	abc
A10 seedling	4.3	bc	4.2	abc	56.9	abc	250	abc
Velvick seedling (Anderson)	5.1	ab	4.9	ab	46.3	bcd	191	bcd
Velvick clonal (Whiley)	4.9	b	3.8	bc	35.2	cd	144	cd
Reed seedling	6.7	a	6.0	a	23.9	d	97	d

Average tree (canopy) health ratings were assessed using a rating scale of 0-10, where 0 = healthy and 10 = dead, at approx. 4 and 4.5 years after planting. Yield parameters assessed 4 years after planting.
Mean values within columns followed by the same letter are not significantly different at P = 0.05.

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