Final Report

Evaluation of new rootstocks for the Australian citrus industry 2017-2022

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Public summary

The national citrus rootstock evaluation program of Australia is a multi-stage process involving establishing source trees, ensuring uniformity of rootstock seeds and seedlings, glasshouse screening for disease and salt tolerance, short-term preliminary field trials to evaluate horticultural performance, and longer-term evaluation in semi-commercial plantings in a range of soil, climatic and management conditions. The objective of the project was to test a range of rootstocks in different soil and climatic conditions and recommend the superior rootstocks that can produce higher yields and fruit quality as good as, or better than, existing rootstocks used in Australia. This report describes results from preliminary field trials conducted to investigate rootstock effects on the horticultural performance of a range of scion varieties. The trials were conducted in major regions for citrus production in the Murray Valley, Riverina, Riverland, Queensland, and Western Australia. During the program, 77 scion/rootstock combinations were tested in several trials, and another 120 scion/rootstock combinations will be planted around Australia in October 2023. The promising rootstocks were identified from the commercially orientated and industry-based trials in the major regions for citrus production. The dwarfing effect rootstocks for high density planting and the Italian rootstocks were established at the NSW DPI Dareton Research Institute. The program also initiated the establishment of the HLB tolerant rootstocks at NSW DPI Dareton, NSW DPI Griffith and around Australia.

The rootstock evaluation program with a range of scion varieties has been a great success. During the start of the project, 6 high performing rootstocks were released for the citrus industry in 2017. The rootstock seed for the 6 rootstocks is now available from AusCitrus. Rootstock will be available to overseas institutes under a research agreement for research purposes.

The selected Chinese rootstocks were expanded to the semi-commercial trial on processing oranges and Zao Yang was identified as the best rootstock with Valencia 5 (DV Valencia) the superior scion. The work on salt tolerant rootstock was a great success and 2 hybrid rootstocks 3822 (Scarlet mandarin × *Poncirus trifoliata*) and 3834 (Scarlet mandarin × *Poncirus trifoliata*) from the NSW DPI breeding program were identified as the best rootstock able to tolerate saline irrigation conditions. The dwarfing potential for high density planting was tested by introducing 2 Chinese rootstocks to a trial at Dareton with M7 navel and Tangold mandarin. Although the trial is not completed yet, 2 rootstocks (No. 24, *Poncirus trifoliata* and 85-24, *Poncirus trifoliata*) are showing promise as a potential rootstock for high-density plantings. Semi-commercial trial sites around Australia were established in 2017 with Chinese rootstocks in different soil and climatic conditions. The data collected during those trials indicate that Ghana (*Poncirus trifoliata*) and Tanghe (*Poncirus trifoliata*) are proving to be promising rootstocks for yield and Zao Yang (*Poncirus trifoliata*) is continuing to produce sweeter fruit in Afourer mandarins. However, another 4 years of data are required to complete these trials and make recommendations.

During the program, 3 Italian rootstocks were introduced and were budded with 3 scion varieties: Imperial, Nectar and Tangold mandarins. The trial was planted in 2020 and another 5 years of data are required to make recommendations to the citrus industry. HLB tolerant rootstocks were recently imported from the United States. These rootstocks have now been raised and will be budded with sweet orange, mandarin, and limes. The experimental plan has been finalised to establish trials at the NSW DPI research institutes at Dareton and Griffith. Trials will also be established around Australia in 5 states at growers' properties. After the trial establishment in October 2023, rootstocks will be evaluated for their effects on yield, fruit quality, fruit size distribution and tree growth.

Technical summary

The national citrus rootstock evaluation program of Australia is a multi-stage process involving establishing source trees, ensuring uniformity of rootstock seeds and seedlings, glasshouse screening for disease and salt tolerance, short-term preliminary field trials to evaluate horticultural performance, and longer-term evaluation in semi-commercial plantings in a range of soil, climatic and management conditions. The objective of the project was to test a range of rootstocks in different soil and climatic conditions and recommend the superior rootstocks that can produce higher yields and fruit quality as good as, or better than, existing rootstocks used in Australia. This report describes results from preliminary field trials conducted to investigate rootstock effects on the horticultural performance of a range of scion varieties. The trials were conducted in major regions for citrus production in the Murray Valley, Riverina, Riverland, Queensland, and Western Australia. During the program, 77 scion/rootstock combinations were tested in a range of trials, and another 120 scion/rootstock combinations will be planted around Australia in October 2023. The promising rootstocks were identified from the commercially orientated and industry-based trials in the major regions for citrus production. The dwarfing rootstocks for high density planting and the Italian rootstocks were established at the NSW DPI Dareton Research Institute. The program also initiated the establishment of the HLB tolerant rootstocks at NSW DPI Dareton, NSW DPI Griffith and around Australia.

The program for the rootstock evaluation with a range of scion varieties has been a great success. During the start of the project, 6 high performing rootstocks were released for the citrus industry in 2017. The rootstock seed for the 6 rootstocks is now available from AusCitrus. Rootstock will be available to overseas institutes under a research agreement for research purposes.

The selected Chinese rootstocks were expanded to the semi-commercial trial on processing oranges and Zao Yang was identified as the best rootstock with Valencia 5 (DV Valencia) the superior scion. The results indicated the cumulative yield over 5 years produced 194 kg/tree with Valencia 5/Zao Yang scion/rootstock combination compared to 139 kg/tree with the control combination of Keenan/Tri22. The Valencia 5/Zao Yang combination produced 40% extra yield. The average °Brix values during the 5 years were 1.7 degrees higher for Valencia 5 than Keenan Valencia.

The work on salt tolerant rootstock was a great success and 2 hybrid rootstocks, 3822 (Scarlet mandarin × *Poncirus trifoliata*) and 3834 (Scarlet mandarin × *Poncirus trifoliata*), from the NSW DPI breeding program were identified as the best rootstocks able to tolerate saline irrigation conditions. The yield data indicated that rootstock 3834 produced the cumulative yield of 352 kg/tree followed by 3822 (348 kg/tree) compared to *Troyer citrange* (317 kg/tree). The fruit size distribution data indicated that the NSW hybrids (3834, 3812, 3835) had a slight increase in per cent large fruit size (76–90 mm) compared to *Troyer citrange*.

The potential of the dwarfing rootstock for high density planting was tested by the introduction of 2 Chinese rootstock to a trial at Dareton with M7 navel and Tangold mandarin. Although the trial is not completed yet, 2 rootstocks (No. 24, *Poncirus trifoliata* and 85-24, *Poncirus trifoliata*) are showing promise as potential rootstocks for high-density plantings. The data collected on trunk circumference in 2021 indicated that 85-24 and Tri22 had a trunk circumference of 13.5 cm compared to No. 24 (11.7 cm). Tree height was very similar for these 3 rootstocks. This suggests that No. 24 seems to be more dwarfing than the other 2 *Poncirus trifoliata* rootstocks. Two rootstocks, 85-24 and No. 24, have the potential to be used ina high-density situation. After the completion of this, an economic analysis is needed before recommendations are made to the citrus industry.

Semi-commercial trial sites around Australia were established in 2017 with Chinese rootstocks in different soil and climatic conditions. The data collected during those trials are indicating that Ghana (*Poncirus trifoliata*) and Tanghe (*Poncirus trifoliata*) are proving to be promising rootstocks for yield and Zao Yang (*Poncirus trifoliata*) is continuing to produce sweeter fruit in Afourer mandarins. However, another 4 years of data are required to complete these trials and make recommendations. During the program, 3 Italian rootstocks (F5 P12, F6 P12 and F6 P13) were introduced and were budded with 3 scion varieties: Imperial, Nectar and Tangold mandarins. The trial was planted in 2020 and another 5 years of data are required before recommendations can be made to the citrus industry. HLB tolerant rootstocks were recently imported from the United States. These rootstocks have now been raised and will be budded with sweet orange, mandarin and limes. The experimental plan has been finalised to establish trials at the NSW DPI research institutes at Dareton and Griffith. Trials will also be established around Australia in 5 states at growers' properties. After the trial establishment in October 2023, rootstocks will be evaluated for their effects on yield, fruit quality, fruit size distribution and tree growth.

Keywords

Valencia, Washington navel, Afourer, Tangold, Huanglongbing, salt tolerant, dwarfing, processing oranges, fruit quality, fruit size distribution, Italian rootstocks, Chinese rootstocks.

Introduction

The Australian citrus industry is one of Australia's largest horticultural industries, with over 28,300 ha planted in 5 states and one territory. In 2019, over 290,000 tonnes of citrus fruit valued at $524.5 million were exported. Sweet oranges accounted for 68% of the volume and 58% of the value, while mandarins accounted for 30% of the volume and 40% of the value. Australia exported fruit to 48 countries, with 24 of those countries in Asia (Milner 2022). The breakup of export tonnage is given in Table 1.

Table 1: Total export in tonnes and per cent of the total export to 48 different countries in 2019.

Countries	Export (tonnes)	Per cent of total export
China, Japan, Hong Kong	150,513	52
14 other Asian countries	112,643	39
US, Canada, New Zealand, PNG	23,660	8
Others	4,118	1

Increasing fruit sales at profitable prices is vital for the growth and sustainability of the citrus industry. Information on consumer preferences and motivators for purchase are important in that process. In general, large-size fruit with a good external appearance will prompt consumers to buy, while a good fruit quality will encourage them to make repeat purchases.

History of the rootstock evaluation program

Rootstocks have a major effect on the horticultural performance of citrus scion varieties and consequently influence the health and productivity of the citrus industry (Broadbent and Gollnow, 1993). Citrus rootstocks affect tree vigour and size, fruit yield and size (Castle 1987) and enable scions to be grown in a range of growing conditions. Therefore, using improved rootstocks is an important step toward achieving a more productive and competitive industry. The Australian citrus industry is focused on developing fresh fruit and juice production as well as expanding export market opportunities.

The priorities for rootstock improvement in Australia were determined by a national citrus rootstock screening working party that formed in 1985. The major objectives of this working party were to promote a nationally coordinated rootstock evaluation program and to review screening procedures to determine the most effective means of evaluating germplasm for characteristics deemed essential, desirable or of minor importance. These characteristics reflect disease pressures and growing conditions in major production areas as well as anticipated developments within the industry. Fruit production, fruit quality, fruit size and tree size have become significantly important for the citrus industry for domestic and export markets. The ranking of characteristics deemed necessary for Australian citrus rootstocks and agreed to by the working party in the mid-1980s has since underpinned the national program for rootstock improvement.

The National Citrus Rootstock Improvement Program was initiated because of the deliberations of the mid-80s working party. Rootstock improvement in Australia incorporates a multi-stage process starting with screening in a greenhouse for disease tolerance, graft union compatibility, seedling uniformity and salt tolerance before short-term replicated field trials are conducted on a range of scion varieties in different climatic and soil conditions, where tree growth, yield, fruit size, and quality are evaluated. Promising rootstocks are then selected for long-term commercial trials under a range of soil, climatic and management conditions (Bevington 1998; Khurshid et al. 2007; Khurshid and Donovan 2018)

Background of the current project

The development, evaluation, and commercialisation of high-performing rootstocks to increase yield efficiency, fruit size and external and internal fruit quality are important for developing a more productive and competitive citrus industry in Australia. *Poncirus trifoliata*, Troyer and Carrizo citranges are rootstock varieties commonly used in Australia for oranges and mandarins. While these rootstocks have many desirable characteristics, they also have some negative attributes that can affect citrus production. For example, these rootstocks are highly susceptible to salinity found in the soil and irrigation water in the major citrus growing areas in Australia (i.e., the Sunraysia region in north-west Victoria, south-west New South Wales, the Riverland of South Australia and Bindoon, Western Australia). Root zone salinity has been shown to affect citrus fruit yields and quality (Sykes 2011). In another example, *Poncirus trifoliata* rootstocks are often unsuitable for Australian mandarin varieties and a strong overgrowth at the graft union is observed on mature Imperial mandarin trees.

Accordingly, the National Citrus Rootstock Improvement Program seeks to identify and develop new rootstocks with advantages over currently used stocks where biotic and abiotic stress factors restrict Australian citriculture from reaching its full potential. This project was closely aligned with the national citrus industry and used many short-term rootstock trials established in the main citrus growing regions to identify rootstocks that improved scion performance for yield, cropping efficiency, fruit quality, salt tolerance and disease resistance. The anticipated output from the project was that superior genotypes would be recommended for testing in wider, commercial trials. Some of those trials are now completed and reported on in this final report, while some of those trials, which were initiated during the start of this project, will be completed in the next project.

Project objectives

The objectives of this project were:

1. to assess the horticultural performance of Chinese trifoliata type rootstocks in a semi-commercial trial with a range of Valencia selections in the Riverina (Experiment 1).
2. to establish and evaluate the salt tolerance of rootstocks in Bindoon, Western Australia (Experiment 2).
3. to establish the dwarfing rootstock trials and assess their horticultural performance with M7 navel and Tangold mandarin at NSW DPI Dareton (Experiment 3).
4. to establish rootstock trials on grower's properties with a range of newly released rootstock and scion combinations throughout Australia (Experiment 4).
5. to propagate 3 new Italian rootstock hybrids grafted to 3 mandarin varieties and establish a trial at NSW DPI Dareton (Experiment 5).
6. to import HLB tolerant rootstocks from the USA and establish experimental trials at Dareton (Experiment 6).

Therefore, this final report will present the methodology and results of the experiments in the following order:

Experiment 1: Evaluation of selected Chinese rootstocks on a range of Valencia selections conducted in a semi-commercial trial in Riverina.

Experiment 2: Establishment and evaluation of salt tolerant rootstocks on Washington navel in Bindoon.

Experiment 3: Evaluation of dwarfing rootstocks on M7 navel and Tangold mandarin at Dareton.

Experiment 4: Evaluation of selected rootstocks at grower's properties around Australia.

Experiment 5: Establishment and evaluation of Italian rootstocks trial at Dareton.

Experiment 6: Establishment of HLB tolerant rootstock trials at Dareton and around Australia.

Methodology

A brief description of the methodology for each experimental trial is given below, however, the detailed methodology is given in the representative experimental chapters in Appendix 1.

Experiment 1. Evaluation of selected Chinese rootstocks on a range of Valencia selections was conducted in a semi-commercial trial in the Riverina

This trial was planted in October 2010 at a grower's property as a semi-commercial trial in sandy clay loam soil at Stanbridge, Leeton. Trees were planted 1.8 m apart within the rows and 5 m between rows in an east-west orientation. The trial was designed as a two-factorial set-up in a randomised block design. There were 7 Valencia selections; Valencia 1, Valencia 2, Valencia 3, Valencia 4, Valencia 5, Valencia 6, and Keenan Valencia (control) as Factor 1 and 4 *Poncirus trifoliata* rootstocks; Zao Yang, Tanghe, Donghai, and Tri22 (control) as Factor 2. Treatment combinations were replicated 3 times with 5 tree plots for each combination. The middle 3 trees were selected for data collection. Data on fruit yield and internal fruit quality were collected for 5 years, while data for tree growth were collected for 6 years from 2014 to 2019.

Experiment 2. Establishment and evaluation of salt tolerant rootstocks on Washington navel in Bindoon

The salt tolerant rootstock trial was established in Bindoon, Western Australia on 4 April 2013. There were 11 rootstocks grafted to Washington navel. Trees were planted 3 m apart within the rows and 7 m between rows in a north-south orientation. Rootstocks were planted in a single tree plot as a randomised complete block design replicated 3 times. The rootstocks were introduced from NSW DPI and USDA breeding programs, and China. Data on fruit yield were collected for 6 years and fruit quality for 4 years. Tree growth data were collected for the consecutive 8 years from 2014 to 2021.

Experiment 3. Evaluation of dwarfing rootstocks on M7 navel and Tangold mandarins at Dareton

Two trials were established on M7 navel and Tangold mandarin with 7 rootstocks at the NSW DPI Dareton Research Station in October 2017. These rootstocks were from China and the Californian breeding program; Tri22 (Australian strain) was used as a control. Trees were planted 2.6 m apart within the rows and 3.5 m between rows in a north-south orientation with a tree density of 1,098 trees/ha. The performance of these new rootstocks was evaluated from 2019 to 2021. Data on tree growth, fruit yield and fruit quality were recorded and presented.

Experiment 4. Evaluation of selected rootstocks at grower's properties around Australia

Trial sites were established around Australia in October 2017 and 2018. Scions of sweet oranges and mandarins were grafted to a range of Chinese rootstocks. Trees in grower's trials were planted 3 m apart within the rows and 5 m between rows with a tree density of 666 trees/ha. Four to 8 tree plots were replicated 4 times in a randomised completed block design depending on the trial. A more detailed methodology is presented in Chapter 4 of this report in Appendix 1. Data on tree growth, fruit yield and fruit quality were collected in the last 3 years.

Experiment 5. Establishment and evaluation of Italian rootstocks trial at Dareton

Trees were planted on 10 March 2020 at NSW DPI Dareton Research Station. Trees were planted 3 m apart within the rows and 6 m between rows in an east-west orientation with a tree density of 555 trees/ha. Four tree plots were replicated 5 times in a randomised completed block design for each rootstock-scion combination. Yield and fruit quality data will be collected in the coming years. However, data on fruit quality and tree growth are presented in this report.

Experiment 6. Establishment of HLB tolerant rootstock trials at Dareton and around Australia

27 HLB rootstocks arrived in Australia in 2021 from the United States. A set of 7 rootstocks were provided by the USDA, Fort Pierce, which arrived at Dareton Research Institute in November 2020. These rootstocks have been germinated (Figure 1) and were grafted to a range of varieties in November 2022. At this time, trials will be established at Dareton Research Station and the rootstocks will be evaluated for tree growth, fruit yield and internal fruit quality. A set of 20 rootstocks were provided by the University of Florida, Lake Alfred, which arrived at Dareton Research Station in April 2021 (Figure 2). These rootstocks have been germinated and will be grafted to a range of varieties once ready. The trials will be established at Dareton Research Station, and they will be evaluated for tree growth, fruit yield and internal fruit quality. Trial sites have been identified in 5 states of Australia; therefore, trials will be established around Australia in

Spring 2023. Two mirror trials will be established at NSW DPI Dareton and Griffith Research Stations in 2 soil types. Details are given in Chapter 6 (Appendix 1).

Results and discussion

The experimental program for the national rootstock evaluation was conducted over 5 years from 2018 to 2022. This program involved 6 experimental components (Appendix 1), and there were a range of field trials under each experimental component (Refer to Methodology section of this report). This section discusses the key results from the program; however, detailed results are given in Appendix 2 (Chapters 1–6).

Release of 6 high-performing rootstock to the Australian citrus industry

Six high-performing rootstocks were released to the industry at the start of this project in late 2017 at the Parliament building in Sydney (Appendix 1). The recommendation of these rootstocks was based on the experimental data collected on fruit yield, fruit quality, tree growth and fruit size distribution at the NSW DPI Dareton Research Institute. The recommended rootstocks Zao Yang, Donghai, Tanghe and Ghana are *Poncirus trifoliata* types, while Anjiang hongju and Cao shixhiangju are *Citrus erythrosa* (mandarin) types. These recommended rootstocks were expanded to semi-commercial trials that were established during the current project and results are presented in this final report.

Experiment 1: Processing orange trial in Stanbridge Leeton, NSW

The first component of the program was to test the selected Chinese rootstocks in a replicated semi-commercial trial at a grower's property in the Riverina. The trial was planted in October 2010 with the recommended Chinese rootstocks: Zao Yang, Tanghe and Donghai, while Tri22 (Australian strain) was used as a control. Six Valencia selections (Valencia 1 to Valencia 6) were used as a scion variety, while Keenan Valencia was used as a control. Data were collected for yield, fruit quality, tree growth and fruit size distribution for 5 years. The data indicated that Zao Yang had increased cumulative yield (180 kg/tree) compared to Tri22 (137 kg/tree); this was an increase of 27% in fruit yield. Yield efficiency for Zao Yang was 3.5 kg/TCSA (Trunk Cross Sectional Area) compared with 3.1 kg/TCSA for Tri22. Zao Yang also displayed a low ABI (Alternate Bearing Index) of 0.19 compared to other rootstocks including Tri22. In terms of Valencia selections, Valencia 5 trees had significantly higher cumulative yields (162 kg/tree) than other selections, except for Valencia 2.

The interaction effect between scion and rootstock selections was not statistically significant for cumulative yield, however, the Valencia 5/Zao Yang combination produced 194 kg/tree compared to Keenan/Tri22 (139 kg/tree) and Valencia 4/Donghai (127 kg/tree). This result has a significant importance to the citrus industry as the Valencia 5/Zao Yang combination was able to produce 40% more yield than the Keenan/Tri22 combination.

Scion variety had a significant effect on fruit quality over the 5 growing seasons. Fruit produced on Valencia trees had significantly increased TSS (Total Soluble Solids) levels compared with Keenan Valencia each season. In the 2015, 2016 and 2018 seasons, fruit produced on Valencia 5 trees had an average of 12.0 °Brix compared to 10.7 °Brix in fruit produced on Keenan Valencia. In 2017, the °Brix values were lower, and in 2019 the °Brix values were higher for all treatment combinations. The average °Brix values across the 5 years were 1.7 degrees higher for Valencia 5 than Keenan Valencia. Zao Yang rootstock had the highest percentage of fruit larger than 75 mm diameter (43%) compared with other rootstocks that produced an average of 30% fruit in the higher size class. Valencia 6 had the highest percentage of large fruit (47%) compared with all other Valencia selections tested in this experiment. The interaction effect indicated the Valencia 6/Zao Yang combination had a significantly higher percentage of large sized fruit (58%) compared to the control combination of Keenan/Tri22 (35%). Generally, Valencia 5 trees had a larger trunk circumference compared to Keenan Valencia. Zao Yang had larger canopy volumes compared to Tri22. The net contribution of Zao Yang rootstock towards the yield increases and fruit size was 10%

Experiment 2: Salt tolerant rootstock trial, Bindoon, WA

The salt tolerant rootstocks were tested with Washington navel in Bindoon, WA with saline irrigation water in a trial planted in April 2013. Ten rootstocks (including *Troyer citrange* as a control) from the NSW DPI breeding program, USDA breeding program and the Chinese rootstock program were evaluated. Data on fruit yield, fruit quality and tree growth were collected for 6 years. Soil, leaves and irrigation water were tested for salinity during the trial. The yield data indicated that rootstock 3834 produced a cumulative yield of 352 kg/tree followed by 3822 (348 kg/tree) compared to *Troyer citrange* (317 kg/tree). The fruit size distribution data indicated that the NSW hybrids (3834, 3812, 3835) had a slight increase in per cent of large size fruit (76–90 mm) compared to *Troyer citrange*. The fruit quality effects were not significant, however, an average of 5 years data for TSS suggested that °Brix values ranged from 11.0 to 13.0. Zao Yang was among the rootstock producing 12 °Brix. A larger trunk circumference was recorded for 3822 (30.9 cm) followed by *Troyer citrange* (30.4 cm) in 2021 at the end of this experiment.

Experiment 3: Dwarfing effect trial for high-density planting, Dareton, NSW

The dwarfing rootstock trial (Chapter 3, Appendix 2) for high density plantings was established at Dareton in October 2017. Selected Chinese rootstocks and Californian hybrid rootstocks were used with M7 navel and Tangold mandarin. Since the Chinese rootstock No. 24 and 85-24 used in this trial were *Poncirus trifoliata* selections Tri22 was used as a control rootstock. The Californian rootstocks C-22, C-35, C-54, and C-57 produced higher yields (approximately 50 kg/tree) compared to C-146 (37 kg/tree) and C-57 (41 kg/tree). It should be noted that the Californian rootstocks had large tree size and they were citrange and citrandarin types. These are generally well suited to the deep soil loam conditions of the Sunraysia district. The dwarfing rootstocks, 85-24 and No. 24 produced 29 kg/tree and 15 kg/tree of yield respectively, compared to Tri22 (28 kg/tree). The TSS values were higher for No. 24 (13.7 °Brix) in 2020 and 14.7 °Brix in 2021, suggesting that No. 24 rootstock will have sweeter fruit if the pattern in sugar increase is going to be consistent for another 3 years. Tree size is one of the important variables in selecting a dwarfing rootstock for high density planting. The data collected on trunk circumference in 2021 indicated that 85-24 and Tri22 had a trunk circumference of 13.5 cm compared to 11.7 cm for No. 24. Although tree height was very similar for these 3 rootstocks, No. 24 seems to be dwarfing more than the other 2 *Poncirus trifoliata* rootstocks. Two rootstocks, 85-24 and No. 24, have the potential to be used in a high-density situation. After the completion of this, an economic analysis is needed before recommendations are made to the citrus industry.

Experiment 4: Grower's trials (NSW, Vic, WA, SA, QLD)

The selected Chinese rootstocks with the new scion varieties in different soil types and climatic condition at growers' properties were established in 5 states of Australia. Several trials were established in October 2017 or 2018. The rootstocks used in these trials were Zao Yang, Tanghe, Ghana, Nianju and Anjiang hongju. Most of the trials were established with Afourer mandarins and a few with sweet oranges. The data collected so far for yield and quality are insufficient to form a recommendation, and another 4 year of data collection is required to complete the experiments. However, the data collected from 2019 to 2021 are given in Appendix 2, Chapter 4.

Afourer trials:
Trial no. 1: The trial was established at Curlwaa, NSW, and the data indicated that Tanghe had higher cumulative yield (85 kg/tree) compared to Tri22 (52.7 kg/tree). The rootstocks did not affect °Brix values. Trunk circumference and tree height were increased in all Chinese rootstocks compared to Tri22.

Trial no. 2: The data from trial no. 2 established at Dareton indicated slightly higher cumulative yield with Ghana (36.7 kg/tree) compared to Tri22 (33.7 kg/tree), but this was not statistically significant. Rootstocks did not affect the °Brix values. Tree trunk circumference for Ghana was slightly larger than Tri22.

Trial no. 3: The data from trial 3 established at Leeton, NSW, indicated that fruit yield data collected for 2021 were increased with Ghana (36.6 kg/tree) compared to Tri22 (18.0 kg/tree). The °Brix values were higher for *Poncirus trifoliata* rootstocks (13.5 °Brix) compared to Anjiang hongju (12.7 °Brix), but no differences were found among *Poncirus trifoliata* rootstock types. Tree trunk circumference was higher for Ghana (13.3 cm) compared to Tri22 (12.7 cm). On this site, there was no difference in tree height observed since the trees in this trial were established on a trellis and tree height was kept at 1.5 m at the time of data collection. The trees in this trial are planted at a density of 1,515 tree/ha.

Trial no. 4: The data from trial 4 established at Gayndah, QLD, indicated that cumulative yield was increased with Nianju (77.5 kg/tree) and Zao Yang (77.3 kg/tree) compared to Tri22 (67.5 kg/tree). Rootstocks did not have any effect on °Brix values for the 2 consecutive years. Tree trunk circumference and tree height were increased for Nianju compared to Tri22 and other *Poncirus trifoliata* rootstocks. Nianju is a *Citrus erythrosa* (mandarin) type and has a vigorous growth habit as compared to *Poncirus trifoliata* rootstocks, especially in deep sandy soil types.

Valencia trials:
Trial no. 5: This trial was established in Waikerie, SA, with McMahon Valencia on deep sandy loam soil. The data indicated

there was no significant difference in cumulative yield between rootstocks. The tree produced from 8–10 kg/tree. Trees on this property were slower to start since its establishment, however, the yields are looking promising for the 2022 harvest, which will occur in Nov–Dec 2022. Rootstock did not have any significant effect on °Brix values in 2020, however, in 2021, Zao Yang had 12.0 °Brix compared to 11.0 °Brix for Ghana. Ghana had increased trunk circumference of 14 cm compared to Tri22 (12.4) in 2021. However, there was no difference in tree height between rootstocks, and the average tree height was 1.5 m.

Trial no. 6: The trial was established in Gunnedah with Keenan Valencia on clay loam soil. The yield data collected for 2021 indicated that Ghana produced 19.4 kg/tree compared to 12.9 kg/tree for Tri22. The rootstocks did not have any significant effect on °Brix values. Trunk circumference was 19.2 cm for Ghana and Tanghe compared to 17.7 cm for Tri22. The average tree height was 2 m, and this was not significantly different for rootstock. The yield for 2022 is looking promising and the tree harvest will occur in Nov–Dec 2022.

Experiment 5: Italian rootstock trial, Dareton, NSW

To evaluate the Italian rootstocks, a trial was established at Dareton with 3 mandarin varieties. Imperial, Nectar and Tangold were budded onto 3 Italian rootstocks in March 2020. The trees in this trial are very young, and yield data are not available yet. A few trees produced a small number of fruits that were used to assess quality and tree growth data were collected since planting the trial. The data indicated that there were significant differences for the varieties. Imperial mandarin and Nectar had slightly higher °Brix values (12.0) than the Tangold mandarin (11.7). The interaction effect of rootstock and varieties was significant for °Brix values. Rootstock F5 P12 had high °Brix (13.3) values for Imperial mandarin, F6 P12 had higher °Brix for Nectar (12.2) and F6 P13 had higher °Brix (12.1) for Tangold. This information is of significant value for the citrus industry as it reconfirms the role of rootstock in influencing fruit quality. The effect of trunk diameter was significant for the 3 mandarin varieties. Tangold had a larger trunk diameter of 24.7 mm compared to Nectar (20.0 mm) or Imperial (21.5 mm). There was no main effect on tree height noticed across 3 scion varieties. The interaction effect between the rootstocks and varities on trunk circumference showed that F6 P12 on Tangold was larger (26.9 mm) compared to F6 P13 on Tangold (23.7 mm). The data indicated that in general, Tangold had larger trees compared to Imperial mandarin or Nectar, suggesting the faster rate of growth in Tangold is an inherent character of this variety.

Experiment 6: HLB tolerant rootstock trials (NSW, Vic, SA, QLD, WA)

The HLB tolerant rootstocks were imported from the USDA breeding program in Fort Pierce and from the University of Florida breeding program in Lake Alfred. These rootstocks will be used in the trials planned in 5 states of Australia. These rootstocks are US802, US812, US897, US942, US1283, US1284 and US1516, while Tri22 (Australian *Poncirus trifoliata*) or *Troyer citrange* will be used as the control, depending on soil types. Trees will be ready to be planted in October 2023.

The rootstocks from the University of Florida will be used in trials established at the NSW DPI Dareton Research Station in deep sandy loam soil, while a mirror trial will be established at NSW DPI Griffith in clay loam soil. These rootstocks will be compared for yield, fruit quality, tree growth, and fruit size distribution in 2 soil types.

A comprehensive trial plan for NSW DPI Dareton, NSW DPI Griffith and 5 states in Australia including New South Wales, Victoria, South Australia, Queensland, and Western Australia has been decided and site selection has been completed (Appendix 2, Chapter 6).

Outputs

The outputs presented in Table 3 have delivered more than what was promised in Milestone 102 (M&E) Plan. This includes international collaboration with the USA and China. The project results were delivered to growers via field days, forums, workshops, industry articles, national and international conferences, and results handouts.

Table 2. Output summary based on the project outputs for 5 years of research work on the rootstock evaluation program.

Output	Description	Detail
International collaboration	Collaboration between The University of Florida, USDA Florida and IVIA, Valencia, Spain and Sicily, Italy were established	The collaboration was established, and the MTA was officially signed between the 2 countries. Due to the successful collaboration, 27 rootstocks were imported into Australia during the project. The collaboration is continuing to be strengthened and the collaborators will come to Australia to deliver presentations to the Australian growers about the results and characteristics of their rootstocks.
Information sheets	Information sheets were provided as handouts to growers at the field days, and forums	The information sheets had updated information on the progress of the rootstock evaluation program. The information sheets were provided as hard copies to participants at field days and workshops.
CAL Citrus Juicing Forum 20 October 2022	An oral presentation was delivered at Leeton	50 citrus growers, packers, marketers, industry personnel, industry development officers and researchers attended the forum. The update on the rootstock suitability for juicing oranges was presented.
International Conference Mersin, Turkey 4-12 November 2022	2 oral presentations were delivered to the conference audience	National rootstock evaluation update was presented and in the second presentation the importance of HLB work was highlighted to 200 participants.
International Conference Valencia, Spain 30 June 2022	An oral presentation was delivered at the conference	Rootstock update was presented at Frutic2020 14th International Symposium in Valencia, Spain. The importance of HLB work was highlighted to a crowd of 300 participants.
VLG meeting 20 June 2022	Project progress for the Project reference group	Project progress was presented to the project reference group at CAL office Mildura via Zoom. A written progress update was provided to the reference group.
Citrus breeding workshop 16 June 2022	Oral presentation and field walk at Dareton	A field visit was held for 2 Italian scientists/breeders at Dareton. The project update and progress on the Italian rootstock trial were presented. The current Italian rootstocks were imported from their breeding program.
Horticulture Unit Group 9 June 2022	Oral presentation and field walk at Dareton	The project update was presented to the Horticulture Unit group of New South Wales. 25 scientists and industry development officers attended the meeting followed by the field session.
ACN Article June 2021	Australian Citrus News Article	'Establishing HLB tolerant rootstock trials for the Australian citrus industry' was published.
Industry Journal June 2022	Citrus Industry Florida	'Australia evaluation dwarfing rootstocks' was published
ACN Article July 2022	Australian Citrus News Article	'Potential dwarfing rootstocks No 24 and 85–24 for the citrus industry – an update' was published https://citrusaustralia.com.au/news/latest-news/potential-dwarfing-rootstocks-no-24-and-85-24-for-the-citrus-industry-an-update
Journal article Dwarfing rootstock	Australian tree crops	'*New Citrus Foundation*' was published.
CAL Citrus Conference 9 March 2022	An oral presentation was delivered in	The update on HLB tolerant rootstock was presented to 200 participants.

	Maroochydore	
VLG meeting 11 February 2022	Project progress for the Project reference group	Project progress was presented to the project reference group at Dareton. A written progress update was provided to the committee.
CAL Citrus Roadshow 20 April 2021	An oral presentation was delivered at Renmark	The rootstock project update was presented to the forum participants. 43 citrus growers, packers, marketers, industry personnel, industry development officers and researchers attended the forum.
CAL Citrus Roadshow 22 April 2021	An oral presentation was delivered at Leeton	The rootstock project update was presented to the forum participants. 86 citrus growers, packers, marketers, industry personnel, industry development officers and researchers attended the forum.
CAL Citrus Roadshow 19 April 2021	An oral presentation was delivered at the conference at Dareton	The rootstock project update was presented to the forum participants. 85 citrus growers, packers, marketers, industry personnel, industry development officers and researchers attended the forum.
Strategic Project Review 13 April 2021	Hort Innovation Limited	A strategic project review was held by Michael White (Relationship Manager – Federal Department of Water and Environment). Mr White visited Dareton, and the project update and extension activities were presented, interviews were held, and field trials were visited. The outcome of the review was positive, and he recommended the continuation of the research program for rootstock evaluation.
WA Citrus Field Day 10 March 2021	An oral presentation was delivered by Kevin Lacey on my behalf	A presentation was held by Kevin Lacy in the field regarding salt-tolerant rootstock outcomes. I could not participate in person due to the Covid19 travel restrictions to WA.
VLG meeting 3 February 2021	Project progress for the Project reference group	Project progress was presented to the project reference group at CAL office Mildura via Zoom. A written progress update was provided to the group.
VLG meeting 18 August 2020	Project progress for the Project reference group	Project progress was presented to the project reference group at Dareton. A written progress update was provided to the group.
ACN Article June 2020	An article for the Australian Citrus News	'DV Valencia ticking all the boxes' was published.
Visit to Citrus Research Institute Jeju Island, South Korea 7 October 2019	An oral presentation was delivered	Rootstock project update and results were presented at the Citrus Research Institute RDA, Jeju Island. The trip was followed by inspecting the citrus breeding program and a visit toa deficit irrigation trial. The simulated climatic laboratory was also inspected during the trip.
VLG meeting 19 August 2019	Project progress for the Project reference group	Project progress was presented to the project reference group at CAL office Mildura. A written progress update was provided to the group.
MTA for HLB tolerant rootstock July 2019	MTA finalised	MTA was signed between the University of Florida and NSW DPI to import HLB tolerant rootstocks. Before that 2 video conference meetings were held at CAL Mildura by Dr Tahir and Nathan Hancock with Dr Fred Gmitter (University of Florida) on 15 May 2019 and 19 June 2019.
Dr Maria Badenes visit June 2019	Spanish rootstocks	A discussion was held to evaluate Spanish rootstocks at Dareton, and Dr Badenes decided to establish an MTA with NSW DPI to provide Australia with the selected

		Spanish rootstocks. Later, MTA was signed between NSW DPI and IVIA, Valencia Spain.
Strategic project Review	ACIAR, Canberra	ACIAR investment in citrus rootstock, scion and production improvement in China, Vietnam, Bhutan, and Australia. *ACIAR Impact Assessment Series Report* No. 98. ACIAR, Canberra.
CAL Citrus Conference 4 March 2019	An oral presentation was delivered in a field session at Adelaide	The rootstock project update was presented to the conference participants at Dareton. 100 handouts were distributed among conference participants. The handouts included the necessary information about the 'Dwarfing rootstock trial" on M7 navel and Tangold mandarin.
Journal Article December 2018	Portuguese Horticulture Journal	'Citrus research and development in Australia' were published.
University Lecture Faro, Portugal October 2018	Presentation on the Australian rootstock program	A presentation was made to the 60 staff and postgraduate students at the University of Algarve, Faro Portugal.
WA Citrus Industry Day 18 October 2018	Presentation on the update of rootstocks	The rootstock project update was presented to the 60 growers at Harvey, Bunbury, as a part of the WA Citrus Industry Day.
Riverina Growers Visit 10 September 2018	Presentation to the Riverina growers at Dareton	26 Riverina growers visited Dareton. A progress report on rootstock trials was presented followed by a field session. 26 handouts were distributed among growers.
Visiting Scientist 22 August 2018	Presentation and field session for Mr Dien from Vietnam	Mr Dien from Vietnam visited, and he inspected the rootstock program and took a keen interest in the Vietnamese rootstocks.
VLG meeting 18 June 2018	Project progress for the Project reference group	Project progress was presented to the project reference group at CAL office Mildura. A written progress update was provided to the group.
CAL Citrus Field Day 15 May 2018	A presentation was delivered at Dareton	The rootstock project update was presented to the conference participants at Dareton. In a field session, the progress on the dwarfing trial was presented and 57 handouts were distributed among growers.
Newspaper article 8 May 2018	The Rural News	'Leeton hots inaugural juice forum' was published.
Journal Article April/May 2018	Australian Tree Crops	'*New Citrus Foundation*' was published.
ABC Radio Interview 1 May 2018	Radio Interview at Leeton	A radio interview was held at Leeton about the release of new rootstocks.
Journal Article January 2018	Partner ACIAR Magazine	'Citrus benefits from Australia–China ag science partnership'. Issue 1, Pages 30–31.
Field Day Chislett Farms 2 May 2018	An oral presentation was delivered followed by a field session Kenley, Victoria.	The rootstock project update was presented to 50 growers in the field day and handouts were distributed.
Citrus Juicing Forum 1 May 2018	An oral presentation was delivered followed by a field session in Leeton	The rootstock project update was presented to the forum participants at Leeton. In a field session, 100 handouts were distributed among growers at Stanbridge, Leeton.
Journal Article 30 April 2018	The Land	'*Solid Citrus Foundation*' was published.

Journal Article 2018	The Australian Agronomist	'Promising new rootstocks for Australia citrus' was published.
CAL Regional Forum 29 November 2017	An oral presentation was delivered in Gayndah	The rootstock project update was presented to the forum participants at Gayndah, Queensland.
NSW DPI Road Show 11 November 2017	An oral presentation was delivered in Perth	The rootstock project update was presented to the forum participants in Perth Western Australia.
NSW DPI Road Show 19 October 2017	An oral presentation was delivered in Loxton	The rootstock project update was presented to the forum participants in Loxton, South Australia.
NSW DPI Road Show 18 October 2017	An oral presentation was delivered in Sunraysia	The rootstock project update was presented to the forum participants in Mildura, Victoria.
NSW DPI Road Show 16 October 2017	An oral presentation was delivered in Griffith	The rootstock project update was presented to the forum participants in Griffith, New South Wales.
ACN Article June 2017	An article for the Australian Citrus News	'Six new high-performing citrus rootstocks launched in Australia'. Pages 30–31 (Winter issue)
ACN Article 2017	An article for the Australian Citrus News	'All smiles for rootstock trials. Pages 18–19 (Winter issue)
Newspaper Article 2017	Sunraysia Daily	'Rootstock program launches 6 rootstocks.

Outcomes

Table 3. Outcome summary based on the project outcomes for 4 years of research work on the rootstock evaluation program.

Outcome	**Alignment to fund outcome, strategy and KPI**	**Description**	**Evidence**
End of Project Outcome (SIP)	Outcome 1: Market opportunities in both domestic and especially export markets have been developed and maintained, leading to increased demand and support for citrus products. Strategy 1.2: Identify and develop new and existing domestic market opportunities. KPI: At least 20 new varieties/rootstocks evaluated for Australian conditions and accessible by growers.	This project work was aligned with the relevant SIP outcome. According to KPI, 20 new scion/rootstock combinations should have been evaluated. However, in the current project, **77** scion/rootstock combinations have been evaluated under different soil and climatic conditions in Australia. Trees are being prepared for the next **120** scion/rootstock combinations to be planted under different soil types and climatic conditions across Australia.	Industry magazine articles, field days, farm walks, CAL forums, national and international conferences, Final Report. These combinations will be related to the HLB tolerant rootstocks. These new rootstocks will be evaluated in the next phase of the project.
Access to new rootstocks by nurserymen and growers for testing	Same as above	6 rootstocks have been recommended to the Australian citrus industry at the start of this project.	AusCitrus has commercialised the recommended rootstocks for the Australian citrus

		These rootstocks are now available to the wider citrus industry throughout Australia.	industry. The rootstocks can be purchased from AusCitrus under a non-propagation agreement.
Diversified plantings suited to high-density cropping	Same as above	The trial on high-density planting on dwarfing rootstocks was established with both navel and mandarins in this project and will be completed in the new project. The immediate outcome of the projects is that 2 Chinese *Poncirus trifoliata* rootstocks No. 24 and 85–24 may be recommended after collecting additional data for 3 years. The dwarfing rootstocks trial has good synergies with the existing small tree project at Dareton.	Growers have visited the trial site during field days, farm walks and forums and an article on the performance of these 2 rootstocks has been published on CAL website.
Informed decisions for growers to choose from a range of rootstocks	Same as above	Growers now have a wider choice of rootstocks to suit specific conditions such as sandy soils, clay soil and mildly saline soil. Growers should be able to choose dwarfing rootstocks with different levels of growth reductions in the near future.	Results sections and Final Report (Appendix 1 & 2).
Increased knowledge and understanding of new rootstocks by growers and researchers about early and late maturing, dwarfing, resistance to diseases, salt tolerance	Same as above	There is improved knowledge available on the suitability of different rootstocks for both early and late navel crops. Macrophylla rootstocks are not used with Washington navel (mid-season) and Lane Late (late maturing). Rootstock (Zao Yang) is now available for processing oranges in heavier soil conditions of the Riverina, and it is also in use in Sunraysia with navel oranges. Salt tolerant rootstock	Results sections and Final Report (Appendix 1 & 2).

		3822 (Scarlet mandarin × *Poncirus trifoliata*) has been identified from the trial work in Western Australia. The dwarfing trial at Dareton with a potential of 2 new rootstocks No. 24 and 85–24 may become available to growers in the near future.	

Monitoring and evaluation

The monitoring and evaluation of the project based on the key evaluation questions are given in Table 4.
Table 4. Monitoring and evaluation based on key evaluation questions.

Evaluation question	**Project performance**	**Continuous improvement opportunities**
Effectiveness	This project has been very effective since it is a national rootstock program. This program worked with a range of experiments with a range of scion/rootstock combinations in 5 states of Australia. The project has achieved all expected outcomes as per project Milestone report 102.	The growers' trials provided a direct opportunity to see the results immediately on their property and other growers can visit the property to see the effects of rootstocks on yield, fruit quality and tree growth. Growers also had the opportunity to visit the trial sites at NSW DPI Dareton. It has provided an opportunity for the growers to test the rootstocks immediately on new emerging scion varieties, which have high domestic market value or export potential. Therefore, the project was very effective in gaining its objectives.
Relevance How relevant was the project to the needs of intended beneficiaries?	The project was very relevant to the need of growers. Growers are using only 2 main rootstocks, *Poncirus trifoliata* in heavy soil conditions and Troyer/Carrizo citrange in sandy loam soils. Therefore, there was a need to have a rootstock that can produce a higher yield, large fruit size with superior eating quality. There were also no salt tolerant rootstocks, which can be used in areas with high salt content in the irrigation water. There is no rootstock available that can be used as a dwarfing rootstock for high-density plantings. The existing rootstock Flying Dragon is	This project has met the needs of citrus levy payers in achieving the desired results from the rootstock program. Therefore, the new rootstocks recommended for yield and quality performance, salt tolerance and dwarfing effect can continue to be planted and trialled on a semi-commercial scale by the growers. The evidence includes: *6 high-performing rootstocks* • Zao Yang (*Poncirus trifoliata*) • Donghai (*Poncirus trifoliata*)

	extremely slow growing and does not provide economic benefits for many years. There was a rootstock needed which is an intermediate vigour rootstock between Flying Dragon and *Poncirus trifoliata*.	• Tanghe (*Poncirus trifoliata*) • Ghana (*Poncirus trifoliata*) • Anjiang hongju (*C. Erythrosa*) • Cao shixiangju (*C. Erythrosa*) <u>*New recommendations*</u> • DV Valencia (Registered) • 3822 (Scarlet mandarin x *Poncirus trifoliata*) • 3834 (Scarlet mandarin x *Poncirus trifoliata*) • No. 24 (*Poncirus trifoliata*) • 85-24 (*Poncirus trifoliata*)
Appropriateness	The intended beneficiaries such as growers and packers were well engaged and were aware of the project activities and results. This was possible through field days, conferences, magazine articles, phone calls and one on one trial site visits. Field days in 2020 and 2021 were restricted due to Covid19 on entry to NSW state government facilities. The R&D manager was engaged via phone discussions, Milestone reports and Emails. 6 VLG Meetings were arranged, and the project progress was presented during the course of the project.	Dareton Research Station always had a high industry reputation both in Australia and overseas for research and extension-based activities to impart knowledge to visitors. The extension events such as field days, workshops and citrus conferences were fully accessible to the industry members.
Efficiency What efforts did the project make to improve efficiency?	The project was expanded with the existing budget to evaluate a range of rootstock trial sites throughout Australia. During the project, additional articles were published than originally agreed upon, and we participated in additional field days and workshops to provide information updates to citrus growers. Despite Covid19, the project was still on track and the necessary data were collected. We did have the difficulty of travelling to SA, QLD, WA and some parts of NSW, however, the project was efficiently managed, and the required data were collected. The project was engaged with stakeholders by conducting the project reference group meetings. Six	The project will be further improved by strengthening the collaboration with the existing partners in Fort Pierce, Florida, University of Florida, Lake Alfred, University of California, Riverside, agricultural research institute, IVIA, Spain, CRIC Chongqing, China and Italy. <u>PRG Meetings:</u> 20 June 2022 11 February 2022 3 February 2021 18 August 2020 19 August 2019 18 June 2018

	project reference group meetings (PRG) meetings were conducted during the project life with inputs from the group.	

Recommendations

Rootstocks have a major effect on the profitability of citrus orchards. Rootstocks can influence tree growth, fruit yield, yield efficiency, fruit size distribution and fruit quality. The ideal citrus rootstock should ensure tree longevity and encourage consistently high annual yields, large fruit size (or size appropriate for the target market) and acceptable internal quality. Fruit size is an important fruit quality characteristic as buyers have shown a distinct preference for larger fruit in recent years, particularly for navel oranges. Results presented from the rootstock trials at Dareton have led to the selection of several new types for entry into longer-term, industry-based commercial trials.

The following 6 high-performing rootstocks were released at the start of the project and are now available from AusCitrus:

- Zao Yang (*Poncirus trifoliata*)
- Donghai (*Poncirus trifoliata*)
- Tanghe (*Poncirus trifoliata*)
- Ghana (*Poncirus trifoliata*)
- Anjiang hongju (*Citrus erythrosa*)
- Cao shixiangju (*Citrus erythrosa*)

A range of experimental components are now completed, and the following rootstocks and scion variety are recommended.

Juicing oranges

- Valencia 5 scion variety is recommended for processing oranges. This variety is now registered and known as DV Valencia. Valencia 5 scion variety is suitable to be budded onto Zao Yang rootstock. This combination produced higher yield and superior fruit quality with 1 to 2 degrees higher Brix.
- Valencia 6 scion variety is suitable to be budded onto Zao Yang rootstock. This combination produced higher yield and superior fruit quality with 1 to 2 degrees higher Brix.

Salt tolerance

Two rootstocks from the NSW DPI breeding program are recommended as salt tolerant rootstocks.

- 3822 (Scarlet mandarin × *Poncirus trifoliata*)
  Washington navel budded onto this rootstock had salt-excluding ability. The rootstock had 69% of fruit in size class (76–90 mm), desirable internal fruit quality with 12.0 °Brix, and an acceptable graft compatibility score of 1.5. Trees produced a 10% higher fruit yield than *Troyer citrange* and the biennial bearing index was 0.26.
- 3834 (Scarlet mandarin × *Poncirus trifoliata*)
  Washington navel budded onto this rootstock had 83% of fruit in the large size class (76–90 mm), desirable internal fruit quality with 11.7 °Brix, and an acceptable graft compatibility score of 1.3. Trees produced a 2% higher fruit yield than *Troyer citrange* and the biennial bearing index was 0.24.

Further research

Future research to be conducted in a proposed project 'Evaluation of new rootstocks for the Australian citrus industry' – CT22001 (2022–2027)

This research will potentially continue in a new project supported by Hort Innovation. Specifically, the following activities remain to be completed with these trials:

- HLB rootstocks trial will be established in October 2023 and will be evaluated for yield, fruit quality and tree growth throughout Australia.
- Commercial trials of the most promising rootstocks will be further evaluated for the next 5 years on growers' properties.
- High density dwarfing trial established at Dareton with M7 navel and Tangold mandarin will be evaluated for the next 5 years. The rootstocks included in these trials are Chinese rootstocks and US rootstocks imported from the University of California.
- Italian rootstocks F5 P12, F6 P12 and F6 P13 will be further evaluated at Dareton in collaboration with ANFIC (Australian Nurseryman's Fruit Improvement Company). These rootstocks will be tested for the first time in Australia with Tangold, Imperial and Nectar mandarins.

Refereed scientific publications

Khurshid T, Creek A, and Sanderson G. 2022. Tree performance, yield and fruit quality of 'Valencia' sweet orange (*Citrus sinensis* L. Osbeck) selections on Chinese (*Poncirus trifoliata*) rootstocks in Australia. *Submitted to "Scientia Horticulturae".*

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People's Republic of China. *Scientia Horticulturae* 128, 443–449.

Intellectual property

There is no intellectual property attached to this project.

Acknowledgements

During this research, several staff members participated in establishing the trials, field data collection, harvest and fruit grading, fruit quality assessments and extension of the preliminary results. The following are duly acknowledged for their inputs and without their help, the research goals could not have been achieved.

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Technical staff

I am especially thankful to Jane Khurshid who has been involved in program since 2007. Jane managed the trials, organised and collected the tree growth data and quality analysis. Jane also organised and managed the harvest programs for the last 5 seasons. This involved organising harvest, transferring fruit to the station packing shed, grading the fruit and dispatching it to commercial packing sheds.

Troy Witte (Manager, research farm at Dareton) for assisting in operating the grading machine and his timely help throughout the project.

Andrew Creek (Citrus Development Officer, Leeton) was responsible for managing the Valencia trial at Leeton. Andrew was also involved in organising the harvest operation and assisting with data collection.

Kevin Lacey (Senior Technical Officer, DPIRD WA) was responsible for managing the salt tolerant rootstock trial in Bindoon, WA. Kevin also assisted with trial harvest and data collection for tree growth and fruit quality. Kevin also hosted my trips to WA during the project life.

Farm staff

Thanks are extended to Doug Carmin (former lead farm hand/farm manager) at the NSW DPI Dareton Research Station. Doug was actively involved in maintaining the trials and provided logistical assistance. Doug took responsibility to arrange the full harvest program for the rootstock trials. He was also involved in pruning, fertilising, irrigating, and harvesting the trials. Doug also communicated with the local packing shed staff and harvested the trials accordingly to secure premium prices for the crop. Since Doug retired, Brad Bowes and Darren Howard took the responsibility to arrange the harvest programs. They were also involved in managing the cultural practices for the trial. Brad and Darren were very helpful during the peak harvest season, both in the field and during packing shed operations.
During the experimental program, several casual technical staff also assisted in data collection, harvest and tree maintenance including Fred Bacon, Kate Watts, Rob Bishop, Adrian Hartley, Brett Walding, Alexander Mitchell and Phil Baird, Anna Treeby, Lucas Creek and Hannah Creek.

Participating growers (5 states) & Participating nurseries

I am also thankful to the growers around Australia, who participated in the grower's trials. For their assistance in maintaining the trials and their assistance in crop harvest. Thank you to Jason Bowes and Sean Arkinstall who were responsible for raising trees for national grower's trials and also for the trial established at Dareton. I also grateful to Tim Herrmann (AusCitrus) for developing the trees for the HLB trial program.

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The overseas collaborators are equally recognised during this project. Thanks to Dr Kim Bowman for providing 7 rootstocks from the USDA breeding program for the project. Thank is also extended to Dr Fred Gmitter for providing 20 rootstocks from the University of Florida breeding program for this project. I am also grateful to Dr Mikeal Roose who provided the rootstocks from the Californian breeding program for this project.

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Editorial assistance

Thank you to Dr Amanda Warren-Smith for assistance with editing this report.

Appendixes

Appendix 1: Release of new rootstocks to the Australian Citrus Industry

The primary output of the project was the release of 6 new rootstocks to the Australian citrus industry in July 2017. The rootstocks were released by the Hon. Niall Blair (Minister of Primary Industries) at Parliament House in Sydney (Figure 1).

Figure 1: Release of new rootstocks on 17 May 2017 at the Parliament building, Sydney NSW; [from Left: Mr Brad Wells - Hort Innovation, The Hon. Niall Blair - Minister of Primary Industries, Dr Tahir Khurshid - NSW DPI, Dr John Dixon - ACIAR and Mr Lu Pin - Council for Science and Technology Affairs, the People's Republic of China.

The recommended rootstocks are Zao Yang, Ghana, Tanghe, Donghai, Anjiang honju and Cao shixiangju. The recommendation of these rootstocks is based on testing them with Navelina, Lane Late, Imperial mandarin and Valencia oranges. AusCitrus has been licensed by agreement to handle the distribution of seeds from any rootstocks released to the Australian citrus industry. The newly released rootstocks are given in Figure 2.

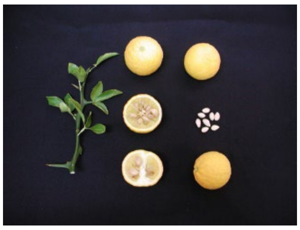		
Zao Yang (*Poncirus trifoliata*)	Tanghe (*Poncirus trifoliata*)	Donghai (*Poncirus trifoliata*)
		
Ghana (*Poncirus trifoliata*)	Cao shixiangju (*Citrus erythrosa*)	Anjiang hongju (*Citrus erythrosa*)

Figure 2: Six promising Chinese rootstocks released in May 2017. The photo shows the external characteristics of the rootstocks.

The characteristics of the new rootstocks are given in Table 1 and compared to the standard Australian Trifoliata22 rootstock. Seeds for the new rootstocks are now available for purchase from Auscitrus. The results were obtained from trial sites at NSW DPI Dareton and also from a trial site in the Riverina. At Dareton, trees were planted in deep sandy loam soil (light), while the soil type in Riverina was sandy clay loam (heavy soil).

Table 1. Six new Chinese rootstocks characteristics compared to Tri22.

Rootstock variety	**Zao Yang**	**Tanghe**	**Ghana**	**Donghai**	**Anjiang hongju**	**Caoshi xiangju**
Rootstock type	*Poncirus trifoliata*	*Poncirus trifoliata*	*Poncirus trifoliata*	*Poncirus trifoliata*	*Citrus erythrosa* (mandarin)	*Citrus* erythrosa (mandarin)
Compatibility	No incompatibility with Eureka to date	Excellent with all scions tested	Excellent with all scions tested	Variable	Variable	Variable
Vigour	Similar	Less than, might be suitable for high-density planting	Similar	Less than, might be suitable for high-density planting	More than, might be suitable for medium to low-density planting	More than, might be suitable for medium to low-density planting
Yields	Higher for Navelina and Valencia	Above for all scions tested	Above for all scions tested	Higher on Valencia	Higher for Valencia	Higher
Fruit quality	Higher for Valencia and similar for Navelina	Slightly larger fruit size for Navelina and Lane Late	Similar internal quality to all scions tested. Large fruit size for Lane Late and Imperial	Smaller fruit for Valencia and Navelina. Sweetness is better than Tanghe for Navelina	Internal quality is acceptable for Valencia and higher for Imperial mandarin	Internal quality acceptable for Valencia

			mandarin			
Disease	Highly resistant to CTV, Phytophthora collar and root rot	Highly resistant to CTV, Phytophthora collar and root rot	Highly resistant to CTV, Phytophthora collar and root rot	Highly resistant to CTV, Phytophthora collar and root rot	No CTV replication and is moderately resistant to Phytophthora	Moderately resistant to Phytophthora root rot
Special	Excludes sodium and flowers later	Excludes sodium	Excludes sodium and accumulates chloride		Excludes sodium and chloride, suited to shallow and sandy soils	Excludes sodium and chloride. Deep-rooted suited for deep sandy soils
Suggested scions	Valencia and Lane Late navel	Valencia and Lane Late navel	Navel oranges and Imperial mandarin	Valencia and Navelina	Lane Late and Imperial mandarin	Valencia

Industry adoption:

There has been strong industry adoption after the release of the Chinese rootstocks. The seeds are sold by AusCitrus which is an accredited national seed and budwood scheme. There have been 0.5 million seeds of Zao Yang sold by October 2021. Therefore, a significant number of trees are now planted with Zao Yang in Australia. This rootstock may replace Tri22 in future.

Appendix 2: Detailed results and discussion

The trials reported for experiments 1 and 2 were established during previous projects (CT07002 and CT13042) and evaluated and completed in the current project (C17002). Trials reported for experiments 3 and 4 were established during the previous project (CT13042) and are being evaluated in the current project (CT17002) and will complete in a new project. The trials reported for experiments 5 and 6 were established in the current project (CT17002) and these will be evaluated in a new project (CT22001) potentially funded by Hort Innovation. The methodology given below describes each experimental program. Results and progress for each experiment are outlined in the Output section of this report.

Experiments	**Established during project**	**Evaluated during project**	**Completed during project**
Experiments no. 1 Valencia trial at Stanbridge Leeton, NSW	CT07002 (2014)	CT13042 (2018)	CT17002 (2022) **completed**
Experiments no. 2 Salinity trial at Bindoon, WA	CT07002 (2014)	CT13042 (2018)	CT17002 (2022) **completed**
Experiments no. 3 Dwarfing effect trial at Dareton, NSW	CT13042 (2018)	CT17002 (2022)	Continuing (2023 -2027)
Experiments no. 4 Growers' trials in NSW, VIC, WA, QLD, and SA	CT13042 (2018)	CT17002 (2022)	Continuing (2023 -2027)
Experiments no. 5 Italian rootstock trial at Dareton, NSW	CT13042 (2018)	CT17002 (2022)	Continuing (2023 -2027)
Experiments no. 6 HLB rootstock trial Dareton and other states	CT17002 (2022)	Continuing	Continuing (2023 -2027)

Chapter 1: Evaluation of selected Chinese rootstocks on a range of Valencia selections conducted in a semi-commercial trial in the Riverina

This chapter is written for a refereed scientific journal; therefore, the chapter is presented in the format of a journal.

Background

This trial was initiated through discussions between John Davidson (Fruit Purchasing Manager – National Foods), Peter Morrish (former CEO Riverina Citrus) and NSW Department of Primary Industries (NSW DPI) in 2005. A need was identified to select high-producing local selections of Valencia for future replanting of old Valencia blocks. This would help to ensure the continuing supply of high-quality Valencia fruit in sufficient volumes to meet the processing needs of the local citrus industry in the Riverina.

In the project, a range of high-performing Valencia selections identified by Berri Ltd. from long-term processing records were propagated to selected Chinese trifoliata rootstocks identified by NSW DPI as worthy of further investigation in clay loam soil types. Trifoliata is the dominant rootstock used on the heavier soils in the Riverina with 75% of trees established on this stock.

This trial was established (Figure 1.1) in October 2010 with Hort Innovation and Riverina Citrus funds as a voluntary contribution project CT07006, 'Evaluation of superior processing oranges for fresh juice with selected Chinese rootstocks' (Sanderson, 2011). The objective of the trial was to assess the horticultural performance of the superior Valencia clones with Chinese rootstocks to determine the best rootstock-scion combination for maximum yield and internal fruit quality.

Figure 1.1: The trial site at Stanbridge, Leeton, NSW.

Tree performance, yield and fruit quality of 'Valencia' sweet orange (Citrus sinensis L. Osbeck) selections on Chinese (Poncirus trifoliata) rootstocks in Australia

This trial was planted in October 2010 at a grower's property as a semi-commercial trial in sandy clay loam soil at Stanbridge, Leeton. Trees were planted 1.8 m apart within the rows and 5 m between rows in an east-west orientation. The trial was designed as a 2-factorial set-up in a randomised block design. There were 7 Valencia selections; Valencia 1, Valencia 2, Valencia 3, Valencia 4, Valencia 5, Valencia 6, and Keenan Valencia (control) as Factor 1 and 4 *Poncirus trifoliata* rootstocks; Zao Yang, Tanghe, Donghai, and Tri22 (control) as Factor 2. Treatment combinations were replicated 3 times with 5 tree plots for each combination. The middle 3 trees were selected for data collection. Data on fruit yield and internal fruit quality were collected for 5 years, while data for tree growth were collected for 6 years from 2014 to 2019.

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Abstract

This study reports the performance (tree growth, yield, fruit size distribution, and fruit quality) of 7 Valencia *(Citrus sinensis*) selections on 4 *Poncirus trifoliata* selections in the Riverina region of south-east Australia. Six of the Valencia selections (numbered as Valencia 1 to 6) were from local farmer properties and the other is a standard commercial variety 'Keenan' in Australia. Three of the 4 trifoliata rootstock selections ('Zao Yang', 'Tanghe' and 'Donghai') were imported from the People's Republic of China and the fourth is the dominant 'Tri22' selection used commercially in Australia.

Data collection occurred over 5 seasons from 2015 to 2019 for all treatment combinations. 'Valencia 5' trees had increased trunk circumference and tree height compared to 'Keenan' Valencia in both 2014 and 2019. In 2014, canopy volumes were similar for all rootstock selections trialled but in 2019, trees on 'Zao Yang' rootstock had a larger canopy volume compared to trees on 'Tri22'.

'Valencia 5' produced the highest cumulative yield (162 kg/tree), significantly greater than other Valencia selections except for 'Valencia 2'. Trees on 'Zao Yang' rootstock produced the highest yield compared with 'Tri22' (control) and other rootstock treatments. 'Valencia 6' on 'Zao Yang' rootstock had the highest percentage (58%) of fruit larger than 75 mm in diameter compared with other scion and rootstock combinations. Over the 5 harvest seasons, 'Valencia 5' fruit had significantly higher levels of total soluble solids (TSS) than fruit of 'Keenan' Valencia. The average (2015 to 2019) TSS value was 1.7 degrees higher for 'Valencia 5' than 'Keenan' Valencia. There was no significant effect of rootstock variety on TSS values, but the acid level was highest in fruit harvested from trees on 'Zao Yang' rootstocks. The early results and recommendations from this evaluation trial have assisted the commercialisation of 'Valencia 5' and 'Zao Yang' for sweet orange production in Australia.

1. Introduction

The citrus industry is one of Australia's largest fresh produce exporters, with export volumes increasing 84% from 158,000 tonnes in 2014 to over 250,000 tonnes in 2020 planted over 28,000 ha (Milner 2020). Thirty per cent of Australian citrus is grown in the Riverina region of Australia with Valencia orange [*Citrus sinensis* (L.) Osb.] the dominant variety. Riverina fruit production comprises 50% Valencia, 42% navel, 5%, 'Imperial mandarin' and 3% other citrus types. Total production in the 2020 season for Valencia orange in the Riverina was 140,000 tonnes over 4,233 hectares (Milner 2020). Riverina plantings are predominantly grown on 'Tri22' rootstock, the Australian selection of *Poncirus trifoliata* (Milner 2020).

The citrus industry has thrived in the Riverina since the 1950s. A significant proportion of the orchards were reaching the end of their productive life; therefore, it was suggested that productive local selections may be identified in the old blocks for future replanting. This would ensure the continued supply of high-quality Valencia fruit in sufficient volumes to meet the processing needs of the local citrus industry in the Riverina.

Six Valencia orchards, established in the 1950s, were selected by National Foods Limited, Leeton. A budwood source tree was selected in each block. Budwood of each scion variety was transferred to Dareton Primary Industries Institute in the Sunraysia citrus growing region, and mother trees were established to supply budwood material for the propagation of trial trees.

New rootstock selections were also identified from previous work at Dareton. Chinese rootstocks that were imported as seeds from the People's Republic of China in 1992 as part of an Australian Centre for International Agricultural Research (ACIAR) project were evaluated in field trials at the Primary Industries Institute, Dareton, New South Wales for 10 years (Khurshid and Donovan 2018) in deep sandy loam soils, typical of those in the Sunraysia region. Six high-performing rootstocks were released for commercial use in Australia based on yield, quality and graft union compatibility (Khurshid 2017). Three of those trifoliata high-performing rootstocks were identified for field evaluation in the Riverina to test their performance in sandy clay soil conditions and in combination with the selected Valencia clones.

Rootstock variety is reported to significantly influence the entire grafted tree, particularly vigour, productivity, fruit quality and resistance to abiotic and biotic stress (Castle et al. 2011). Carefully conducted field trials to compare citrus rootstock performance demonstrated there was more than a six-fold yield difference between the best and worst performing rootstocks (Wutscher and Bowman 1999). Internal fruit quality, measured by sugar content, acidity, juiciness and taste, is important for both fresh consumption and processing oranges (Chen and Opara 2013). However, sweetness and juice per cent are very important for the juicing industry. Sweetness is often governed, in part, by sugar concentration (Hong et al. 2014). Therefore, the determination and quantification of sugars are of great importance to the processing industry (Genizi and Cohen 1988).

Fruitfulness or productiveness of Valencia selections, expressed as production of fruit or sugar total soluble solids (TSS) per unit area of tree canopy, demonstrates the suitability of selections for fresh fruit marketing and juice processing (El-Zeftawi et al. 1982). Replicated field evaluation over a long timeframe is ideal but there is pressure to provide short-term comparative data (Sanderson and Treeby 2014). Relative rootstock performance with the Hamlin processing orange variety in Florida demonstrated that reliable conclusions could be made based on results from the first 4 cropping years (Castle et al. 2011).

This work reports the response of 7 Valencia selections established on 4 different *Poncirus trifoliata* rootstocks in a field trial in Riverina, NSW, to assess tree growth, yield and fruit quality. Data from the first 5 cropping years are presented. This work aimed to identify a superior Valencia and trifoliate rootstock combination for the Australian juicing industry.

2. Materials and Methods

2.1. Plant material

Budwood of 6 Valencia scion selections was collected from 6 citrus orchards in the Riverina region of NSW in January 2005. The budwood was selected from old trees of unknown health status. The 6 Valencia selections were labelled as 'Valencia 1', 'Valencia 2', 'Valencia 3', 'Valencia 4', 'Valencia 5', 'Valencia 6' and 'Keenan' Valencia (control) was used as the industry standard.

Buds from the selected source trees were grafted to Troyer citrange rootstocks to establish mother trees at Dareton Primary Industries Institute. The health status of the mother trees was established by sending material for biological and serological testing at the Elizabeth Macarthur Agricultural Institute, Menangle, NSW. Biological indexing was undertaken for citrus exocortis viroid on 'Etrog' citron indicator plants, citrus tristeza virus (CTV) on West Indian lime and Eureka lemon, citrus psorosis virus (CPsV) and CPsV-like viruses on Symons sweet orange and Emperor mandarin and citrus tatter leaf virus on Rusk citrange (Roistacher 1991). CTV was detected by direct tissue blot immunoassay (Garnsey et al. 1993) and moderate symptoms, indicative of CTV infection, were observed on indicator plants of 5 clones (1, 2, 3, 4, 6), typical of older citrus trees in Australia. CTV was not detected in Valencia selection 5. No other pathogens were detected, and symptoms observed on indicator plants did not indicate CTV variants were present that could induce severe disease.

Rootstock fruit was collected, and the seed was extracted from Chinese trifoliate source trees that were established at Dareton of the following varieties 'Donghai', 'Tanghe', and 'Zao Yang'. The seed of the Australian standard trifoliate selection 'Tri22' (control) was sourced from the Auscitrus propagation scheme. Valencia selections were budded to the 4 rootstocks and grown in a protected shade house over 2 years before planting.

2.2 Field layout and experimental design

The trial site was located on a commercial property at Stanbridge (Latitude. 34.5175°S, Longitude. 146.2356°E), near Leeton in the Riverina region of NSW, approximately 550 km west of Sydney, Australia. The trial site was cleared of an old citrus planting, cultivated and rested for 12 months before planting. Two tonnes of cow manure and one tonne of gypsum were applied per acre, evenly spread and worked into the soil before forming 600 mm high mounds.

An EM38 soil survey and soil cores to 1,200 mm soil depth were extracted for analysis to assist the experimental design. The soil textures were predominantly sandy loam in the 0–100 mm layer, sandy clay from 100–400 mm and light clay from 400–1200 mm. The 600 mm high, flat-topped planting mounds were hand-cored to assess soil characteristics before planting. Particle size analysis gave a clay content (< 2 µm) of 17%, silt (> 2 µm to < 20 µm) of 8%, fine sand (20 µm to 200 µm) and coarse sand (200 µm to 2,000 µm) of 47%. Soil pH was consistent at 7.5 ($CaCl_2$) at 0–200 mm and 200–600 mm depths. Soil electrical conductivity ranged from 0.10–0.35 dS/m within the planting mound.

Trees were planted in October 2010 at a spacing of 1.8 m within the rows and 5 m between rows in an east-west orientation, creating a density of 1,111 trees/ha. The high-density planting was established with the future aim of mechanised fruit harvest. The experiment was a randomised complete block design with 2 × 2 factorial with the 7 Valencia selections and 4 rootstocks replicated 3 times. There were 5 trees per plot giving a trial size of 420 trees. The site is also buffered by 2 rows on each side and an individual tree at both ends of each trial row.

The typical dry semi-arid climate of south-east Australia requires irrigation for crop production. The trees were initially irrigated via a single drip line with a second line added in year 3 from planting. Irrigation scheduling was based on watermark sensors (gypsum blocks) established at 250 mm and 500 mm soil depths and mid-way between drip emitters within the planting mound. The sensors were linked to a GDot visual display with an MEA switch box (www.mea.com.au). Fertiliser was applied via the drip system and standard commercial cultural practices were followed during the experiment. Trees were pruned during the experiment to allow easy access of farm machinery and spray operations.

2.2. Climatic conditions

The average daily maximum temperature at Stanbridge ranges from 30–32 °C from December to February and 15–17 °C from June to August with an average annual rainfall of 420 mm. Annual accumulated heat units average 1,800 (calculated as [Maximum temperature + Minimum temperature]/2–13 °C (maximum threshold of 35 °C) (Khurshid and Hutton 2005). Detailed climatic data throughout the experimental trial are given in Table 1.

2.3. Data collection and analyses:

Vegetative growth: Data on trunk diameter were recorded at 100 mm above the graft union each year from 2014 to 2019. Canopy height and radius were recorded for each tree every year. Canopy volume was calculated from the formula:

$v = 2/3 (\pi r^2 h)$, where v is the canopy volume, r is the mean canopy radius and h is canopy height (Bevington and Cullis 1990).

Fruit yield: Fruit yield for each experimental tree was recorded at each commercial harvest from 2015 to 2019 and cumulative yield was calculated for 5 years. Cumulative yield efficiency (YE) was calculated using data from the final cropping year by dividing cumulative yield by trunk cross sectional area (TCSA) (Lombard et al. 1988).

Fruit size distribution: Fruit size (diameter) was sorted into 5 size classes based on < 65 mm (> 138 fruit/carton), 65–67 mm (138–125 fruit/carton), 69–72 mm (113–100 fruit/carton), 75–77 mm (88 fruit/carton) and > 77 mm (< 80 fruit/carton).

Alternate bearing index (ABI): ABI was calculated using the deviation in fruit yield in successive years (I) from 2015 through to 2019 (Hoblyn et al. 1936):

$$ABI = 1/n-1 * [(|a_2 - a_1| / a_2 + a_1) + (|a_3 - a_2| / a_3 + a_2) + \ldots + (|a_n - a_{(n-1)}| / a_n + a_{(n-1)})]$$

n = number of years, $a_1, a_2, \ldots, a_n, a_{n-1}$ = fruit yield in corresponding years.

An ABI of 1 indicates a very strong tendency towards alternate (also called biennial) bearing and ABI close to zero indicates that season-to-season yield variability was random.

Internal fruit quality: The measurements for internal fruit quality were carried out at harvest for fruit from each experimental tree for 5 growing seasons. Ten fruit per tree were randomly selected at harvest from around the tree canopy and taken to the laboratory to assess internal fruit quality. Per cent TSS of the juice was measured as °Brix with an Atago PAL-1 refractometer (www.atago.net Japan) and % citric acid (% acid) was estimated by titrating 10 mL of juice against standard 0.1 mol/L NaOH solutions. Juice sugar:acid ratio was calculated from this data as described by El-Zeftawi et al. (1982). BrimA was calculated as °Brix-(acid*4) * 16.5 (Clark 2016).

Statistical analyses were carried out using GenStat (2020), as a two-way analysis of variance with a 2 factorial (7 Valencia selections × 4 rootstocks) and mean separation was carried out using Duncan's Multiple Range. The relationship between the YE and TCSA was calculated by a regression model.

3. Results

3.1. Yield and yield components

There were significant differences in fruit yield each harvest season between trees on different rootstock selections. 'Zao Yang' had the highest yield with a cumulative yield increase of 27% (180 kg/tree) compared to the standard commercial rootstock 'Tri22' (137 kg/tree) (Table 2). Yield efficiency for 'Zao Yang' was 3.5 kg/TCSA compared with 3.1 kg/TCSA for 'Tri22'. 'Zao Yang' also displayed a low ABI of 0.19 compared to other rootstocks including 'Tri22' (Table 2).

There was annual variability in the yield data for the different Valencia selections. However, cumulative yield data for each tree indicated that 'Valencia 5' trees had significantly greater yields (162 kg/tree) than other selections, except for

‘Valencia 2’ (Table 2). ‘Valencia 4’ produced the lowest yield of 143 kg/tree (Table 2). The interaction effect between scion and rootstock selections was not statistically significant for cumulative yield, however, the ‘Valencia 5’/‘Zao Yang’ combination produced 210 kg/tree, higher than ‘Keenan’/‘Tri22’ and ‘Valencia 4’/‘Donghai’ combinations, which each produced 127kg/tree (data not shown). The yield efficiency for ‘Valencia 1’ was higher than ‘Keenan’ and other selections. The interaction effect was significant for yield efficiency. Yield efficiency was higher in ‘Valencia 4’/‘Zao Yang’ and ‘Valencia 1’/‘Zao Yang’ (3.8) compared to ‘Keenan’ (3.2). In this trial, ‘Valencia 5’/‘Donghai’ had the lowest yield efficiency of 2.1 (data not shown).

3.2. Fruit size distribution (> 75 mm)

Fruit size distribution data demonstrated significant main and interaction effects. ‘Zao Yang’ rootstock had the highest percentage of fruit above 75 mm diameter (43%) compared with other rootstocks and ‘Valencia 6’ had the highest percentage of large fruit (47%) compared with all other Valencia selections trialled. The ‘Valencia 6’/‘Zao Yang’ combination had the highest percentage of large-sized fruit (58%), significantly higher than fruit produced on the control trees of ‘Keenan’/‘Tri22’ (35%). The lowest percentage of fruit greater than 75 mm diameter was produced by the ‘Valencia 4’/‘Tanghe’ (19%) and ‘Valencia 1’/ ‘Tri22’ (22%) combinations (Table 3).

3.3. Fruit quality components

Data for TSS (measured as °Brix) varied across the growing seasons for the Valencia and rootstock selections. Generally, there was no effect of rootstock selection on TSS each year or on the average across the 5 years. However, fruit acidity was affected by rootstock treatment. Fruit produced on ‘Zao Yang’ rootstock had the highest acid value (0.98%) compared with other rootstocks (Table 4). Sugar:acid ratios, juice% and BrimA values were not significantly affected by rootstock selections.

Scion variety had a significant effect on fruit quality over the 5 growing seasons. Fruit produced on ‘Valencia 5’ trees had significantly increased levels of TSS compared with ‘Keenan’ Valencia each season. In the 2015, 2016 and 2018 seasons, fruit produced on ‘Valencia 5’ trees had an average of 12.0 °Brix compared to 10.7 °Brix in fruit produced on ‘Keenan’ Valencia’. In 2017, the °Brix values were lower and in 2019 the °Brix values were higher for all treatment combinations. The average °Brix values across the 5 years were 1.7 degrees higher for ‘Valencia 5’ than ‘Keenan’ Valencia’ (Table 4).

The average acid values and sugar:acid ratios across the 5 seasons were higher in fruit produced on ‘Valencia 5’ trees than fruit produced on ‘Keenan’ and trees of other selections. The juice percentage was slightly higher in ‘Valencia 5’ compared to all other selections. The effects were more prominent in BrimA values across Valencia selections. ‘Valencia 5’ had a BrimA value of 131 compared with ‘Keenan’ at 110 (Table 4).

3.4. Tree growth components

The trunk circumference measured during the 2014 and 2019 growing seasons was significantly greater for trees on ‘Zao Yang’ rootstock compared with ‘Tri22’ (Table 5). The rate of trunk circumference increment was higher for ‘Zao Yang’ and ‘Donghai’ compared with ‘Tanghe’ and ‘Tri22’. For the scion treatments, ‘Valencia 5’ had significantly increased trunk circumference compared to ‘Keenan’ in both 2014 and 2019. The trunk circumference increments over the 5 seasons followed the same trend. Tree height differences across rootstocks became more significant over time as the trees grew. ‘Zao Yang’ and ‘Donghai’ trees were higher than trees on ‘Tanghe’ and ‘Tri22’ and this difference was more evident in the height increment from 2014 to 2019 (Table 5).

‘Valencia 5’ trees were significantly taller and had a faster growth rate (1.05) in 2014 and 2019 compared with the commercial standard ‘Keenan’ Valencia (0.71) and the other scion selections (Table 5). The canopy volumes were very similar for all treatments in 2014, but by 2019 trees on ‘Zao Yang’ had a larger canopy volume (5.7) than ‘Tri22’ (4.8) (Table 5). Trees of ‘Valencia 5’ had significantly greater canopy volumes compared with ‘Keenan’ in both 2014 and 2019. This was also evident in canopy increment data that was highly significant for ‘Valencia 5’ (6.2) compared to ‘Tri22’ (2.8). ‘Valencia 1’ trees had the lowest canopy volume increase of 2.5 (Table 5).

Trunk circumference was significantly influenced by the rootstock and scion interaction (data not shown). Tree heights and canopy volumes were also significantly influenced by the interaction between rootstock and scion treatments, except for 2014.

Discussion

This study investigated the performance of 'Valencia' sweet orange selections on *P*. *trifoliata* rootstocks in a fully replicated field trial on a commercial orchard in the Riverina region of NSW. The new rootstock selections under evaluation were released to the Australian industry due to their high performance in fully replicated field trials conducted at Dareton Primary Industries Institute, but it was important to assess their performance in other regions and soil types. Australia was the only country granted access to Chinese rootstock material over the past 50 years. Therefore, no work has been reported elsewhere about the field performance of Chinese trifoliata rootstocks with Valencia orange in a sandy clay soil type.

The yield data collected in this trial demonstrated the superior performance of 'Zao Yang' compared with 'Tri22', the standard selection used in clay (heavy) soil conditions in Australia. Our results for the yield data were consistent throughout 5 growing seasons. However, fruit yield varied across seasons. Annual yield variation in Valencia sweet orange is common due to the alternate bearing nature of this variety (Martinez-Fuentes et al. 2010; Jones et al. 1974; Moss 1971; Bani 1958) and in 'Murcott' (Li et al. 2003) and 'Nules' clementines (Chao et al. 2011). Alternate bearing is caused by fruits inhibiting the formation of flowers on the same branch. The tendency of trees towards alternate bearing increases with an increase in age (Monselise and Goldschmidt 1982). In this study, the trees were only 9 years of age at the last harvest but were already exhibiting yield variations. Trees on 'Zao Yang' rootstock had a slightly lower alternate bearing index than the other rootstock varieties trialled. This result was encouraging as typically rootstock variety does not affect alternate bearing (Turner 2004; Hoblyn et al. 1936). Due to the variable yield across different growing seasons, it was meaningful to assess the cumulative yields for 5 seasons. The cumulative yield for the 'Valencia 5' selection was higher than other 'Valencia' selections tested in this study. The most striking feature of the data was that 'Valencia 5' trees on 'Zao Yang' had a 65% increase in fruit yield over the standard control combination of 'Keenan Valencia' on 'Tri22'.

Commercial citrus trees are pruned and hedged regularly, which affects canopy volume, however, tree circumference typically expands each year, therefore the yield efficiency, calculated by measuring the trunk circumference, gives a reliable measure of the tree size compared with tree canopy volume (Westwood and Roberts 1970). In our work, trunk circumference explained 73% of the variation in the cumulative yield (data not shown). 'Valencia 5' trees on 'Zao Yang' had 30% greater yield efficiency than the control combination. This was due to the large trunk circumference of 'Zao Yang' and large canopy volumes of the 'Valencia 5' selection. 'Valencia 5' had larger canopy volumes than all other Valencia selections observed in our study.

The effect of rootstock variety is expressed in a range of variables (Castle 2010). The combination of rootstock and scion variety has been shown to exert its effect on fruit quality of 'Or' and 'Odem' mandarins and Valencia oranges (Benjamin et al. 2013). Fruit size is one of the important variables in sweet orange production where fruit are destined for fresh consumption. Therefore, it is significant that trees on 'Zao Yang' rootstock produced 43% of fruit above 75 mm in diameter, while the 'Valencia 6' scion selection had enhanced fruit size when compared to other Valencia selections. The combination of 'Valencia 6' on 'Zao Yang' is a good candidate to produce the larger fruit sizes often demanded by fresh fruit markets. Large-sized fruit can generate high returns for citrus growers.

Internal quality variables are important for both juice processing and fresh fruit consumption (El-Zeftawi et al. 1982). In our study, 'Valencia 5' was found to be a superior scion because trees of this selection produced fruit with higher sugar levels than the other Valencia treatments evaluated. 'Valencia 5' was able to consistently produce high sugar levels for 5 consecutive years, and this was more pronounced when 'Valencia 5' was grafted to 'Zao Yang' rootstock. The effect of scion and rootstock combination on fruit quality has been reported previously for mandarins (Benjamin et al. 2013). The climatic conditions influenced the sugar and acid levels in the 2017 and 2019 growing seasons across all rootstock and Valencia selections but did not affect the overall trends exhibited in the quality variables. In the 2017 growing season, the fruit had lower °Brix values due to an extremely cold winter and the number and extent of frost events that occurred between May and September (Table 1). An early freeze or drastic fluctuations in temperature have been found to exacerbate cold injury (Nesbitt et al. 2000; Yelenosky 1991). In 2019, very hot summer conditions and an irrigation system failure for several weeks in February caused the °Brix values to increase above expected values. Water stress imposed in late summer to early autumn in Australia has been reported to enhance sugar and acid levels at the expense of fruit size in Satsuma mandarins (Sanderson 2003). This has also been reported in early navel oranges in California (Kallesen and Sanden 2011). Fruit yields were lower for 2019 in our studies, and this could likely be due to the reduced fruit size caused by heat and water stress. Due to the reported issues in 2017 and 2019, the 5-year average is a more reliable indicator for making recommendations, as suggested by Castle et al. (2011).

The 'Valencia 5' selection also produced fruit with high acid levels and high sugar:acid ratios. Processing fruit with a blend of 12 °Brix and 1% acid is considered to produce good quality juice for the consumer (H Baird, Manager Mildura Fruit Juices, *pers. comm*.). Bates et al. (2001) also recommended 12 °Brix and 1% acid to be ideal for producing good quality orange juice. BrimA values are a Californian–Australian quality standard for harvest maturity (Clark 2016) and it measures the balance between °Brix (sweetness) and acidity (sourness) (McDonald et al. 2013). The sugar:acid ratio is currently used as a maturity index for fruit however, this measurement does not always correlate with the perception of sweetness or sourness (Obenland et al. 2009). BrimA is a better indicator of flavour (taste) and was adopted in 2012 by the Californian Department of Food and Agriculture as the standard quality parameter to determine the sweetness of Navel oranges (Clark 2016). BrimA is now also used by the Australian citrus industry to define fruit maturity. In our work, 'Valencia 5' produced higher BrimA values than any other selection. 'Valencia 5' also had a small advantage with an increase in juice% over other selections which would make it more acceptable for the juicing industry.

'Valencia 5' is a clonal mutation found in the Riverina as a single tree in a Valencia orchard. Application has been made for Plant Breeders Rights (PBR) to protect the variety before commercialisation. 'Zao Yang' trifoliate rootstock is commercially available through the Auscitrus budwood and seed scheme with young trees now established in a range of soil types in southern Australia.

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Table 1: The total number of days of maximum and minimum temperature extremes for (December and January) for 5 growing seasons.

Temperature	2015	2016	2017	2018	2019
	Minimum temperatures (May to September)				
< 0	23	13	44	26	32
0 to -1	13	11	15	11	18
-1.1 to -2	7	2	6	6	10
-2.1 to -3	3	0	16	4	4
-3.1 to -4	0	0	4	5	0
-4.1 to -5	0	0	3	0	0
	Maximum temperatures (October to April)				
> 35.0	40	42	42	44	62
35.1 to 40.0	31	37	35	31	36
40.1 to 45.0	9	5	7	13	22
45.1 to 50.0	0	0	0	0	4

Table 2: The effect of yield components for Valencia selections budded to *P. trifoliata* rootstocks from the 2015 to 2019 growing seasons.

	Yield components and year of measurement							
	Fruit yield (kg)/tree					Cumulative yield (kg)/tree	Yield efficiency (kg)/trunk circumference (cm)	Biennial bearing index (BBI)
Main factors	2015	2016	2017	2018	2019	2015–19	2015–19	2015–19
Rootstock								
Tri22 (control)	33 a	17 a	25 a	32 a	32 a	137 a	3.1 b	0.22 ab
Donghai	35 ab	19 a	26 a	32 a	33 a	144 a	2.9 a	0.22 bc
Tanghe No. 6	37 b	17 a	27 a	31 a	32 a	144 a	3.1 b	0.24 c
Zao Yang	41 c	26 b	31 b	43 b	36 b	180 b	3.5 c	0.19 a
Variety								
Keenan (control)	37 ab	21 c	24 b	40 b	32 ab	153 a	3.2 b	0.23 a
Valencia 1	32 a	20 bc	21 a	40 b	34 bc	147 a	3.4 c	0.20 a
Valencia 2	36 ab	24 d	30 c	30 a	36 c	156 ab	3.3 bc	0.22 a
Valencia 3	38 bc	19 abc	28 c	32 a	30 a	146 a	3.1 b	0.21 a
Valencia 4	33 ab	17 a	26 bc	34 a	32 ab	143 a	3.2 b	0.21 a
Valencia 5	42 c	20 abc	36 d	34 a	34 bc	162 b	3.0 a	0.24 a
Valencia 6	37 abc	18 ab	27 bc	32 a	34 bc	148 a	3.2 b	0.21 a
Analysis of variance								
Rootstock	***	***	***	***	**	***	***	***
Variety	***	***	***	***	***	**	***	NS
Rootstock*Variety	NS	NS	NS	NS	***	NS	***	NS

The probability value for the ANOVA, $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$, and NS (non-significant). Mean separation within the columns was tested using Duncan's multiple range test ($P < 0.05$). The mean followed by the same letter within the column was not significantly different.

Table 3: The main and interaction effect of percentage fruit size (> 75 mm in diameter) for Valencia selections budded to *P. trifoliata* rootstocks.

	Tri22 (control)	Donghai	Tanghe No. 6	Zao Yang	Variety (Mean)
Keenan (control)	35	36	39	44	38
Valencia 1	22	29	25	31	27
Valencia 2	37	34	40	49	40
Valencia 3	31	39	26	38	34
Valencia 4	30	27	19	48	31
Valencia 5	27	25	33	37	31
Valencia 6	40	43	46	58	47
Rootstock (Mean)	32	33	32	43	

The main effects rootstock is significant at $P < 0.001$ (LSD = 2.3) and varieties at $P < 0.001$ (LSD = 3.9). The treatment differences should be compared within the column for varieties and within the rows for rootstocks. The interaction effect rootstocks*varieties were significant at $P < 0.001$ (LSD = 7.8) and should be compared across different rootstock and variety combinations.

Table 4. Fruit quality variables total soluble solids (°Brix), acid (%), °Brix:acid ratio, juice (%) and BrimA for the 2015 to 2019 growing seasons.

	Fruit quality variables and year of measurements									
	Total soluble solids (^{0}Brix)					^{0}Brix	Acid (%)	Ratio	Juice (%)	BrimA
Main factors	2015	2016	2017	2018	2019	2015-19	2015-19	2015-19	2015-19	2015-19
Rootstock										
Tri22 (Control)	10.7 a	11.0 a	8.0 a	10.6 a	12.8 a	10.6 a	0.96 b	11.2 a	52 a	112 a
Donghai	10.6 a	11.0 a	7.9 a	10.3 a	12.7 a	10.5 a	0.94 a	11.2 a	51 a	111 a
Tanghe	10.9 b	11.0 a	7.8 a	10.7 a	12.8 a	10.6 a	0.95 ab	11.3 a	51 a	113 a
Zao Yang	10.9 b	11.1 a	7.8 a	10.6 a	12.9 a	10.7 a	0.98 c	11.1 a	51 a	111 a
Variety										
Keenan (Control)	11.1 b	10.6 a	7.5 a	10.4 a	12.3 a	10.4 abc	0.94 a	11.3 bc	50 a	110 abc
Valencia 1	10.3 a	10.6 a	7.5 a	10.2 a	12.1 a	10.1 a	0.93 a	11.0 abc	50 a	106 a
Valencia 2	10.5 a	11.0 ab	7.9 a	10.2 a	12.8 ab	10.5 bc	0.93 a	11.3 c	51 a	111 bc
Valencia 3	10.5 ab	11.4 b	7.8 a	10.5 a	13.2 b	10.7 c	0.97 b	11.1 bc	52 a	112 c
Valencia 4	10.5 ab	10.8 ab	7.7 a	10.5 a	12.3 a	10.4 ab	0.97 b	10.8 a	51 a	107 ab
Valencia 5	12.0 c	12.2 c	9.3 b	11.9 b	14.8 c	12.1 d	1.03 c	11.9 d	53 b	131 d
Valencia 6	10.5 ab	10.4 a	7.3 a	9.9 a	12.2 a	10.1 a	0.93 a	11.0 ab	51 a	105 a
Analysis of variance										
Rootstock	*	NS	NS	NS	NS	NS	*	NS	NS	NS
Variety	***	***	***	***	***	***	***	***	**	***
Rootstock*Variety	NS	NS	NS	NS	NS	NS	**	NS	NS	NS

The probability value for the ANOVA, $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$, and NS (non-significant). Mean separation within the columns was tested using Duncan's multiple range test ($P < 0.05$). The mean followed by the same letter within the column was not significantly different.

Table 5. Tree growth variables trunk circumference (cm), tree height (m), canopy volume (m^3) and canopy spread (m) from the 2014 to 2019 growing seasons.

	Tree growth variables and year of measurements											
	Trunk circumference (cm)			Tree height (m)			Canopy volume (m^3)			Canopy spread (m)		
Main factors	2014	2019	Increase	2014	2019	Increase	2014	2019	Increase	2014	2019	Increase
Rootstock												
Tri22 (control)	14.7 a	23.8 a	9.1 a	1.47 ab	2.18 a	0.71 a	1.8 a	4.8 a	3.0 a	1.52 a	2.01a	0.50 a
Donghai	15.1 a	25.4 b	10.3 b	1.45 a	2.26 b	0.81 b	1.8 a	5.3 b	3.4 bc	1.54 ab	2.07 b	0.54 a
Tanghe No. 6	15.1 a	24.2 a	9.0 a	1.52 b	2.21 ab	0.69 a	2.0 b	5.2 b	3.2 ab	1.56 bc	2.08 bc	0.52 a
Zao Yang	15.6 b	25.9 b	10.2 b	1.51 b	2.34 c	0.82 b	2.0 b	5.7 c	3.7 c	1.59 c	2. 14 c	0.55 a
Variety												
Keenan (control)	15.2 c	24.7 b	9.5 a	1.46 ab	2.17 ab	0.71 a	1.9 b	4.7 b	2.8 ab	1.56 d	2.02 b	0.46 a
Valencia 1	14.1 a	23.2 a	9.1 a	1.39 a	2.07 a	0.68 a	1.5 a	4.0 a	2.5 a	1.44 a	1.92 a	0.47 ab
Valencia 2	15.0 bc	24.5 b	9.5 a	1.51 b	2.18 ab	0.67 a	1.9 b	4.7 b	2.8 ab	1.53 bcd	2.08 b	0.48 ab
Valencia 3	15.1 bc	24.3 b	9.1 a	1.50 b	2.22 b	0.73 a	1.9 b	4.9 b	3.1 b	1.55 cd	2.06 b	0.51 ab
Valencia 4	14.6 ab	23.7 ab	9.2 a	1.41 a	2.15 ab	0.74 a	1.7 a	4.7 b	3.0 b	1.49 abc	2.03 b	0.54 b
Valencia 5	17.4 d	29.4 c	12.0 b	1.71 c	2.76 c	1.05 b	2.9 c	9.1 c	6.2 c	1.80 e	2.50 c	0.70 c
Valencia 6	14.6 abc	24.0 ab	9.4 a	1.45 ab	2.18 ab	0.73 a	1.7 a	4.6 b	2.9 ab	1.48 ab	2.00 b	0.52 ab
Interaction effect												
Rootstock	**	***	***	*	***	**	*	***	***	**	***	NS
Variety	***	***	***	***	***	***	***	***	***	***	***	***
Rootstock*Variety	***	**	***	NS	**	*	NS	*	NS	*	NS	NS

The probability value for the ANOVA, $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$, and NS (non-significant). Mean separation within the columns was tested using Duncan's multiple range test ($P < 0.05$). The mean followed by the same letter within the column was not significantly different.

Chapter 2: Establishment and evaluation of salt tolerant rootstocks on Washington navel in Bindoon

Introduction

Previous research at Dareton, NSW DPI has identified a few Chinese mandarin rootstock selections as having some salt tolerance (Khurshid and Donovan, 2018). To further test the salt tolerance of these rootstocks, a trial was established on a grower's property at Bindoon (Western Australia) in April 2013 (Figure 2.1).

Figure 2.1: Trees planted in April 2013 (left) and tree on NSW DPI hybrid rootstock 3822 (Scarlet mandarin x *Poncirus trifoliata*) in May 2019 (right).

An additional set of rootstock hybrids from the NSW DPI breeding program and hybrids from the USDA that are reported to be salt tolerant were included in the trial. The main objective of this trial was to identify salt tolerant rootstocks with a higher yield, large fruit size and desirable fruit quality.

Materials and methods

Salt tolerance rootstock trial was established in Bindoon, Western Australia on the 4th of April 2013. There were 11 rootstocks grafted to Washington navel. The rootstocks were introduced from NSW DPI and USDA breeding programs, and from China. Trees were planted 3 m apart within the rows and 7 m between rows in a north-south orientation. Rootstocks were planted in a single tree plot as a randomised complete block design replicated 3 times. Data on fruit yield were collected for 6 years and fruit quality for 4 years. Tree growth data were collected for 8 consecutive years from 2014 to 2021. During the study, leaf samples and water samples were also tested for sodium and chloride content to assess the salt tolerance levels of trees. The rootstocks used in the trial are given in Table 2.1.

Results and discussion

Fruit yield components at harvest

Fruit yield data were collected for 6 consecutive years. There were significant differences between the rootstocks compared to the control (Tri22). In all years, rootstocks 3822, 3834 and 3835 had higher yields than other rootstocks (Table 2.2). The data were presented as the cumulative years for 6 years and, rootstocks 3835, 3822 and 3834 have 352, 348 and 324 kg/tree compared to the control (317 kg/tree). The yield efficiencies (kg/cm^2) of the rootstocks were 5.3, 4.7 and 4.9 kg/cm^2 for 3812, 3822 and 3834 respectively compared to the control 4.3 (Table 2.2). The lowest cumulative yield of 50 kg/tree was recorded for F1-199-40 and the lowest yield efficiency of 1.6 kg/cm^2. The average fruit weight was higher for 3812 (268 g) compared to the control (255 g). F1-199-40 produced a lower fruit weight of 202 g. The biennial bearing index (BBI) values varied across different rootstocks. Rootstocks 3812, F1 (63-199-31), F1 (62-109-49), 3834, and XOP had lower BBI values compared to the control (0.31) (Table 2.2).

Table 2.1: The salt tolerant rootstocks planted in Bindoon, Western Australia.

The rootstock used in the Bindoon trial	Breeding program
3812 (Scarlet mandarin* × *Poncirus trifoliata*)	Gosford breeding program, NSW DPI
3822 (Scarlet mandarin × *Poncirus trifoliata*)	Gosford breeding program, NSW DPI
3834 (Scarlet mandarin × *Poncirus trifoliata*)	Gosford breeding program, NSW DPI
3835 (Scarlet mandarin × *Poncirus trifoliata*)	Gosford breeding program, NSW DPI
Cox hybrid (Scarlet mandarin × *Poncirus trifoliata*)	Gosford breeding program, NSW DPI
F1 (63-199-31) Sunki mandarin × F. Dragon *Pocirus trifoliata*	USDA breeding program
F1 (62-109-49) Sunki mandarin × Mars *Poncirus trifoliata*	USDA breeding program
F1 (62-109-40) Sunki mandarin × Mars *Poncirus trifoliata*	USDA breeding program
X OP (59-24-8) Rangpur lime × Swingle *Poncirus trifoliata*	USDA breeding program
Zao Yang (Poncirus trifoliata)	Chinese rootstock selection, Dareton
Troyer citrange (Citrus sinensis × Poncirus trifoliata)	Standard rootstock (control)

* Scarlet mandarin is an old Australian variety, and no longer grown commercially.

Table 2.2: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree) and yield efficiency (kg/cm^2)/tree for 2020–2022 on Washington navel orange.

Rootstocks	Yield (kg/tree)						2016–2021			
	2016	2017	2018	2019	2020	2021	Cumulative yield (kg/tree)	Yield efficiency (kg/cm^2)	Average fruit weight (g)	BBI Index
3812	10	18	41	40	47	72	229	4.4	268	0.22
3822	12	32	52	72	73	107	348	4.7	232	0.26
3834	10	29	50	51	72	113	324	4.9	251	0.24
3835	6	28	60	65	77	117	352	5.3	242	0.27
Cox hybrid	8	20	40	40	57	87	251	5.2	240	0.26
F1 (63-199-31)	8	16	33	34	33	40	163	2.5	228	0.24
F1 (62-199-49	10	22	39	45	51	54	221	4.1	240	0.24
F1 (62-109-40)	0	1	11	9	13	15	50	1.9	202	0.36
X OP (59-24-8)	9	22	43	43	51	60	227	3.8	235	0.22
Zao Yang	5	16	33	30	28	48	160	4.5	246	0.34
Troyer citrange	9	24	49	60	67	108	317	4.3	255	0.31
Probability	*	***	***	***	***	***	***	**	***	***
LSD ($p < 0.05$)	4.8	8.7	13.2	14.8	12.2	25.9	71.0	1.5	15.9	0.05

Mean separation within the columns was tested with LSD (Least significant difference) in different rootst treatments. $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$

Fruit size distribution at harvest

Fruit trees were harvested, and fruit size was assessed for the exportable size classes (76 mm to 90 mm). The data in Table 2.3 indicated the percentages of fruit from (77 mm to 90 mm). Fruit distribution varied from year to year in different rootstocks. However, the fruit size percentages were higher for 3834, 3812 and 3835 in 4 years compared to the remaining rootstocks. The mean data over 4 years indicated that the percentage of large fruit for 3834 (83%), 3812 (81%) and 3835 (81%) compared to the control (78%) and the remaining rootstocks. The rootstocks from the Californian breeding rootstocks have a lower percentage of fruit in the larger size class (76–90 mm). Rootstocks F1 (62-109-40), F1 (62-199-49) and F1 (63-199-31) had 35%, 54% and 60% fruit in large size class compared to the control (78%). These rootstocks could not perform in terms of yield and fruit size despite the very low value of chloride% in leaf tissue.

Table 2.3: The effect of rootstocks on per cent fruit size distribution for 2019 to 2021 (76 to 90 mm) on Washington navel orange.

Rootstocks	2019	2020	2021	2022	Mean
3834	79	92	74	89	83
3812	76	86	81	82	81
3835	76	92	69	85	81
Troyer citrange	69	91	66	87	78
Cox hybrid	64	87	43	88	71
3822	52	86	53	86	69
Zao Yang	66	81	49	78	69
X OP (59-24-8)	64	85	35	64	62
F1 (63-199-31)	56	85	33	66	60
F1 (62-199-49	46	90	23	56	54
F1 (62-109-40)	25	60	21	34	35

Fruit quality components at harvest

Fruit quality component data are presented for 5 consecutive years (Table 2.4). The data indicated that °Brix slightly varied from year to year across different rootstocks but these results were not statistically different. The average °Brix data over 5 years indicated that the highest value was 12.8 °Brix for F1 (62-109-40) and the lowest value of 11.4 °Brix was for 3835. The average of 5 years of data indicated that the BrimA values for F1 (62-109-40), Zao Yang and 3812 have significantly increased compared to the control (113). These results indicated that these rootstocks have sweeter fruit than other rootstocks. The average acid% values over 5 years indicated a low acid value of 1.2 for 3812, Troyer citrange, 3824 and 3835, while F1 (62-109-40) and Zao Yang had acid values of 1.3. The remaining rootstocks had acid values of 1.4. The average juice% over 5 years was significantly different, however, these differences have low commercial importance since Washington navel fruit is used for fresh consumption. Average fruit weight was higher for Troyer citrange (269 g) followed by 3812 (262 g)). Fruit from trees grown on F1 (62-109-40) and F1 (63-199-31) rootstocks carried an average weight of 220 g and 224 g respectively.

Tree growth components

Trunk circumference (cm)

In 2014, the trunk circumference was larger in all rootstocks compared to the control apart from F1 (62-109-40) and F1 (63-199-49) (Table 2.5). The larger circumference was recorded for 3834 (8.7 cm) and 3822 (8.6 cm) compared to the control (6.2 cm). F1 (62-109-40) and F1 (63-199-49) had a smaller trunk circumference.

Table 2.4: The effect of rootstocks on °Brix, BrimA, acid%, juice% and individual fruit weight (g) from 2017 to 2021 on Washington navel orange.

	°Brix					Average values (2017–2021)				
	2017	2018	2019	2020	2021	°Brix	BrimA	Acid (%)	Juice (%)	Fruit weight (g)
3812	11.6	11.9	12.4	11.8	11.5	11.9	120	1.2	50	262
3822	11.4	13.1	12.1	12.0	11.4	12.0	108	1.4	50	246
3834	11.0	12.5	11.6	12.0	11.0	11.7	115	1.2	49	261
3835	11.4	11.6	11.0	11.6	11.6	11.4	110	1.2	51	259
Cox	12.0	12.4	13.0	12.0	12.0	12.1	110	1.4	52	247
F1 (63-199-31)	12.2	13.1	12.2	12.4	12.0	12.4	114	1.4	52	224
F1 (62-199-49	12.0	12.8	12.8	12.2	12.3	12.5	113	1.4	52	239
F1 (62-109-40)	12.0	12.9	13.2	12.7	12.3	12.8	126	1.3	49	220
Troyer citrange (control)	11.8	11.9	12.3	12.0	11.2	11.8	113	1.2	50	269
X OP (59-24-8)	11.6	12.7	12.3	12.2	12.0	12.3	112	1.4	52	244
Zao Yang	12.1	13.1	13.0	12.5	12.0	12.5	122	1.3	47	237
Probability	ns	ns	ns	ns	ns	ns	***	ns	*	**
LSD ($p < 0.05$)	-	-	-	-	-	-	1.56		2.87	1.56

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

In 2021, the trunk circumference was larger for 3822 (30.9 cm), Troyer citrange (30.4 cm), 3835 (29.1 cm) and 3834 (29.1 cm). The remaining rootstocks had trunk circumference below 28 cm. in 2021, Zao Yang and F1 (62-109-40) had the smallest trunk circumference (Table 2.5). The rate of trunk circumference was calculated by subtracting the trunk circumference of the final year (2021) from the initial trunk circumference (2014). The data indicated that trees on *Troyer citrange* grew faster than other rootstocks, while the slower-growing trees were Zao Yang (13.6 cm) and F1 (62-109-40; 14.1 cm). These small trees may be used for high-density plantings. The rootstock F1 (62-109-40) will be particularly suitable for high-density plantings in areas with higher salt content in irrigation water and sandy soil conditions. This rootstock has demonstrated the ability to exclude salt during the current study. The Zao Yang rootstock will be suitable for heavier soil conditions where water quality is good with no salt content in irrigation water.

Tree height

In 2014, the tree height was between 0.8 m to 1.2 m and was not significant. This result was not surprising since trees were only planted in 2013 and at the time of planting, they had the same height. Nursery trees are normally 1 m high at the time of planting. In 2021, the tree height was 2.9 m for 3822 and *Troyer citrange* (Table 2.5). The remaining rootstocks had tree heights below 2.9 m. In 2021, Zao Yang and F1 (62-109-40) had the lowest tee height of 2 m. The rate of tree growth was calculated by subtracting the tree height of the final year (2021) from the initial tree height (2014). The data indicated that trees on *Troyer citrange* and 3822 grew faster than other rootstocks, while the slower growing trees were from rootstocks Zao Yang, F1 (62-109-40) and 3812 which added 0.8 to 1.1 m height to trees (Table 2.5).

Graft union

Graft union data were collected for all rootstocks to assess the degree of smoothness at the graft union. A smooth union indicates similar growth rates for the stock and scion, and this permits a thorough fusion of tissues at the graft union. The scion may overgrow the stock or vice versa. The ratio between stock to scion growth near the graft union provides a measure of the degree of 'benching' and can give a means of predicting at a very early stage of a tree's life if a stock/scion

incompatibility could be an issue with older trees. Benching is a term used to describe where either the stock or scion overgrows the other.
The data on benching scores indicated that Zao Yang had the highest score of 2.8 (Table 2.5). The rootstocks F1 (63-199-31), Cox, and F1 (62-199-49) had a score of 2.0, while the control rootstock had a score of 1.8. The best score of 1.3 was recorded in rootstocks 3834, X OP and F1 (62-109-40), which suggested the trees were close to having a smooth union (Table 2.5).

Table 2.5: The effect of rootstocks on trunk circumference (cm) and tree height (m) and graft union for 2019 to 2021 on Washington navel oranges.

Rootstocks	Trunk circumference (cm)			Tree height (m)			Graft union
	2014	2021	Diff.	2014	2021	Diff.	
3812	7.7	26.0	17.0	1.1	2.5	1.1	1.5
3822	8.6	30.9	23.1	1.1	2.9	1.8	1.5
3834	8.7	29.1	21.8	1.0	2.8	1.7	1.3
3835	7.6	29.1	22.7	1.2	2.8	1.7	1.8
Cox hybrid	8.2	24.5	17.5	0.8	2.6	1.6	2.0
F1 (63-199-31)	6.5	28.8	22.0	1.0	2.6	1.6	2.0
F1 (62-199-49	6.0	26.2	20.0	0.9	2.2	1.3	2.0
F1 (62-109-40)	4.0	18.3	14.1	0.8	2.0	1.0	1.3
X OP (59-24-8)	7.8	27.8	20.0	1.1	2.5	1.3	1.3
Zao Yang	7.7	21.0	13.6	1.0	2.0	0.8	2.8
Troyer citrange	6.2	30.4	26.5	0.9	2.9	1.9	1.8
Probability	***	***	***	ns	***	***	***
LSD ($p < 0.05$)	1.2	2.85	3.26		0.35	0.46	0.64

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. $^{***}p < 0.001$ and ns (non-significant).

Salt data collection for leaves and irrigation water

Salt leaf content:

The leaf sample data were collected for 5 consecutive years. The data indicated that for each growing season the leaf chloride levels were higher in 3812, Zao Yang, 3835 and *Troyer citrange* rootstocks compared to the remaining rootstocks (Table 2.6). The 5-year average data indicated the highest chloride levels for 3812 (0.70) followed by Zao Yang (0.68), compared to the control rootstock (0.52). The lower values of 0.21, 0.23, 0.24, 0.28 and 0.29 were recorded for Cox, F1 (63-199-31), F1 (62-199-49), X OP and 3822 respectively. The data revealed the chloride exclusion ability of certain rootstocks.

Salt water content:

Water samples were collected from the water supply for 5 consecutive years and were tested for EC (electric conductivity) and pH. The data indicated that 2017, 2018 and 2019 were the heavy salt years and the EC was 3.7, 3.4 and 3.2 ds/m respectively (Table 2.7). In 2020 EC was 2.8 ds/m, while in 2021 this value was 2.7 ds/m. The amount of salt is given in Table 2.6, which indicated that in 2017 there was 2 g/L (0.7 teaspoons) of salt in the irrigation water. In 2020 and 2021, the salt was 1.5 g/L (0.5 teaspoons). In my calculations, one small teaspoon given in Figure 3.2 held 3 g of salt. However, the salt values from the samples derived from the fertigation will be different. The values will further increase when nutrients are added to the irrigation water to apply as fertigation. The water EC figures recorded from our trial from

Bindoon were much higher than the normal irrigation water of Mildura which has the levels of EC of 160 micoSiemens/cm (https://www.mdba.gov.au/sites/default/files/weeklyreports/River-Murray-Operations-Weekly-Report-12-October-2022.pdf).

Table 2.6: Mean chloride levels measured in spring flush leaves collected for 5 growing seasons.

Rootstocks	2017	2018	2019	2020	2021	Average (2017–21)
3812	0.85	0.52	0.81	1.09	0.66	0.79
Zao Yang	0.43	0.43	0.70	1.08	0.74	0.68
3835	0.61	0.33	0.49	0.84	0.75	0.60
Troyer citrange	0.43	0.43	0.49	0.65	0.59	0.52
3834	0.38	0.20	0.31	0.58	0.70	0.43
F1 (62-109-40)	0.46	0.27	0.30	0.46	0.27	0.35
3822	0.22	0.19	0.27	0.33	0.44	0.29
X OP (59-24-8)	0.20	0.31	0.19	0.2	0.52	0.28
F1 (62-199-49	0.26	0.25	0.27	0.24	0.19	0.24
F1 (63-199-31)	0.19	0.19	0.27	0.35	0.13	0.23
Cox hybrid	0.17	0.18	0.18	0.34	0.18	0.21

Table 2.7: Salt content in irrigation water from 2017–2021, Bindoon WA.

	EC (micoSiemens/cm)	EC (deciSiemens/m)	pH	Sodium Chloride (g/L)
2017	3700	3.70	6.5	2.04
2018	3440	3.44	6.8	1.89
2019	3240	3.24	6.4	1.78
2020	2760	2.76	6.8	1.52
2021	2740	2.74	6.4	1.51

Figure 2.2: A full teaspoon held 3 g of salt.

Recommendations

Given the data on tree growth, fruit production, fruit quality, fruit size distribution, leaf and irrigation water chloride levels the following 2 rootstocks were recommended:

1. 3822 (Scarlet mandarin × *Poncirus trifoliata*)

   Washington navel budded onto this rootstock had salt-excluding ability. The rootstock had 69% of fruit in size class (76 90 mm), desirable internal fruit quality with 12.0 °Brix, and an acceptable graft compatibility score of 1.5. Trees produced a 10% higher fruit yield than the *Troyer citrange* and the biennial bearing index was 0.26.

2. 3834 (Scarlet mandarin × *Poncirus trifoliata*)

   Washington navel budded onto this rootstock had 83% of fruit in size class (76–90 mm), desirable internal fruit quality with 11.7 °Brix, and an acceptable graft compatibility score of 1.3. Trees produced a 2% higher fruit yield than the *Troyer citrange* and the biennial bearing index was 0.24.

Chapter 3: Evaluation of dwarfing rootstocks on M7 navel and Tangold mandarin with high-density planting at Dareton

Introduction

High-density planting systems produce higher and earlier yields and have been adopted overseas for both domestic and export fruit production. Control of vegetative and reproductive growth characteristics of citrus trees is becoming increasingly important when plantings are established at high densities. To get the benefits of high-density planting systems, tree size and vegetative growth should be controlled. Once trees are grown on a dwarfing rootstock, high-density planting can result in increased yield and fruit quality. Other benefits of dwarfing rootstocks (smaller trees) are increased light interception, efficient spraying, fertilising and harvest without the use of ladders leading to improved safety and management efficiency. The use of dwarfing rootstocks is a cost-effective and robust method and does not need any expensive trellis system or hedging techniques.

Therefore, a range of dwarfing and semi-dwarfing rootstocks were established at Dareton with M7 navel and Tangold mandarin. The objective of this trial was to evaluate the effect of rootstocks on tree growth, yield and quality of navel and mandarin crops grown at a density of 1,098 trees/hectare. The results will help make a recommendation of the most suitable rootstocks under the Sunraysia conditions.

Materials and methods

Selected Chinese and American rootstocks were budded to M7 navel and Tangold mandarin. Two trials were established on M7 navel and Tangold mandarin with 7 rootstocks at NSW DPI, Dareton in October 2017 (Figure 3.1). Trees were planted 2.6 m apart within the rows and 3.5 m between rows in a north-south orientation with a tree density of 1,098 trees/ha. These rootstocks were from China and the Californian breeding program, with Tri22 (Australian strain) used as a control (Table 3.1). The performance of these new rootstocks was evaluated from 2019 to 2021. Data on tree growth, fruit yield and fruit quality were recorded and presented.

Figure 3.1. M7 navel trial planted in 2017 at NSW DPI Dareton. The photos were taken in 2019 (left) and September 2022 (right).

Results and discussion

Experiment 1. (M7 navel)

Fruit yield components at harvest

Fruit yield data were collected for the 2020, 2021 and 2022 growing seasons.

In 2020, fruit yield of C-22, C-35 and C-54 was significantly higher compared to the control Tri22 rootstock. At the same time, No. 24 had a significantly reduced yield compared to the control (Table 3.2). In 2021, fruit yield increased for C-22 and C-35 rootstocks and significantly decreased for No. 24 rootstock. Data were collected for tree growth, fruit quality and fruit yield during the evaluation study. M7 and Tangold navel was budded onto 8 rootstocks and were treated as separate experiments.

Table 3.1: Rootstocks used in the dwarfing effect trial were sourced from different institutes.

Rootstock	Type	Source
85-24	*Poncirus trifoliata*	People's Republic of China
C-146	Citrus sunki × *Poncirus trifoliata* L. Raf 'Swingle'	*University of California, Riverside
C-22 (Bitters)	Citrus sunki × *Poncirus trifoliata* L. Raf 'Swingle'	*University of California, Riverside
C-54 (Carpenter)	Citrus sunki × *Poncirus trifoliata* L. Raf 'Swingle'	*University of California, Riverside
C-57 (Furr)	Citrus sunki × *Poncirus trifoliata* L. Raf 'Swingle'	*University of California, Riverside
Flying Dragon	*Poncirus trifoliata*	Auscitrus, Australia
No. 24	*Poncirus trifoliata*	People's Republic of China
Tri22	*Poncirus trifoliata*, Australian	Auscitrus, Australia

*USDA Breeding Program, Indio

In 2022, the fifth year after planting, yield increases were observed in many rootstocks compared to the control. The yield increased with C-54, C-35, C-22 and C-57 rootstocks compared to the control Tri22 but remained lower in the No. 24 rootstock. The data can be best presented as cumulative yield for 3 years. The data indicated that cumulative yield increased for C-35 (54.5), C22 (54.2), C-54 (51.1), and C-57 (40.6) compared to the control (28.2), while decreased with No. 24 (15.4) compared to the control (28.2). The yield efficiency (kg/cm^2) remained higher for C-35 and lower for No. 24 when compared to the control Tri22 (Table 3.2).

Table 3.2: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree) and yield efficiency (kg/cm^2)/tree for 2020–2022 on M7 navel orange.

Rootstocks	Yield kg/tree			2020–2022 Cumulative yield kg/tree	2020–2022 Yield efficiency kg/cm^2
	2020	2021	2022		
85-24	5.7	5.1	18.4	29.1	2.0
C-146	7.3	7.1	23.0	37.3	1.7
C-22	11.6	12.8	29.8	54.2	2.2
C-35	11.3	11.2	32.1	54.5	2.3
C-54	8.0	6.5	36.7	51.1	1.7
C-57	7.1	7.1	26.4	40.6	1.6
No. 24	2.0	3.1	10.3	15.4	1.5
Tri22	5.3	5.2	17.8	28.2	1.9
Probability	*	***	***	**	***
LSD ($p < 0.05$)	2.22	2.67	6.21	8.48	0.34

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.

*$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$

Fruit quality components at harvest

Fruit quality component data are presented for 2 consecutive years (Table 3.3).

In 2020, No. 24 (13.7) had increased °Brix compared to Tri22 (control), while C-35 had 12.9 °Brix compared to Tri22 (13.3 °Brix). BrimA levels were significantly increased with No. 24 (155) compared to the control (145), while the lowest BrimA values were recorded in C-35 (137). Rootstocks did not affect the acid levels in the fruit. Rootstocks C-146, C-57, C22, and C-54 had slightly higher juice percentage than the control, but the findings have no commercial significance. Average fruit weight was higher for C-57 compared to the control, but the remaining rootstocks did not affect fruit weight (Table 3.3).

In 2021, No. 24 and C-22 (14.7) had increased °Brix compared to the control Tri22 (13.9). BrimA levels were significantly increased with No. 24 and C-22 (161) compared to the control (151). Rootstocks did not affect the acid levels in the fruit. Rootstocks No. 24 had a slightly higher juice percentage than the control, but the findings have no commercial significance. Average fruit weight was higher for 85-24 compared to C-146, C-54, C-57, and No. 24, but the remaining rootstocks did not affect fruit weight (Table 3.3).

Table: 3.3: The effect of rootstocks on °Brix, BrimA, acid%, juice% and individual fruit weight (g) from 2020 to 2021 on M7 navel orange.

Rootstocks	2020					2021				
	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
85-24	13.2	141	1.2	46	266	13.7	152	1.1	45	274
C-146	13.3	145	1.1	51	239	14.4	154	1.3	50	246
C-22	13.4	143	1.2	50	241	14.6	161	1.2	48	248
C-35	12.9	137	1.1	49	258	14.2	152	1.2	48	266
C-54	13.3	140	1.2	50	243	14.1	153	1.2	49	224
C-57	13.2	139	1.2	51	238	14.1	151	1.2	50	229
No. 24	13.7	152	1.1	47	251	14.7	161	1.2	50	224
Tri22	13.3	145	1.1	47	258	13.9	151	1.2	46	259
Probability	**	***	ns	***	*	**	*	ns	*	***
LSD ($p < 0.05$)	0.35	6.71		2.29	19.85	0.54	8.58		3.38	22.94

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatment *$p<0.05$, **$p < 0.01$ and ***$p < 0.001$ and ns (non-significant).

Tree growth components

Trunk Circumference (cm)

In 2019, the trunk circumference significantly increased with C-22 (11.1) and C-35 (10.4) compared to the control (6.9). In 2020, the trunk circumference significantly increased with all citrange rootstocks compared to the control (Table 3.4). There was no effect of *Poncirus trifoliata* rootstocks on trunk circumference. In 2022, the same trend as 2020 occurred for trunk circumference. The difference in total circumference growth from 2019 to 2022 was significant with C-54 (10.7), C-57 (7.9) and C-146 (7.4) compared to Tri22 (5.4), but not between *Poncirus trifoliata* rootstocks. The lower trunk circumference was recorded for No. 24 for 2020 and 2021. The trunk circumference growth between 2019 and 2021 was also only 4.8 cm (Table 3.4).

Trunk height (m)

In 2019, the trunk circumference was significantly increased with C-35 (1.3) and C-22 (1.3) and C-54 (1.2) compared to the control (1.0). In 2020, tree height significantly increased with all citrandarin rootstocks compared to the control (Table 3.4). There was no effect of *Poncirus trifoliata* rootstocks on tree height. The year 2022 followed the same trend as 2020with increasing tree height; however, there was no tree height increase in No. 24. The lowest tree height was recorded for No. 24 for 2019, 2021, and 2022. The difference in total tree height increases from 2019 to 2022 was significant with C-54 (0.5) and C-57 (0.3) compared to Tri22 (0.2), but not between *Poncirus trifoliata* rootstocks (Table 3.4).

Table 3.4: The effect of rootstocks on trunk circumference (cm) and tree height (m) 2019–2021 on M7 navel orange.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
85-24	6.8	10.2	13.6	6.7	1.0	1.1	1.2	0.3
C-146	9.4	12.6	16.8	7.4	1.1	1.2	1.4	0.3
C-22	11.1	13.7	17.7	6.6	1.3	1.4	1.5	0.2
C-35	10.4	13.7	17.3	6.9	1.3	1.4	1.6	0.3
C-54	8.9	14.6	19.6	10.7	1.2	1.4	1.7	0.5
C-57	9.1	12.8	17.0	7.9	1.1	1.3	1.4	0.3
No. 24	6.9	8.7	11.7	4.8	0.9	1.0	1.0	0.1
Tri22	8.1	10.3	13.5	5.4	1.0	1.1	1.2	0.2
Probability	*	***	***	***	**	***	***	***
LSD ($p < 0.05$)	1.73	1.60	1.79	1.95	0.15	0.12	0.15	0.16

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.

$^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$

Experiment 2. (Tangold mandarin)

Fruit yield components at harvest

Fruit yield data were collected for the 2020, 2021 and 2022 growing seasons and presented in Table 3.5.

In 2020, fruit yield C-22 (17.6 kg/tree) and C-35 (14.5 kg/tree) was significantly higher compared to the control Tri22 (4.7 kg/tree) rootstock. At the same time, C-57 had a reduced yield compared to the control, but the effect was not significant.

Table 3.5: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree) and yield efficiency (kg/cm^2)/tree for 2020–2022 on Tangold mandarin.

Rootstocks	Yield kg/tree			2020–22 Cumulative yield	2020–22 Yield efficiency
	2020	2021	2022	kg/tree	kg/cm^2
85-24	8.4	18.1	63	88	2.1
C-146	9.0	17.9	72	99	1.8
C-22	17.6	25.8	94	138	2.1
C-35	14.5	30.6	93	138	2.5
C-57	10.8	14.5	60	84	1.7
No. 24	2.5	6.7	51	60	1.2
Tri22	7.2	14.6	58	80	2.2
Zao Yang	4.7	13.0	42	59	2.0
Probability	***	***	***	***	***
LSD ($p < 0.05$)	4.7	8.0	15.3	25.1	0.4

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.

$^{***}p < 0.001$

In 2021, fruit yield was increased for C-35 (30.6 kg/tree) and C-22 (25.8 kg/tree) compared to the control (13.0 kg/tree). C-57 resulted in 14.5 kg/tree compared to the control, but the effect was not significant. In 2022, the fifth year after planting, yield increases were observed in many rootstocks compared to the control. Yield was significantly increased with C-22 (94 kg/tree), C-35 (93 kg/tree), C-146 (72 kg/tree), 85-24 (63 kg/tree), Zao Yang (42 kg/tree), and No. 24 (51 kg/tree) compared to the control Tri22 (58 kg/tree). The data can be best presented as cumulative yield over 3 years. The data indicated that cumulative yield was significantly increased for C22 (138 kg/tree), C-35 (138 kg/tree), C-146 (99 kg/tree), and 85-24 (88 kg/tree) compared to the control (80 kg/tree). The yield efficiency remained higher for C-35 (2.5 kg/cm^2) and remain lower for C-57 (1.7 kg/cm^2), when compared to the control Tri22 (2.2kg/cm^2).

Fruit quality components at harvest

Fruit quality component data are presented for 2 consecutive years and presented in Table 3.6.

In 2020, there were no significant effects found for °Brix, BrimA, acid%, juice% or average fruit size. However, the control rootstock Tri22 has the highest °Brix. BrimA was higher for C-22, No. 24 and C-146. Acid levels were higher for C-22, No. 24 and C-146. Juice% was higher for Tri22, C-146 and No. 24, while the average fruit weight was higher for No. 24, C-57 and 85-24.

In 2021, there were no significant effects found for °Brix, BrimA, juice% or average fruit size. However, the C-35 has the highest °Brix. BrimA was higher for Tri22, C-146, and C-35. Acid levels were significantly affected and were higher for C-57, C-35 and 85-24. Juice% was higher for C-146, while the average fruit weight was higher for Tri22.

Table: 3.6: The effect of rootstocks on °Brix, BrimA, acid%, juice% and individual fruit weight (g) 2020–2021 on Tangold mandarin.

Rootstocks	2020					2021				
	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
85-24	13.9	143	1.3	57	97	12.4	141	1.0	55	135
C-146	14.0	148	1.3	60	89	12.4	143	0.9	56	138
C-22	14.0	150	1.2	57	91	12.3	141	0.9	53	134
C-35	13.5	141	1.3	55	93	12.5	142	1.0	55	129
Zao Yang	13.3	139	1.2	59	89	12.1	137	0.9	55	131
C-57	13.5	142	1.2	53	98	12.3	138	1.0	55	121
No. 24	13.3	141	1.2	60	103	12.1	138	0.9	53	137
Tri22	14.1	149	1.3	62	94	12.3	143	0.9	55	146
Probability	ns	ns	ns	ns	ns	ns	ns	*	ns	ns
LSD ($p < 0.05$)	-	-	-	-	-	-	-	0.06	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.

$^*p < 0.05$ and ns (non-significant)

Tree growth components

Tree growth component data are presented for 3 consecutive years and presented in Table 3.7.

Trunk circumference (cm)

In 2019, trunk circumference significantly increased with C-22 (14.1), C-35 (13.9) and C-146 (13.7) compared to the control (10.9). In 2020, trunk circumference was significantly increased in C-22 (22.2), C-146 (20.8) and C-35 (19.6) compared to the control (15.2). The year 2021 followed the same trend as 2020 for trunk circumference responses, however, the trunk circumference increased in No. 24 (25.8) compared to the control (21.0). The difference in total circumference growth from 2019 to 2021 was significant in C-22 (14.8), No. 24 (13.4), C-146 (13.1), C-57 (12.4) and C-35 (12.3) compared to Tri22 (10.1). A lower trunk circumference was recorded for Zao Yang for 2020 and 2021. The trunk circumference growth between 2019 and 2021 was also only 8.2 cm

Trunk height (m)

In 2019, the tree height was significantly decreased with C-57 (1.4) compared to the control (1.7). There was no effect of other rootstocks observed on tree height. It is quite logical to have this result as the trees were planted at the end of 2017 and the average tree height at the time of planting was very similar for each rootstock. In 2020, the tree height was significantly increased in C-146 (2.6) and C-22 (2.6) compared to the control (2.2) but reduced significantly in Zao Yang (1.9) compared to the control.

Table: 3.7: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on Tangold mandarin.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
85-24	12.1	16.5	22.8	10.8	1.8	2.1	2.9	1.1
C-146	13.7	20.8	26.7	13.1	1.9	2.6	3.0	1.1
C-22	14.1	22.2	28.8	14.8	1.8	2.6	2.8	1.0
C-35	13.9	19.6	26.1	12.3	2.0	2.4	2.9	0.9
C-57	9.8	15.4	22.3	12.4	1.4	2.1	2.6	1.2
No. 24	12.4	17.7	25.8	13.4	1.7	2.4	3.0	1.3
Tri22	10.9	15.2	21.0	10.1	1.7	2.2	2.6	0.9
Zao Yang	10.5	13.3	18.7	8.2	1.6	1.9	2.3	0.7
Probability	***	***	***	***	***	***	***	***
LSD ($p < 0.05$)	2.35	2.70	3.00	2.19	0.30	0.32	0.33	0.27

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.

$^{***}p < 0.001$

Tree height in 2021 increased in C-146 (3.0) and No.24 (3.0) compared to the control (2.6). The difference in total tree height increases from 2019 to 2021 were significant in No. 24 (1.3) and C-57 (1.2) compared to Tri22 (0.9). The lower tree height was recorded for Zao Yang, and while the effect was not significant, it is commercially important. The most interesting feature was the rate of growth in *Poncirus trifoliata* rootstock No. 24 which grew faster than expected.

Conclusions

The data sets are very limited to exploit the yield and quality potential of these rootstocks at this stage. There is a need to collect data for the next 3 growing seasons to make recommendations. However, at this stage, No. 24 rootstock is looking promising as a dwarfing rootstock for Tangold, while 85-24 is looking promising for M7 navel.

Chapter 4: Evaluation of selected rootstocks at grower's properties around Australia

Introduction

Chinese rootstocks have been previously tested in the deep sandy loam soil conditions at NSW DPI Dareton, while one trial was underway in clay soil conditions in Leeton, Riverina, which is now completed and reported in this final report (Appendix 1 – Chapter 1). To test the performance of Chinese rootstocks in wider soil and climatic conditions, it was decided to establish trial sites at commercial growers' properties around Australia. This was a direct request from Citrus Australia Limited. Therefore, an advertisement was placed in the Australian Citrus News asking growers who may want to participate. An overwhelming response from different regions of Australia was received to participate in the program. Growers were registered to participate in small-scale replicated research trials. The scion and rootstock selection was decided after discussion with NSW DPI and the participating grower based on their scion variety preference and their soil types.

The objective of the growers' site trials was to assess the performance of Chinese rootstocks with existing and new scion varieties in a range of soil and climatic conditions in 5 states (NSW, VIC, SA, QLD, and WA).

Materials and methods

Propagation of rootstock seedlings

Rootstock fruit was collected from the Chinese rootstock source trees established at Dareton and the seeds were extracted from the collected fruit. The Australian standard *Poncirus trifoliata* selection (Tri22) or *Troyer citrange* was used as a control rootstock and was obtained from Auscitrus. Seeds were provided to Victorian Citrus Farms, Red Cliffs, Victoria to raise rootstock seedlings. Seeds were planted in Polystyrene boxes on 14 September 2014 and germination started on 25 Sep 2014.

Seedling Selection and budding

The process of seedling selection and potting was carried out on 15 October 2015. Seedlings with well-established root systems were removed from the polystyrene boxes, and uniform healthy seedlings were selected to be potted for the next growth stage. Seedlings with distorted roots, small-sized seedlings unsuitable for future grafting were discarded. Selected uniform seedlings with a healthy fibrous root system were potted into 4-litre pots, and pots were shifted to the screen house for further development. Potted seedlings remained in the screen house until they developed to a suitable thickness (pencil thickness) for grafting (Figure 4.1).

Figure 4.1: Seedling selection (left) and potting of the selected rootstock seedlings (right).

Trees were budded in March 2016 using a chip budding method with a range of scion varieties for both growers and dwarfing trials. After budding, trees were managed as per nursery practices. Trees were ready to be dispatched in August 2017 (Figure 4.2).

Figure 4.2: The chip budding method was practised (left) on one-year-old seedlings and trees were ready after one year from budding (right).

Establishment of growers' trial sites

Trial site preparation was carried out by the respective growers before the arrival of trees at their properties. Trees were dispatched to the grower's properties in 5 states around Australia. Trees were planted according to an experimental design sent to each grower before planting.

Trial sites were established around Australia in October 2017 and 2018. Scions of sweet oranges and mandarins were grafted to a range of Chinese rootstocks. Trees in growers' trials were planted 3 m apart within the rows and 5 m between rows with a tree density of 666 trees/ha. Four to 8 tree plots were replicated 4 times in a randomised completed block design depending on the trial and the grower. Details of the trial design are given individually for each grower in the results sections. Data on tree growth, fruit yield and fruit quality were collected.

A research agreement was drawn between each grower and NSW DPI to meet milestones during the project. Growers were fully responsible for the trial management including fertigation, irrigation, and other cultural practices as per their orchard management practices and local conditions. Data for tree growth, yield and quality were collected by NSW DPI with some assistance from the grower during the trial. The trials were established during the existing project CT 17002 'Evaluation of new rootstocks for the Australian citrus industry'. The details of the trial sites are given in Table 4.1.

Table 4.1: Growers' rootstock trials around Australia and their scions and rootstocks combinations.

Grower's site/state	**Scion variety**	**Rootstock type**
Trial 1: Curlwaa NSW	Afourer	Tanghe, Zao Yang, Tri22, Nianju, Ghana
Trial 2: Dareton NSW	Afourer	Zao Yang, Tri22, Ghana, Anjiang hongju
Trial 3: Gunnedah NSW	Valencia	Tanghe, Zao Yang, Tri22, Ghana
Trial 4: Leeton NSW	Afourer	Tanghe, Zao Yang, Tri22, Ghana, Anjiang hongju
Trial 5: Waikerie SA	Valencia	Tanghe, Zao Yang, Tri22, Ghana
Trial 6: Gayndah QLD	Afourer	Tanghe, Zao Yang, Tri22, Nianju
Trial 7: Harvey WA	Afourer	Tanghe, Zao Yang, Tri22, Ghana

Grower trials were established in October 2017 around Australia; however, it took time for the trees to grow in some soil types and climatic conditions of certain regions. There has been data recorded on those trials since their establishment, however, the trials need another 4 years before recommendations for wider industry adoption can be made.

Trial no. 1 (Curlwaa NSW)

This experiment was established at a property in Curlwaa NSW, situated 10 km from the NSW DPI Dareton Research Institute. The soil type was heavy clay. The experiment has 4 selected Chinese rootstocks and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Ghana, Tanghe and Zao Yang were trifoliata types, while Nianju was a mandarin type. Afourer mandarin variety was budded onto these rootstocks. Trees were 3 m apart within the row, while rows were 5 m apart giving a density of 666 trees/hectare. The trial was a randomised complete block design with 6 tree plots for each rootstock replicated twice. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield at harvest:

The fruit yield data were collected for the years 2020, 2021 and 2022. In 2020, Ghana, Tanghe and Zao Yang increased fruit yield compared to the control (Tri22). The higher yield was achieved with Zao Yang rootstock (Table 4.2). In 2021 and 2022, the yield was highest for Tanghe and Zao Yang compared to the control. The cumulative yields were highest for Tanghe (85 kg/tree) followed by Zao Yang (78 kg/tree) compared to the control. The yield efficiency was higher for Tanghe in general compared to other rootstocks, and particularly the increase was significant in comparison with Nianju (Table 4.2).

Table 4.2: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree) and yield efficiency (kg/cm^2)/tree for 2020–2022 on Afourer mandarin.

Rootstocks	Yield kg/tree			Cumulative yield kg/tree	Yield efficiency kg/cm^2
	2020	2021	2022	2020–22	
Ghana	5.4	23.7	31.9	61.0	1.3
Nianju	4.7	24.4	39.5	68.5	1.1
Tanghe	5.7	31.5	47.8	85.0	1.6
Zao Yang	6.8	28.5	43.0	78.3	1.5
Tri22	3.1	19.3	30.3	52.7	1.4
Probability	*	*	**	**	*
LSD ($p < 0.05$)	2.13	7.23	10.6	17.42	0.33

Mean separation within the columns was tested with LSD (Least significant difference) across different rootst treatments. <$^{*}p < 0.05$, *p<0.05, and $^{**}p < 0.01$.

Fruit quality at harvest:

The fruit quality data were collected for 2020 and 2021; there were no significant differences found in any of the fruit quality components for any rootstock (Table 4.3).

However, in 2020, Nianju had the highest BrimA of 143 and this was due to the low acid% of 1.2 compared to the remaining rootstocks. In 2021, Tanghe had the highest BrimA of 160, while fruit weight was slightly higher for Zao Yang compared to the remaining rootstocks (Table 4.3).

Table 4.3: The effect of rootstocks on °Brix, BrimA, acid%, juice%, and individual fruit weight (g) for 2020–2021 on Afourer mandarin.

Rootstocks	2020					2021				
	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
Ghana	13.9	137	1.4	49	108	13.8	158	1.1	56	119
Nianju	13.4	143	1.2	51	109	13.0	145	1.1	57	131
Tanghe	13.5	131	1.4	48	101	14.0	160	1.1	56	119
Zao Yang	13.7	131	1.4	48	107	13.8	153	1.1	55	134
Tri22	13.8	135	1.4	47	102	14.0	159	1.1	54	132
Probability	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD ($p < 0.05$)	-	-	-	-	-	-	-	-	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootst treatments. < ns (non-significant).

Tree growth data:
The data for the tree trunk circumference and tree height were collected for 3 consecutive years (2019, 2020 and 2021). Trunk circumference increased in all rootstocks compared to the control for 2019, 2020 and 2021 (Table 4.4). However, the trunk circumference was higher for Zao Yang in 2019 and 2020, and for Nianju in 2021 compared to the control (Tri22). The data on trunk circumference differences between 2021 and 2019 indicates the rate of growth for each rootstock. In this instance, Nianju grew at a higher rate than the remaining rootstocks, gaining 12.6 cm growth around the trunk. The effect of tree height was not significant apart from in 2020 when there was a slight increase in tree height for the control rootstock compared to Zao Yang (Table 4.4).

The effect of tree height among rootstocks was significant for 2019, 2020 and 2021. In all years Ghana, Tanghe and Zao Yang had increased tree height compared to the control. There was no difference in the growth rate of tree height among rootstocks (Table 4.4).

Table 4.4: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on Afourer mandarin.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
Ghana	9.7	15.6	20.7	10.9	1.7	2.2	2.6	0.9
Nianju	10.3	16.7	22.9	12.6	1.6	2.1	2.6	1.1
Tanghe	10.5	16.4	21.4	10.9	1.7	2.3	2.6	1.0
Zao Yang	11.2	16.8	21.8	10.6	1.7	2.3	2.5	0.8
Tri22	8.1	13.1	17.7	9.6	1.3	1.8	2.1	0.9
Probability	**	**	***	*	**	**	*	ns
LSD ($p < 0.05$)	1.68	2.25	2.37	1.63	0.27	0.28	0.33	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

Trial no. 2 (Dareton NSW)

This experiment was established at a property at Dareton NSW, situated 1 km from the NSW DPI Dareton Research Institute. The soil type was deep sandy loam soil. The experiment has 3 selected Chinese rootstocks and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Ghana and Zao Yang were trifoliata types, while Anjiang hongju was an Erythrosa (mandarin) type. Afourer mandarin was budded onto these rootstocks. Trees were 3 m apart within the row, while rows were 5 m apart giving a density of 666 trees/hectare. The trial was a randomised complete block design with 5 tree plots for each rootstock replicated twice. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield at harvest:

The fruit yield data were collected for 2020, 2021 and 2022. In 2020, Ghana increased fruit yield (9.1 kg/tree) compared to the control (Tri22). The lowest yield of 1.4 kg/tree was recorded on trees budded to Anjiang hongju rootstock (Table 4.5). In 2021 and 2022, fruit yield was 26.9 kg/tree and 36.7 kg/tree respectively for Ghana compared to the control. The cumulative yields were highest for Ghana (72.7 kg/tree) followed by Tri22 (68.5 kg/tree). However, the yield for Ghana was significantly higher than Anjiang hongju. The yield efficiency was higher for Zao Yang and Tri22, however, the lowest yield efficiency was recorded for Anjiang hongju (Table 4.5).

Table 4.5: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree), and yield efficiency (kg/cm^2)/tree for 2020–2022 on Afourer mandarin.

Rootstocks	Yield kg/tree			Cumulative yield kg/tree	Yield efficiency kg/cm^2
	2020	2021	2022	2020–22	
Anjiang hongju	1.4	10.0	16.6	28.0	2.2
Ghana	9.1	26.9	36.7	72.7	2.9
Zao Yang	5.6	18.5	26.8	50.8	3.1
Tri22	7.0	27.8	33.7	68.5	3.2
Probability	***	***	***	***	***
LSD ($p < 0.05$)	1.9	7.6	8.1	16.2	0.73

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatment

$^{***}p < 0.001$.

Fruit quality at harvest:

The fruit quality data were collected for 2020. (Table 4.6). The °Brix values were not significant; however, Zao Yang had the higher °Brix. The data indicated that BrimA values for Anjiang hongju and Zao Yang were higher compared to the control (Tri22) and Ghana. The acid and juice values were not different between rootstocks. The fruit weight was significantly lower for Anjiang hongju compared to Tri22.

Table 4.6: The effect of rootstocks on °Brix, BrimA, acid%, juice%, and individual fruit weight (g) for 2020 on Afourer mandarin

Rootstocks	2020				
	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
Anjiang Hongju	14.6	155	1.3	49	100
Ghana	14.3	149	1.3	51	113
Zao Yang	14.9	155	1.4	49	108
Tri22	14.2	148	1.3	50	117
Probability	ns	*	ns	ns	*
LSD ($p < 0.05$)	-	4.8	-	-	9.8

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. $^{*}p < 0.05$ and ns (non-significant).

Tree growth data:

The data for the tree trunk circumference and tree height were collected for 3 consecutive years (2019, 2020 and 2021; Table 4.7). In 2019, the trunk circumference increased in all rootstocks compared to the control, however, it was significantly increased for Zao Yang (10.0 cm) compared to the control (6.8 cm). Trunk circumference was higher for Ghana in 2020 (13.6 cm) and 2021 (17.5 cm) compared to the control (Tri22). The data on differences in trunk circumference between 2021 and 2019 indicated the rate of growth for each rootstock. In this instance, Ghana and Tri22 grew at a higher rate than the remaining rootstocks, gaining 9.7 cm growth around the trunk. The effect of tree height was not significant in 2019 or 2021, but the tree height was significant for 2020. In 2020, there was a slight increase in tree height for the control rootstock compared to Zao Yang. There was no difference in the growth rate of tree height among rootstocks. The lack of difference in tree height could be due to the young age of the trees.

Table 4.7: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on Afourer mandarin.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
Anjiang Hongju	8.1	8.6	12.0	3.9	1.3	1.5	1.6	0.4
Ghana	7.9	13.6	17.5	9.7	1.3	1.6	1.8	0.4
Zao Yang	10.0	10.2	14.1	4.2	1.3	1.3	1.6	0.3
Tri22	6.8	12.3	16.4	9.6	1.2	1.7	1.7	0.5
Probability	*	***	**	***	ns	*	ns	ns
LSD ($p < 0.05$)	2.3	1.7	1.9	2.7	-	0.23	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. $^{*}p< 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

Trial no. 3 (Gunnedah NSW)

This experiment was established at a property in Gunnedah NSW. The soil type was clay loam. The experiment has 3 selected Chinese rootstocks and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Ghana and Zao Yang and Tanghe rootstocks were *Poncirus trifoliata* types. McMahon Valencia was budded onto these rootstocks. Trees were 2.5 m apart within the row, while rows were 5 m apart, giving a density of 800 trees/hectare. The trial was a randomised complete block design with 8 tree plots for each rootstock replicated twice. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield at harvest:

The fruit yield data were collected for 2020. Ghana had a yield of 19.4 kg/tree and Tanghe had a yield of 18.6 kg/tree compared to Zao Yang (8.3 kg/tree) and Tri22 (12.9 kg/tree) (Table 4.8).

Table 4.8: The effect of rootstocks on fruit yield (kg/tree) for 2020 in McMahon Valencia.

Rootstock	Kg/tree
Ghana	19.4
Tanghe	18.6
Zao Yang	8.31
Tri 22	12.9
Probability	***
LSD ($p < 0.05$)	5.14

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatment $^{***}p < 0.001$.

Fruit quality at harvest:

The fruit quality data were collected for 2021 (Table 4.9). The °Brix values were not significant, however, Tanghe, Ghana and Zao Yang had a 1 degree higher °Brix than Tri22. The data indicated that BrimA values were higher for Zao Yang (116) compared to Tri22. 1. The acid values were slightly higher for Ghana and Tanghe compared to Zao Yang and Tri22. Juice values were non-significant across different rootstocks; however, Ghana has the highest juice values compared to Tri22. The fruit weight was significantly lower for Tanghe (219 g) and Ghana (225 g) compared to Tri22 (266 g).

Table 4.9: The effect of rootstocks on °Brix, BrimA, acid%, juice%, and individual fruit weight (g) for 2020–2021 on McMahon Valencia.

Rootstocks	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
Ghana	11	93	1.2	53	225
Tanghe	11	94	1.2	48	219
Zao Yang	11	116	1.1	48	243
Tri22	10	97	1.1	47	266
Probability	ns	*	*	ns	*
LSD ($p < 0.05$)	-	11.49	0.11	-	35.7

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^{*}p < 0.05$, and ns (non-significant).

Tree growth data:

The data for the tree trunk circumference and tree height were collected for 3 consecutive years (2019, 2020 and 2021). In 2019, the trunk circumference increased in Ghana (10.7 cm) compared to the control (9.2 cm). In 2020, Ghana also had increased trunk circumference compared to the control (Table 4.10). In 2021, Ghana and Tanghe had increased trunk circumference compared to the control. The data on differences in trunk circumference between 2021 and 2019 indicated that the rate of growth for each rootstock was not affected and it was not significant. The effect of tree height was not significant across rootstocks for any year. There was no difference in the growth rate of tree height among rootstocks (Table 4.10). This could be due to pruning and hedging the trees for tree management which is regularly practised by the growers.

Table 4.10: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on McMahon Valencia.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
Ghana	10.7	14.5	19.2	8.5	1.3	1.5	2.2	0.91
Tanghe	10.4	14.0	19.2	8.8	1.3	1.5	2.2	0.93
Zao Yang	8.5	12.2	16.8	8.3	1.3	1.4	2.2	0.94
Tri 22	9.2	13.0	17.7	8.5	1.2	1.4	2.1	0.92
Probability	**	*	*	ns	ns	ns	ns	ns
LSD ($p < 0.05$)	1.2	1.5	1.9	-	-	-	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^{*}p < 0.05$, $^{**}p < 0.01$ and ns (non-significant).

Trial no. 4 (Leeton NSW)

This experiment was established at a property in Leeton NSW. The soil type was heavy clay loam. The experiment has 4 selected Chinese rootstocks and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Ghana, Zao Yang and Tanghe rootstocks were *Poncirus trifoliata* types, while Anjiang hongju was an Erythrosa (mandarin) type rootstock. Afourer mandarin was budded onto these rootstocks. Trees were 2.5 m apart within the row, while rows were 5 m apart, giving a density of 800 trees/hectare. The trial was a randomised complete block design with 4 tree plots for each rootstock replicated 4 times. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield and quality at harvest:

The fruit yield and quality data were collected for the 2021 growing season. Fruit yield was increased for Ghana (36.6 kg/tree) and Anjiang hongju (26.3 kg/tree) compared to Tri22 (18 kg/tree). Fruit number per tree followed the same trend as fruit yield and increased for Ghana (308) and Anjiang hongju (223) compared to Tri22 (Table 4.11).

The fruit quality data were collected for 2021 (Table 4.11). The °Brix values were significantly increased ranging from 13.2 to 13.5 °Brix for all rootstocks compared to Anjiang hongju (12.7 °Brix). The data indicated that BrimA values were higher for Ghana (153) compared to Tri22 (145), but the result was statistically non-significant. However, the result has commercial significance. The acid values were slightly higher for all rootstocks compared to Anjiang hongju. Rootstocks did not affect individual fruit weight or fruit size.

Tree growth data:

The data for the tree trunk circumference and tree height were collected for 3 consecutive years (2019, 2020 and 2021). In 2019, trunk circumference increased for Ghana (5.0 cm) and Zao Yang (4.6 cm) compared to the control (4.0 cm). In 2020, Ghana had an increased trunk circumference of 8.5 cm compared to the control (Table 4.12). In 2021, trunk circumference was increased in Anjiang hongju (15.8 cm) compared to the control (12.7 cm). The data on differences in trunk circumference between 2021 and 2019 indicated that the rate of growth was significant for Anjiang hongju and this rootstock grew at a faster rate of 12 cm in 3 years. The effect of tree height was significant across rootstocks in 2019 and 2020, but these differences were minor and do not have any practical implications. There were no differences in tree height in 2021 (Table 4.12). The main reason for the lack of difference was that the trees were grown on a trellis system to keep the height up to 1.5 m. The grower hedged his trees at a height of 1.5 m in 2021. Therefore, significant differences are not expected. The grower of this property grower will continue to keep the tree height at the same level in the coming years.

Table 4.11: The effect of rootstocks on fruit yield (kg/tree), fruit number/tree, °Brix, BrimA, acid%, individual fruit weight (g) and fruit size (mm) for 2021 on Afourer mandarins.

Rootstocks	Fruit Yield (tree/kg)	Fruit no/tree	°Brix	BrimA	Acid%	Fruit weight (g)	Fruit size (mm)
Anjiang Hongju	26.3	223	12.7	149	0.9	118	68
Ghana	36.6	308	13.5	153	1.1	119	68
Tanghe	21.8	197	13.2	147	1.1	110	66
Zao Yang	18.8	158	13.5	149	1.1	122	68
Tri22	18.0	159	13.2	145	1.1	113	68
Probability	***	***	**	ns	***	ns	ns
LSD ($p < 0.05$)	6.5	59.9	0.4	-	0.1	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

Table 4.12: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on Afourer mandarins.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
Anjiang hongju	3.8	8.1	15.8	12.0	0.9	1.5	1.5	0.6
Ghana	5.0	8.5	13.3	8.3	1.1	1.6	1.5	0.4
Tanghe	4.5	7.9	12.2	7.8	1.0	1.6	1.5	0.5
Zao Yang	4.6	7.8	12.5	7.9	1.0	1.6	1.5	0.5
Tri22	4.0	7.9	12.7	8.7	1.0	1.8	1.5	0.5
Probability	***	*	**	***	***	*	ns	***
LSD ($p < 0.05$)	0. 6	0.5	0.6	0.7	0.1	0.1	-	0.1

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

Trial no. 5 (Waikerie, SA)

This experiment was established at a property in Waikerie, SA. The soil type was deep sandy loam. The experiment has 3 selected Chinese rootstocks Ghana and Zao Yang and Tanghe (*Poncirus trifoliata* types), and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Keenan Valencia was budded onto these rootstocks. Trees were 3 meters apart within the row, while rows were 5 meters apart giving a density of 666 trees/hectare. The trial was a randomised complete block design with 4 tree plots for each rootstock replicated 4 times. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield at harvest:

The fruit yield data were collected for 2020 and 2021. There were no significant differences in rootstocks on fruit yield or cumulative fruit yield. However, Tanghe had the highest yield of 5.5 kg/tree in 2020 and 4.8 kg/tree in 2021 (Table 4.13). The cumulative yield was also higher for Tanghe (10.3 kg/tree), but the results were not significant due to the equally higher yield of the control trees (Table 4.13). Trees are now producing to yield significant numbers of fruit, therefore, there may be some treatment differences after the 2022 harvest in November/December.

Table 4.13: The effect of rootstocks on fruit yield (kg/tree) and cumulative yield (kg/tree) for 2020–2021 on Keenan Valencia.

Rootstocks	Yield kg/tree		Cumulative yield kg/tree
	2020	2021	2020–21
Ghana	3.6	4.6	8.1
Tanghe	5.5	4.8	10.3
Zao Yang	3.2	5.1	8.3
Tri22	4.9	5.1	10.0
Probability	ns	ns	ns
LSD ($p < 0.05$)	-	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. · (non-significant).

Fruit quality at harvest:

The fruit quality data were collected for 2020 and 2021. In 2020, there were no significant differences found in any of the fruit quality components for any rootstock (Table 4.14). However, the °Brix was highest for Zao Yang (10.1) compared to the control (9.6). There were no differences in acid or juice values. Fruit weight was slightly higher for Ghana (255 g) and Zao Yang (250 g) compared to Tri22 (225 g). In 2021, the effects of rootstocks on °Brix, BrimA and acid levels were significant. Zao Yang had significantly increased °Brix values (12.1) compared to Ghana (11.1), but not compared to Tri22 (12.0). The BrimA values were also higher for Zao Yang compared to Ghana. The acid values were lower for Ghana compared to Tanghe. There was no effect of rootstocks on the juice values. Fruit weight remained higher for Ghana (248 g) compared to Zao Yang (219). Although the result was not statistically significant, it is commercially important (Table 4.14).

Table 4.14: The effect of rootstocks on °Brix, BrimA, acid%, juice%, and individual fruit weight (g) for 2020–2021 on Keenan Valencia

Rootstocks	2020					2021				
	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)	°Brix	BrimA	Acid%	Juice%	Fruit weight (g)
Ghana	9.7	104	0.8	47	255	11.1	109	1.1	51	248
Tanghe	9.7	110	0.8	47	238	12.0	117	1.2	52	224
Zao Yang	10.1	111	0.8	44	250	12.1	122	1.2	53	219
Tri22	9.6	102	0.9	49	225	12.0	118	1.2	49	232
Probability	ns	ns	ns	ns	ns	*	*	*	ns	ns
LSD ($p < 0.05$)	-	-	-	-	-	0.64	8.81	0.06	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
$^*p < 0.05$ and ns (non-significant).

Tree growth data:

The data for the tree trunk circumference and tree height were collected for 3 consecutive years (2019, 2020 and 2021). In 2019, trunk circumference increased for Ghana (7.5 cm) and Zao Yang (6.6 cm) compared to the control (7.4 cm). In 2020, Zao Yang had decreased trunk circumference of 9.1 cm compared to the control and other rootstocks (Table 4.15). In 2021, trunk circumference decreased for Zao Yang (12.1 cm) compared to the control (10.0 cm), while in 2021, the trunk circumference for Zao Yang was reduced (12.1 cm) compared to Ghana (12.4). The data on differences in trunk circumference between 2021 and 2019 indicated that the rate of growth for trunk circumference was not significant for any rootstock, however, Ghana had grown at a faster rate of 6.4 cm in 3 years (Table 4.15). The effect of tree height was significant across rootstocks in 2019 and 2020, but these differences were minor and do not have any practical implications. There were no differences in tree height in 2021. The data on differences in tree height between 2021 and 2019 indicated that the rate of growth for trunk circumference was significant for Zao Yang compared to the control, however, the rate of growth of 0.6 m for Zao Yang does not have any practical implications at this stage of the trial.

Table 4.15: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2021 on Keenan Valencia.

Rootstocks	Trunk circumference (cm)				Tree height (m)			
	2019	2020	2021	Diff.	2019	2020	2021	Diff.
Ghana	7.5	10.2	14.0	6.4	1.1	1.2	1.6	0.5
Tanghe	7.4	9.7	12.6	5.2	1.2	1.3	1.5	0.3
Zao Yang	6.6	9.1	12.1	5.5	1.1	1.2	1.6	0.6
Tri22	7.4	10.0	12.4	5.0	1.1	1.2	1.5	0.4
Probability	*	*	*	ns	*	*	ns	*
LSD ($p < 0.05$)	0.63	1.04	1.5	-	0.11	0.12	-	0.17

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments.
< 0.05 and ns (non-significant).

Trial no. 6 (Gayndah, Queensland)

This experiment was established at a property at Gayndah, Qld. The soil type was sandy loam. The experiment has 4 selected Chinese rootstocks and Tri22 (Australia *Poncirus trifoliata* strain) was included as a control rootstock. Tanghe and Zao Yang rootstocks were Chinese *Poncirus trifoliata* types, while Nianju was an Erythrosa (mandarin) type rootstock. Afourer mandarin was budded onto these rootstocks. Trees were 3 m apart within the row, while rows were 6 m apart, giving a density of 555 trees/hectare. The trial was a randomised complete block design with 4 tree plots for each rootstock replicated 4 times. Data on tree growth, yield and fruit quality were collected from each experimental plot. The experimental trial was planted in October 2017.

Fruit yield at harvest:

The fruit yield data were collected for 2020, 2021 and 2022 (Table 4.16). There were no significant differences in rootstocks on fruit yield in 2020 or 2022. The fruit yield was even for each rootstock and produced an average yield of 13.5 kg/tree in 2020 and 24.6 kg/tree in 2022. However, Tanghe had the highest yield of 14.6 kg/tree in 2020 and 28.4 kg/tree in 2021. In 2021, fruit yield was significantly increased in Zao Yang (41.1 kg/tree) compared to the control (30.5 kg/tree). The cumulative yield was not significant across rootstocks due to the consistent yield across rootstocks for the 3 growing seasons. The yield efficiency was significant, and the yield efficiency was increased for Zao Yang (1.3 kg/cm^2) compared to the control (1.1 kg/cm^2) and Nianju (0.8 kg/cm^2) rootstocks. The lowest yield efficiency was due to the large tree size (trunk circumference) for Nianju trees.

Fruit quality at harvest:

The fruit quality data were collected for 2020 and 2021. There were no significant differences found in any of the fruit quality components for any rootstock (Table 4.17). However, in 2020, the °Brix values were highest for Nianju and Zao Yang compared to Tanghe and Tri22. There was no effect of rootstocks on the juice values. However, fruit weight remained higher for Tanghe, Zao Yang and Tri22 compared to Nianju. Nianju is a mandarin rootstock and seems to produce small size fruit. In 2021, °Brix values were the same for all rootstocks (12.5), and there was no effect of rootstocks on juice levels. Fruit weight was also not affected (Table 4.17).

Table 4.16: The effect of rootstocks on fruit yield (kg/tree), cumulative yield (kg/tree) and yield efficiency (kg/cm^2)/tree for 2020–2022 on Afourer mandarin.

Rootstocks	Yield kg/tree			Cumulative yield kg/tree	Yield efficiency kg/cm^2
	2020	2021	2022	2020–22	
Nianju	12.3	39.8	25.4	77.5	0.8
Tanghe	14.5	28.4	26.6	69.5	1.2
Tri22	13.3	30.5	23.7	67.5	1.1
Zao Yang	13.7	41.1	22.5	77.3	1.3
Probability	ns	*	ns	ns	***
LSD ($p < 0.05$)	-	10.1	-	-	0.22

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. *$p < 0.05$, and ***$p < 0.001$ and ns (non-significant).

Table 4.17: The effect of rootstocks on °Brix, juice%, and individual fruit weight (g) for 2020–2021 on Afourer mandarins.

Rootstocks	2020			2021		
	°Brix	Juice%	Fruit weight (g)	°Brix	Juice%	Fruit weight (g)
Nianju	11.8	42	122	12.4	55	113
Tanghe	11.2	37	138	12.5	49	110
Zao Yang	11.8	40	138	12.4	56	111
Tri22	11.2	38	141	12.4	52	104
Probability	ns	ns	ns	ns	ns	ns
LSD ($p < 0.05$)	-	-	-	-	-	-

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. 0.05, $^{**}p$ ns (non-significant).

Tree growth data:

The data for the tree trunk circumference and tree height were collected for 2019 and 2022 (Table 4.18). In 2019, the trunk circumference was increased for Nianju (15.1 cm) compared to the control (13.8 cm). In 2020, the trunk circumference was also increased for Nianju (34.8 cm) compared to the control (27.8 cm). The data on differences in trunk circumference between 2022 and 2019 indicated that the rate of growth for trunk circumference was significant for Nianju (19.7 cm) compared to Tri22 (14.0). The effect of tree height was not significant across rootstocks in 2019. However, in 2022, tree height was 3 m for Nianju and 2.5 m for the control. The data on differences in tree height between 2022 and 2019 indicated that the rate of growth for the tree height was significant for Nianju compared to the control. This data suggests that Nianju, which is an Erythrosa (mandarin) type rootstock, produces large tree canopies compared to the *Poncirus trifoliata* type rootstocks.

Table 4.18: The effect of rootstocks on trunk circumference (cm) and tree height (m) for 2019–2022 on Afourer mandarin.

Rootstocks	Trunk circumference (cm)			Tree height (m)		
	2019	2022	Diff.	2019	2021	Diff.
Nianju	15.1	34.8	19.7	1.9	3.0	1.1
Tanghe	13.7	26.4	12.7	1.9	2.5	0.6
Zao Yang	14.8	27.3	12.5	2.0	2.5	0.5
Tri22	13.8	27.8	14.0	1.9	2.5	0.6
Probability	*	***	**	ns	***	***
LSD ($p < 0.05$)	1.3	2.2	1.8	0.22	0.09	0.22

Mean separation within the columns was tested with LSD (Least significant difference) across different rootstock treatments. $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$ and ns (non-significant).

Conclusions for the growers' trials

The growers' sites mentioned were planted in 2017 and there is limited data to draw any conclusions at this stage. Therefore, the data on fruit yield, tree growth and fruit quality will be collected for another 4 years to complete these trials. These trials will be completed in the proposed rootstock evaluation project from 2023 to 2028. The growers' trials that were established in October 2018 also have only limited data available and are not reported in this final report. The data on those trials will be collected in the next 4 years to complete the trials and make recommendations to the industry.

Chapter 5: Propagation and establishment of Italian rootstocks

Introduction

Rootstock seedlings of Italian hybrid varieties F5P12, F6P12 and F6P13 have been introduced by ANFIC Nurseries. The Italian rootstocks have never been trialled in Australia. Small seedlings arrived at Dareton on 13 February 2018 (Figure 5.1). Seedlings were sorted for size, health and uniformity and established to grow into one-year seedlings for grafting with different scion varieties (Figure 5.2). The main objective of this trial was to evaluate the 3 promising Italian rootstocks with mandarin varieties.

	
Figure 5.1: Arrival of seedlings from ANFIC, 15 Dec 2017	Figure 5.2: Seedlings were sorted for health, size and uniformity on 26 March 2018.

Materials and methods

Seedlings of Italian hybrid rootstock selections for which the Australian Nurserymen's Fruit Improvement Company (ANFIC) owns the rights in Australia were received at NSW DPI, Dareton on 15 December 2017. Three of these (*Citrus latipes* x *Poncirus trifoliata*) called F5 P12, F6 P12 and F6 P13, were grafted to 3 mandarin varieties Imperial, Tangold and Nectar. Rootstock seedlings were budded on 27 October 2018 (Figure 5.3). These varieties were also budded to Carrizo citrange as a control. The trees were maintained for a year after budding (Figure 5.4)

Trees were planted on 17 March 2020 (Figure 5.5) at NSW DPI Dareton. Trees were planted 3 m apart within the rows and 6 m between rows in an east-west orientation with a tree density of 555 trees/ha. Four tree plots were replicated 5 times in a randomised completed block design for each rootstock-scion combination. Yield and fruit quality data will be collected in the coming years. However, data on fruit quality and tree growth are presented in this report. A recent photo of the trial site is shown in Figure 5.6.

Figure 5.3: Three rootstock seedling types were budded with 3 scion varieties, Imperial, Tangold and Nectar mandarins on 27 Oct 2018.

Figure 5.4: Scion growth is underway, 12 February 2019.

Figure 5.5: 2-year-old trees were planted on 17 March 2020 as a replicated design experiment.

Figure 5.6: Trees in the trial are growing since planting. This photo was taken on 28 August 2022.

Results and discussion

Fruit quality components:

There were limited data on fruit quality available for the 3 scion varieties. Therefore, fruit quality was assessed for the 2022 growing season. The main effects of rootstock were not significant for °Brix, BrimA or acid% (Table 5.1). The varietal effect was significant for °Brix values and BrimA. Imperial mandarin has high °Brix values (12.0) compared to Nectar (11.9) and Tangold (11.7). The BrimA values were also higher for Imperial mandarin (154) compared to Nectar (135) and Tangold (131) (Table 5.1). The interaction effect of rootstock and varieties was significant for °Brix values. Rootstock F5 P12 had high °Brix (13.3) values for Imperial mandarin, F6 P12 had higher °Brix for Nectar (12.2) and F6 P13 had higher °Brix (12.1) for Tangold. This information is of significant value for the citrus industry and reconfirms the role of rootstock in influencing fruit quality. The interaction effect of rootstock and varieties was not significant on BrimA or acid% values (Table 5.1).

The main effects of rootstock were not significant for juice% (Table 5.2). However, the average fruit weight was significantly increased by F6 P12. The varietal effect was significant for juice% and average fruit weight. Imperial mandarin has a high juice% (46) compared to Nectar or Tangold. Individual fruit weight was increased for Nectar compared to Imperial mandarin or Tangold (Table 5.2). The interaction effect of rootstock and varieties was significant for individual fruit weight. The average fruit weight for Nectar was 140.4 g with F6 P12 rootstock. F6 P12 also increased fruit weight for Imperial mandarin (Table 5.2).

Tree growth components:

The data for the tree trunk diameter and tree height were collected for 2021. There were 3 rootstocks and 3 varieties in the trial. Tree trunk diameter was significantly increased for the rootstock F6 P12 compared to F6 P13, while tree height was not significant and remained around 1.4 m for all rootstocks. The effect of trunk diameter was significant across the 3 mandarin varieties. Tangold has a large trunk diameter of 24.7 mm compared to Nectar or Imperial. There was no effect of tree height noticed for the 3 varieties.

The interaction effect was significant for rootstock and varieties for trunk diameter. Imperial mandarin had the largest trunk diameter on F5 P12 compared to F6 P13 but was not significantly different. Nectar has the smallest trunk diameter of 19.6 mm on the F 6 P13 rootstock. Tangold had a large trunk diameter on the F6 P12 rootstock compared to other rootstocks.

The interaction effect was significant for rootstock and varieties on the tree height. Imperial mandarin had a tree height of 1.49 m on F6 P13 and compared to F5 P12. There was no effect of rootstocks on Nectar. In Tangold, tree height was higher on F6 P12 compared to the other 2 rootstocks.

Table 5.1: The main and interaction effects of rootstock and varieties on °Brix, BrimA and acid per cent for the 2022 growing season.

Main effects	°Brix			BrimA			Acid%		
Rootstocks	F5 P12	F6 P12	F6 P13	F5 P12	F6 P12	F6 P13	F5 P12	F6 P12	F6 P13
	12.2	12.2	12.2	141	141	138	0.93	0.91	0.95
Probability		ns			ns			ns	
LSD ($p < 0.05$)		-			-			-	
Varieties	Imperial	Nectar	Tangold	Imperial	Nectar	tangold	Imperial	Nectar	Tangold
	12.9	11.9	11.7	154	135	131	0.89	0.94	0.95
Probability		***			**			ns	
LSD ($p < 0.05$)		0.36			8.62			-	
Interaction effect									
	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold
F5 P12	12.6	12.2	11.8	152	136	134	0.85	0.99	0.93
F6 P12	13.3	12.0	11.3	161	137	126	0.87	0.92	0.92
F6 P13	12.9	11.6	12.1	150	132	133	0.95	0.90	0.99
Probability		*			ns			ns	
LSD ($p < 0.05$)		0.62			-			-	

Mean separation within the rows was tested with LSD (Least significant difference) for the main effects, while the interaction effect is tested with LSD across rows and columns. *p < 0.05, **p < 0.01, ***p < 0.001 and ns (non-significant).

Table 5.2: The main and interaction effects of rootstock and varieties on juice per cent and average fruit weight for the 2022 growing season.

Main effects	Juice%			Average fruit weight (g)		
Rootstocks	F5 P12	F6 P12	F6 P13	F5 P12	F6 P12	F6 P13
	42	41	43	107.6	110.3	87.5
Probability		ns			***	
LSD ($p < 0.05$)		-			8.98	
Varieties	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold
	46	41	39	93.2	121	91.2
Probability		**			***	
LSD ($p < 0.05$)		4.61			8.97	
Interaction effect						
	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold
F5 P12	43	43	40	95.2	135.8	91.8
F6 P12	45	39	41	102.4	140.4	88.2
F6 P13	51	40	37	82.1	87.0	93.5
Probability		ns			***	
LSD ($p < 0.05$)		-			15.56	

Mean separation within the rows was tested with LSD (Least significant difference) for the main effects, while the interaction effect is tested with LSD across rows and columns. **$p < 0.01$, ***$p < 0.001$, and ns (non-significant).

Table: 5.3: The main and interaction effects of rootstock and varieties on trunk diameter (mm) and tree height (m) for 2021.

Main effects	Trunk diameter (mm)			Tree height (m)		
Rootstocks	F5 P12	F6 P12	F6 P13	F5 P12	F6 P12	F6 P13
	22.1	22.8	21.2	1.39	1.43	1.44
Probability		*			ns	
LSD ($p < 0.05$)		1.151			-	
Varieties	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold
	21.5	20.0	24.7	1.43	1.44	1.40
Probability		***			ns	
LSD ($p < 0.05$)		1.151			-	
Interaction effect						
	Imperial	Nectar	Tangold	Imperial	Nectar	Tangold
F5 P12	22.8	20.0	23.5	1.39	1.49	1.28
F6 P12	21.3	20.4	26.9	1.40	1.40	1.50
F6 P13	20.4	19.6	23.7	1.49	1.43	1.41
Probability		*			**	
LSD ($p < 0.05$)		1.994			0.11	

Mean separation within the rows was tested with LSD (Least significant difference) for the main effects, while the interaction effect is tested with LSD across rows and columns. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, and ns (non-significant).

Conclusions

During the current project, the Italian rootstock trial was established. At this stage, no conclusions can be drawn from this trial as there is a need to collect yield, fruit quality and tree growth data for the next 4 to 5 years. However, the initial results on fruit quality suggest that rootstocks are influencing the fruit quality. Therefore, this trial will continue into the next new proposed project from 2023 to 2027 funded by Hort Innovation.

Experiment 6: Establishment of HLB tolerant rootstock trials at Dareton and around Australia

Introduction

Huanglongbing (HLB) is a devastating bacterial disease not known to occur in Australia, but it is considered the biggest threat to the Australian citrus industry. There is no cure for HLB. The USDA has recently released rootstocks, such as US-942 and US-802, that have demonstrated tolerance to HLB (Bowman and Faulkner, 2016). Therefore, a range of rootstock trials will be established in 5 states of Australia and tree growth, fruit yield, and fruit quality will be evaluated over the next 5 years. This component is also linked to a joint-funded ACIAR and Hort Innovation project 'Preparedness and management of Huanglongbing (Citrus greening disease) to safeguard the future of the citrus industry in Australia, China and Indonesia', where some of the rootstocks will be tested in Indonesia for HLB tolerance since HLB does not exist in Australia.

Therefore, the objective of this component is to evaluate a range of rootstocks for tree growth, yield and quality in different soil and climatic conditions in Australia and make recommendations to the industry about the high-performing rootstocks for sweet oranges, mandarins, and limes.

Methodology

27 HLB rootstocks arrived in 2021 from the USDA, Fort Pierce and the University of Florida, Lake Alfred.

The arrival of HLB tolerant rootstocks from USDA, Fort Pierce

A set of 7 rootstocks were provided by the USDA, Fort Pierce, which arrived at Dareton Research Institute in November 2020. These rootstocks have been germinated (Figure 1) and were be grafted to a range of varieties in Spring 2022. In spring 2023, trials will be established at Dareton Research Institute, and rootstocks will be evaluated for tree growth, fruit yield and internal fruit quality.

The arrival of HLB tolerant rootstocks from the University of Florida, Lake Alfred

A set of 20 rootstocks were provided by the University of Florida, Lake Alfred, which arrived at Dareton Research Institute in April 2021 (Figure 2). These rootstocks have been germinated and were grafted to a range of varieties inspiring 2022. The trials will be established at Dareton Research Institute, and they will be evaluated for tree growth, fruit yield and internal fruit quality. Trial sites have been identified in 5 states of Australia; therefore, trials will be established around Australia in Spring 2023. Two mirror trials will be established at NSW DPI Dareton and Griffith Research Stations in 2 soil types. Rootstocks will be evaluated for tree growth, fruit yield and internal fruit quality.

	
Figure 1: US 897 rootstocks from USDA Florida	Figure 1: UFR-4 rootstocks from the University of Florida

Experimental plan

The rootstocks arrived from the USDA; Fort Pierce will be used in the trials planned for 5 states of Australia. These rootstocks are US1283, US1284, US1516, US802, US897, US942, and US812, while Tri22 (Australian *Poncirus trifoliata*) or *Troyer citrange* depending on the soil types. Trees will be ready to be planted in October 2023. The details of scion varieties and trial sites are given in Table 6.1.

Table 6.1: Trial site selected for the October 2023 plantation of HLB tolerant rootstocks in Australia.

Sites	Varieties to be used in the trials
Dareton/Mildura	Washington navel
Dareton/Mildura	Lanes Late
Riverina-1	DV Valencia
Riverina-2	DV Valencia
WA-1	Nules Clementine
WA-2	Tangold mandarin
Qld-1	Cara Cara navel
Qld-2	Tahitian Lime
SA-1	Rhode navel
SA-2	Washington navel

The rootstocks arrived from the University of Florida; Lake Alfred and will be used in the planned trials at the NSW DPI Dareton Research Institute and NSW DPI Griffith Research Institute. These rootstocks are AMB+CZO, B11R4T1, B11R5T20, B11R5T51, B11R5T60, B11R5T62, B11R5T64, N40T2T11, N40R2T21, N40R2T24, N40R4T24, Orange 14, Orange 16, UFR1, UFR2, UFR4, UFR5, UFR6, UFR11 and UFR15, while Tri22 (Australian *Poncirus trifoliata*) or *Troyer citrange* depending on the soil types. Trees will be ready to be planted in October 2023. The details of scion varieties and trial sites are given in Table 6.2.

Table 6.2: Trial site selected for the October 2023 plantation of HLB tolerant rootstocks in New South Wales

Sites	Varieties to be used in the trials
NSW DPI Dareton	Washington navel, Lane Late
NSW DPI Griffith	DV Valencia