Hort Innovation

Final Report

Evaluation and Commericalisation of New Citrus Rootstocks

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Delivery partner:

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Evaluation and Commericalisation of New Citrus Rootstocks – CT13042

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Content

Summary

The National Citrus Rootstock Improvement Program evaluates the commercial potential of new rootstock varieties for the benefit of the Australian citrus industry. Rootstock evaluation is a multi-stage process involving the establishment of rootstock seed source trees, ensuring uniformity of rootstock seedlings, greenhouse screening for disease and salt tolerance, short-term preliminary field trials to evaluate horticultural performance, and longer-term evaluation in semi-commercial plantings under a range of soil, climatic and management conditions. This report describes preliminary field trials which investigated the impact of new rootstock varieties on the horticultural performance of a range of scion varieties. The trials were conducted in the Murray Valley and Riverina; 2 major citrus growing regions. The results from these trials will be used to select rootstock varieties worthy of the investment of further testing in longer-term, commercially orientated and industry-based trials in the major regions for citrus production. The new industry based trials will test the performance of current commercial scion varieties of navel and common oranges, and mandarins on the selected rootstock varieties.

The overall objective of the project was to evaluate the horticultural performance of a range of Chinese and Vietnamese rootstock material in different soil types; sandy loam (light) soils in the Sunraysia region and clay loam (heavy) soils in the Riverina region.

The project produced significant results.

- Six new rootstocks (Zao Yang, Tanghe, Donghai, Ghana, Anjiang hongju, Caoshiangju) from the Chinese rootstock program were identified and released to the Australian citrus industry. Rootstock seed of these varieties is now available from the Auscitrus propagation scheme and will be available to overseas institutes under a research agreement.
- The rootstocks were tested with Valencia orange scions in clay soil conditions. Zao Yang rootstock performed best when grafted to a new scion selection, Valencia 5, compared with standard Keenan Valencia scion on Tri22 rootstock. Zao Yang contributed 20% to yield and sweetness. Valencia 5 has now been registered as an IP variety and will be available to Australian growers under permit.
- Imported Vietnamese rootstocks were tested with Navelina, Lane Late navel, Imperial mandarin and Eureka lemon. Hong Nhieu mandarin rootstock was found to be superior for Lane Late navel when compared with citrange rootstock. However, no other combinations were found to provide significant benefits. Two Vietnamese rootstocks Mat orange and Hong Nhieu orange were identified to have dwarfing effects in sweet oranges and Imperial mandarins. Therefore, the Vietnamese rootstock varieties Mat orange and Hong Nhieu orange are recommended for further testing as an interstock on Troyer citrange and *Poncirus trifoliata* rootstocks with navel and mandarin scion varieties.

A number of trials are still underway and will be evaluated in a recently funded project (CT17002, Evaluation of new rootstocks for the Australian citrus industry).

- Rootstock varieties selected for further testing will be evaluated in a national trial established on grower's properties in November 2017.
- NSW DPI (Gosford hybrids), Californian hybrids and Chinese rootstocks will be assessed for salt tolerance when grafted to selected Chinese rootstocks in a rootstock evaluation trial.
- Rootstock varieties with potential to induce mild to moderate dwarfing in trees are being evaluated in trials established at Dareton in October 2017. Dwarfing can be a useful

management tool and enables the planting of high density orchards.

- Italian hybrid rootstocks will be evaluated with Nectar, Tang Gold and Imperial mandarin in collaboration with ANFIC.
- Rootstock varieties reported to have tolerance to Huanglongbing (HLB) will be imported as seed and tested under Australian conditions in preparation for a potential introduction of this devastating disease.

Keywords

Citrus, rootstocks, salt tolerance, dwarfing, disease tolerance, Navel, Valencia, C22, C54 and C146

Introduction

History of the rootstock evaluation program

Rootstocks have a major impact on the horticultural performance of citrus scion varieties and consequently influence the health and productivity of a citrus industry (Broadbent, 1993). Citrus rootstocks impact tree vigour, size, fruit yield, and fruit size (Castle, 1987), and enable scions to be grown in a range of growing conditions. Therefore, the use of improved rootstocks is an important step for 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 formed in 1985. The major objectives of this working party were to promote a nationally co-ordinated 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. 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 as a result 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 and salt tolerance before short-term replicated field trials are conducted on a range of scion varieties where tree growth, yield 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, 2014).

Background of the current project

The development, evaluation and commercialisation of improved rootstocks to increase yield efficiency, fruit size and external and internal fruit quality is 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 impact 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 and the Riverland of South Australia). Root zone salinity has been shown to affect citrus fruit yields and quality (Lehmann, 2003; 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 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 factors restrict Australian citriculture in reaching its full potential. This project was closely aligned to the national industry and used a number of short-term rootstock trials established in the main citrus growing regions to identify rootstocks that improved scion performance with regard to 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.

This report presents the results from the following trials:

- Experiment 1: the evaluation of Vietnamese rootstocks on Navelina navel, Lane Late navel and Imperial mandarin at Dareton.
- Experiment 2: the evaluation of selected Chinese rootstocks on a range of Valencia selections conducted in the Riverina.
- Experiment 3: evaluation of rootstocks with potential salt tolerance established in Bindoon, Western Australia on Houghton navel
- Experiment 4: selected rootstocks with commercial potential in rootstock trials on grower's properties around Australia
- Experiment 5: progress on trials at Dareton evaluating new rootstocks which induce dwarfing
- Experiment 6: the propagation of new Italian hybrid rootstocks and trial establishment at Dareton.

Project objectives

The objectives of this project were:

1. to assess the horticultural performance of a range of Vietnamese rootstock varieties for yield, fruit quality, vegetative growth and rootstock-scion compatibility (Experiment 1)
2. 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 2)
3. to establish and evaluate the salt tolerance of rootstock varieties in a trial in Bindoon, Western Australia (Experiment 3)
4. to establish new rootstock trials on grower's properties with a range of newly released rootstock and scion combinations throughout Australia (Experiment 4)
5. to establish trials at NSW DPI Dareton with rootstocks which induce dwarfing and assess their horticultural performance with M7 navel and Tang Gold mandarin (Experiment 5)
6. to propagate new Italian rootstock hybrids grafted to three mandarin varieties and establish a trial at NSW DPI Dareton (Experiment 6).

Methodology

The trials reported for experiments 1 and 2 were established during previous projects (CT03025, CT07002) and evaluated in the current project (CT13042). Trials reported under experiments 3, 4, 5 and 6 were established during this project (CT13042) and these will be evaluated in a new project (CT17002) recently funded project 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.

Experiment 1. Evaluation of Vietnamese rootstocks with Navelina, Lane Late, Imperial and Eureka

Vietnamese rootstock trials were established in 2005 at NSW DPI, Dareton. Trial trees were planted at 4 individual trial sites with Navelina navel, Lane Late navel, Imperial mandarin and Eureka lemon scion varieties propagated onto the Vietnamese rootstocks. The trees were planted in a randomised complete block design (5m by 3 m) with 5 replicates in single tree plots. The 8 treatments were 7 Vietnamese rootstock varieties (Chanh orange, Hong Kim orange, Hong Nhieu mandarin, Mat orange, Ta mandarin, Tau lime, Tie Son mandarin) and a Carrizo citrange control representing a commonly used rootstock variety. The soil type was sandy loam. Data on tree growth, graft union compatibility, fruit yield and internal fruit quality was collected from 2013-2017.

Experiment 2. Evaluation of superior processing oranges for fresh juice with selected Chinese rootstocks in a semi-commercial situation

This trial was planted in October 2010 at a grower's property as a semi-commercial trial in clay loam soil at Stanbridge, Leeton. The trial was designed as a two factorial setup in a randomised block design. There were seven Valencia selections; Valencia 1, Valencia 2, Valencia 3, Valencia 4, Valencia 5, Valencia 6 and Keenan Valencia (Control) as Factor 1 and five *Poncirus trifoliata* rootstocks; Zao Yang, Tanghe, Donghai, Ghana 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 tree growth, fruit yield and internal fruit quality was collected over three growing seasons.

Experiment 3. Establishment and evaluation of salt tolerant rootstocks

The salt tolerant rootstock trial was established in Bindoon, Western Australia on 4 April 2013. There were 16 rootstocks grafted to Houghton Washington navel. Rootstocks were planted in 3 tree plots as a demonstration trial. The treatment rootstocks were introduced from different breeding programs (see Table 1). Data on tree growth, yield and quality was collected each season during the course of the trial for the next 4 years.

Experiment 4. Propagation and establishment of Chinese rootstock trials on grower's properties

The trees were propagated for the grower trials at a local nursery (Victorian Citrus Farms, Mildura). Trials were established at 16 trial sites around Australia in October 2017. Scions of sweet oranges and mandarins were grafted to a range of Chinese rootstocks. Trees in grower's trials were planted at 3 x 5 m apart. Four tree plots were replicated 4 times in a randomised completed block design. Data on tree growth will start from 2019. Fruit yield and quality data will be collected once the

trees are at a productive stage.

Table 1. The salt tolerant rootstocks planted in Bindoon, Western Australia.

Rootstock	Breeding program
3812 (Scarlet mandarin x *Poncirus trifoliate*)	Gosford breeding program, NSW DPI
3822 (Scarlet mandarin x *Poncirus trifoliate*)	Gosford breeding program, NSW DPI
3834 (Scarlet mandarin x *Poncirus trifoliate*)	Gosford breeding program, NSW DPI
3835 (Scarlet mandarin x *Poncirus trifoliate*)	Gosford breeding program, NSW DPI
Anjiang honghu (Erythrosa type)	Chinese rootstock selection
Caoshi xiangju (Erythrosa type)	Chinese rootstock selection
Cox (Scarlet mandarin x *Poncirus trifoliate*)	Gosford breeding program, NSW DPI
F1 (62-109-40) Sunki mandarin x F. Dragon *Pocirus trifoliata*	USDA breeding program
F1 (62-109-40) Sunki mandarin x Mars *Poncirus trifoliata*	USDA breeding program
F1 (62-109-40) Sunki mandarin x Mars *Poncirus trifoliata*	USDA breeding program
Rangpur lime	Standard rootstock (control)
Sunki mandarin	Standard rootstock (control)
Swingle citrumelo	Standard rootstock (control)
Troyer citrange (Citrus sinensis x Poncirus trifoliata)	Standard rootstock (control)
X OP (59-24-8) Rangpur lime x Swingle *Poncirus trifoliata*	USDA breeding program
Zao Yang (Poncirus trifoliata)	Chinese rootstock selection
Zhoupi jiangjin (mandarin type)	Chinese rootstock selection

Experiment 5. Propagation of Chinese and American rootstocks for dwarfing effect at NSW DPI, Dareton

Two trials were established at the NSW DPI, Dareton site in October 2017. Both trials involved 7 rootstocks known to induce dwarfing; in the first trial these were propagated with M7 navel and in the second trial they were established with Tang Gold mandarin. The performance of these new rootstocks will be evaluated during the next five years. Data on tree growth, fruit yield and fruit quality will be collected once trees are in a productive stage, projected for 2020.

Experiment 6. Propagation and establishment of Italian rootstocks

Seedlings of Italian hybrid rootstock selections for which the Australian Nurserymen's Fruit Improvement Company's (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) will be one year old in September 2018 and will be grafted to 3 mandarin varieties: Imperial, Afourer and ANFIC Nectar. These varieties will also be grafted to Carrizo citrange as a control treatment. Two year old trees will be planted in a randomised complete block design at NSW DPI Dareton in September 2019. The trees will be planted with 6 m between rows and 3 m within the row. There will be 4 tree plots replicated 5 times for each rootstock-scion combination. Once the trees are 3 years old, data on vegetative growth will be collected. Yield and fruit quality data will be collected once the trees are starting to produce commercial crops. The data for all experiments was analysed using a statistical package and appropriate analyses were employed for each experiment (Genstat, 2017).

Outputs

Experimental Program

There were 6 main experiments and each experiment involved different trials. Experiments 1 and 2 reported here are now complete. Experiment 3 will need more data for three growing seasons. Experiments 4, 5 and 6 are recently established. Work on experiments 3, 4, 5 and 6 will continue into the newly funded project (CT17002).

Experiment 1: Evaluation of Vietnamese rootstocks with Navelina, Lane Late, Imperial and Eureka at Dareton

Navelina navel

Tree growth

Analysis of the 2016 data for Navelina navel orange tree growth showed that there were significant differences in trunk circumference, tree height, tree spread and visual scores (Table 2).

Assessment of graft union

Overgrowth at the graft union is an important factor to consider when evaluating rootstock performance. Overgrowth can be associated with incompatibility between the rootstock and scion combination and can lead to tree decline. The circumference of the scion and rootstock was measured 6 cm above and below the graft union, to generate rootstock:scion ratios. The actual graft union was also rated using a visual scale from 1 to 5 (Webber, 1948). The rootstock:scion growth ratio data was not significant in the Navelina trial. However, the visual observation of graft union compatibility showed that Chanh orange and Tau lime had an overgrowth of 2.2 which indicated there was overgrowth of the rootstock at the graft union (Table 2).

Table 2. Effect of Vietnamese rootstocks on trunk circumference, tree height, tree spread, rootstock:scion ratios and graft union scores in Navelina for the 2017 growing season. Values presented are means (n=5).

Rootstock	Trunk circumference (cm)	Tree height (m)	Tree spread (m)	Rootstock: scion	*Visual score
Chanh orange	24	1.8	1.8	1.0	2.2
Carrizo citrange	30	2.3	2.1	1.0	1.6
Hong Kim orange	32	2.5	2.1	0.9	1.2
Hong Nhieu mandarin	31	2.4	2.1	0.8	1.8
Hong Nhieu orange	27	2.3	1.9	1.0	1.2
Mat orange	27	2.3	1.8	0.9	1.0
Ta mandarin	35	2.4	2.1	0.9	1.0
Tau lime	19	1.5	1.4	0.9	2.1
Tieu Son mandarin	34	2.4	2.3	1.0	1.2
LSD	6	0.4	0.3	-	0.9
P<0.05	***	***	**	ns	*

*Mean separation within the column was tested with LSD. Non-significant (ns); *p<0.05; **p<0.01; ***p<0.001.*
**Visual score of graft union: 1 smooth union; 2 rootstock slightly larger than scion; 3 scion slightly larger than rootstock; 4 rootstock significantly larger than scion; 5 scion significantly larger than rootstock.*

Cumulative yield (2013-2017)

The data for cumulative yield showed that Carrizo citrange, Ta mandarin and Hong Nhieu mandarin had significantly higher cumulative yields of 200, 180 and 179 kg respectively, compared with Chanh orange and Tau lime (82 and 48 kg, respectively) (Table 3). Carrizo citrange had the highest yield efficiency (yield/trunk cross sectional area) while Ta mandarin, Tau lime and Tieu Son mandarin had the lowest yield efficiencies (Table 3). There were significant differences for the total fruit per tree across the different rootstocks with Chanh orange and Tau lime having the lowest values and Carrizo citrange had the highest (Table 3). Average fruit weight was significant across the rootstocks; Carrizo citrange produced the highest average fruit weight (231 g/fruit) while Tau lime produced the lowest (194 g/fruit) (Table 3). Differences in biennial bearing index (BBI) values were not statistically significant between the rootstocks. BBI values are less important if the rootstock improves other desirable characteristics such as yield and internal fruit quality. BBI can be managed by fruit thinning during an on-flowering year.

Table 3. Effect of Vietnamese rootstocks on cumulative yield, yield efficiency, total fruit per tree, average fruit weight and biennial bearing values in Navelina during the 2013-2017 growing seasons. Values presented are means (n=5).

Rootstocks	*Cumulative yield (kg/tree)	Yield efficiency (kg fruit/cm^2)	Total fruit/tree	Average fruit weight (g)	*Biennial bearing index
Chanh orange	82	1.7	76	218	0.19
Carrizo citrange	200	2.4	173	231	0.25
Hong Kim orange	154	1.7	142	226	0.17
Hong Nhieu mandarin	179	2.0	168	217	0.16
Hong Nhieu orange	117	1.8	112	217	0.23
Mat orange	133	1.9	136	202	0.20
Ta mandarin	180	1.6	166	228	0.28
Tau lime	48	1.6	53	194	0.30
Tieu Son mandarin	163	1.6	158	205	0.36
LSD	67.0	0.2	60.8	15.3	-
P=0.05	***	*	**	***	ns

*Mean separation within the column was tested with LSD. Non-significant (ns); $^*p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. *Biennial bearing index (BBI) values were calculated as per Hoblyn et al. (1936). A BBI value of 0 indicates no biennial bearing and a value of 1 indicates high biennial bearing.*

**The year wise data for yield is given in Figure 9, Appendix 1.*

Fruit quality

Analyses of the fruit size and internal fruit quality (El-Zeftawi et al., 1982) data indicated that the quality attributes varied between trees depending on the rootstock. Carrizo citrange and Tau lime had the highest levels of total soluble solids while all other rootstocks had reasonably low total soluble solids (Table 4). These results were confirmed by calculating BrimA (an abbreviation for Brix minus acid). Essentially BrimA measures the balance between Brix (sweetness) and acidity (sourness) and is an alternative to the brix:acid ratio. BrimA is calculated by SSC − k (TA) where k is a constant that reflects the tongue's higher sensitivity to TA compared to SSC (Magwazaa and Opara, 2015). Carrizo citrange and Tau lime had the highest BrimA and Ta mandarin had the lowest (Table 4). There was a correlation of 80% between total soluble solids and BrimA. The sugar acid ratio was highest for Hong Nhieu orange (15.1) and lowest for Hong Kim orange (12.3). The juice content in fruit harvested from different rootstocks varied from 53% (Carrizo citrange) to 44% (Chanh orange). Average fruit weight was largest for Hong Kim orange (228 g) and lowest

for Carrizo citrange (205 g). Full results are in Table 4.

Table 4. The effect of rootstock on total soluble solids, BrimA, sugar to acid ratio, juice content and average fruit weight of Navelina for the 2016 season. Values presented are means (n=5).

Rootstocks	Total soluble solids (°Brix)	BrimA	Sugar acid ratio (°Brix:acid)	Juice content (%)	Average fruit weight (g)
Chanh orange	11.0	129	13.8	44	221
Carrizo citrange	11.6	134	12.8	53	205
Hong Kim range	11.1	123	12.3	46	228
Hong Nhieu mandarin	10.7	125	13.6	45	218
Hong Nhieu orange	11.0	133	15.1	45	206
Mat orange	11.1	127	13.1	47	209
Ta mandarin	10.6	124	13.6	46	222
Tau lime	11.5	134	13.8	47	206
Tieu Son mandarin	10.8	125	13.2	46	210
LSD	0.83	10	0.88	4	27
P=0.05	*	*	*	**	***

Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

Lane Late navel

Tree growth

Analysis of the 2016 data for Lane Late navel showed highly significant differences among the rootstocks for trunk circumference with Hong Nhieu mandarin having the greatest and Tau lime the smallest (39.3 and 22.3 cm respectively, Table 5). Tree heights were also significantly different and ranged from 2.6-2.1 m (Table 5). Carrizo citrange had the highest tree spread while trees on Tau lime had the smallest tree spread (Table 5).

Table 5. Effect of Vietnamese rootstocks on trunk circumference, tree height, tree spread, rootstock:scion ratios and graft union scores in Lane Late for the 2016 growing season. Values presented are means (n=5).

Rootstock	Trunk circumference (cm)	Tree height (m)	Tree spread (m)	Rootstock: scion	*Visual score
Chanh orange	25.7	2.1	2.5	1.1	2
Carrizo citrange	32.3	2.6	2.9	1.0	2
Hong Kim orange	34.5	2.6	2.8	1.1	1
Hong Nhieu mandarin	39.3	2.6	2.8	1.1	1
Hong Nhieu orange	30.3	2.3	2.6	1.0	1
Mat orange	26.2	2.2	2.5	1.0	1
Ta mandarin	29.4	2.3	2.6	1.1	2
Tau lime	22.3	2.0	2.1	1.1	3
Tieu Son mandarin	36.2	2.5	2.6	1.2	2
LSD	6.1	0.3	0.4	-	0.8
P=0.05	***	***	**	ns	**

Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.
*Visual score of graft union: 1 smooth union; 2 rootstock slightly larger than scion; 3 scion slightly larger than rootstock; 4 rootstock significantly larger than scion; 5 scion significantly larger than rootstock.

Assessment of graft union

An overgrowth at the graft union is associated with incompatibility between the scion and the rootstock and it can result in poor tree growth, reduced production and ultimately tree death. The data collected on the rootstock and scion circumference 6 cm below and above bud union was not significant. However, the visual scores of the graft unions detected significant differences between the rootstock treatments (Table 5).

Cumulative yield (2013-2017)

The yield data indicated that Lane Late navel on Hong Nhieu mandarin rootstock had the largest cumulative yield (218 kg/tree) and Tau lime (48 kg/tree) produced the lowest yield (Table 6). Yield efficiency (yield/trunk cross sectional area) differed between rootstocks. Trees on Carrizo citrange had the highest yield efficiencies and trees on Hong Nhieu orange had the lowest (Table 6). There were significant differences in both the total fruit per tree and the average fruit weight from trees on different rootstocks. Hong Nhieu mandarin produced the greatest fruit per tree (205) but had the lowest average fruit weight (Table 6). Differences in biennial bearing indices (BBI) were not significant across the rootstocks.

Table 6. Effect of Vietnamese rootstocks on cumulative yield, yield efficiency, fruit per tree, average fruit weight and biennial bearing scores in Lane Late during the 2013-2017 growing seasons. Values presented are means (n=5).

Rootstocks	*Cumulative yield (kg/tree)	Yield efficiency (kg fruit/cm^2)	Total fruit/tree	Average fruit weight (g)	*Biennial bearing index
Chanh range	66	1.2	64	220	0.29
Carrizo citrange	196	2.2	183	232	0.39
Hong Kim orange	151	1.5	157	203	0.25
Hong Nhieu mandarin	218	1.6	205	225	0.25
Hong Nhieu orange	62	0.9	78	180	0.28
Mat range	115	1.7	125	187	0.21
Ta mandarin	109	1.3	116	201	0.25
Tau lime	48	1.2	49	212	0.27
Tieu Son mandarin	132	1.2	136	201	0.20
LSD	0.68	0.69	85.5	18	-
P=0.05	*	*	**	***	ns

*Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. *Biennial bearing index (BBI) values were calculated as per Hoblyn et al. (1936). A BBI value of 0 indicates no biennial bearing and a value of 1 indicates high biennial bearing.*

*The year wise data for yield is given in Figure 10, Appendix 1.

Fruit quality

Analyses of the fruit size and internal quality data indicated that rootstock had an effect on fruit quality attributes with significant differences apparent in the sugar acid ratios, juice content and average fruit weights (Table 7).

Table 7. The effect of Vietnamese rootstocks on total soluble solids, BrimA, sugar to acid ratio, juice content and average fruit weight of Lane Late for the 2016 season. Values presented are means (n=5).

Rootstocks	Total soluble solids (°Brix)	BrimA	Sugar acid ratio (°Brix:acid)	Juice content (%)	Average fruit weight (g)
Chanh orange	12.0	147	15.7	48	212
Carrizo citrange	11.8	132	12.5	47	242
Hong Kim orange	11.7	138	14.1	50	217
Hong Nhieu mandarin	11.7	138	14.0	45	213
Hong Nhieu orange	12.0	146	15.4	48	185
Mat orange	11.8	145	15.6	46	171
Ta mandarin	11.6	138	14.3	47	197
Tau lime	12.0	144	14.9	48	201
Tieu Son mandarin	11.9	142	14.6	48	201
LSD	-	-	1.8	2.4	24
P=0.05	ns	ns	*	*	***

Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

Imperial mandarin

Tree growth

Hong Kim orange trees had the largest trunk circumference (51.9 cm) compared to the other rootstocks (Table 8). Neither tree height nor tree spread differed among the various rootstocks. However, this could be explained by tree management as they were topped and hedged for ease of orchard operations.

Table 8. Effect of Vietnamese rootstocks on trunk circumference, tree height, tree spread, rootstock to scion ratios and graft union scores in Imperial mandarin for the 2016 growing season. Values presented are means (n=5).

Rootstock	Trunk circumference (cm)	Tree height (m)	Tree spread (m)	Rootstock: scion	*Visual score
Chanh orange	32.0	2.7	2.2	1.1	1
Carrizo citrange	38.2	2.8	2.2	1.4	4
Hong Kim orange	51.9	2.8	2.3	1.0	1
Hong Nhieu mandarin	38.1	2.8	2.2	1.1	2
Hong Nhieu orange	34.6	2.8	2.0	1.1	2
Mat orange	31.6	2.7	2.0	1.1	1
Ta mandarin	39.0	2.8	2.2	1.1	2
Tau lime	28.8	2.6	2.0	1.1	1
Tieu Son mandarin	37.9	2.8	2.0	1.1	1
LSD	8.3	-	-	0.2	0.4
P=0.05	**	ns	ns	*	*

*Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. *Visual score of graft union: 1 smooth union; 2 rootstock slightly larger than scion; 3 scion slightly larger than rootstock; 4 rootstock significantly larger than scion; 5 scion significantly larger than rootstock.*

Assessment of graft union

Benching (overgrowth at the graft union due to incompatibility) is a major problem in Imperial mandarin trees in Australia with tree decline starting from 10-15 years after planting. Consequently, it is important to have a rootstock that not only produces a smooth graft union but that can also produce higher yields and acceptable fruit quality in the scion. A smooth graft union reflects a high degree of compatibility between a rootstock and a scion. The graft unions of the trial trees were all assessed and given a rating. The data collected on scion and rootstock growth indicated that only one rootstock was not compatible, i.e. Carrizo citrange (Table 8). This was confirmed with a mean visual score of 4 for Imperial mandarin on Carrizo citrange rootstock.

Cumulative fruit yield (2012-2017)

Carrizo citrange had the greatest cumulative yield of 206 kg/tree while Chanh orange produced the lowest yield of 117 kg/tree (Table 9). Mat orange produced the highest yield efficiency (yield/trunk cross sectional area) while Hong Kim orange produced the lowest yield efficiency (Table 9). There was no significant treatment difference in the average number of fruit per tree; possibly due to large variations among the trees. For example, Ta mandarin generated the highest fruit number per tree (n=374) and Chanh orange the lowest (n=238; Table 9).

Average fruit weight was significantly influenced by rootstock treatment with Carrizo citrange yielding the highest (113 g) followed by Tieu Son mandarin (107 g) while Ta mandarin and Tau lime had the lowest values of 94 g and 98 g respectively (Table 9).

Differences in biennial bearing values were significant across all rootstocks. Trees grafted to Ta mandarin rootstock had a BBI of 0.51 followed by Hong Nhieu mandarin (0.45). Chanh orange and Mat orange had the lowest BBI values of 0.25 and 0.22 respectively (Table 9).

Table 9. Effect of Vietnamese rootstocks on cumulative yield, yield efficiency, fruit per tree, average fruit weight and biennial bearing scores in Imperial mandarin during the 2012-2017 growing seasons. Values presented are means (n=5).

Rootstocks	*Cumulative yield (kg/tree)	Yield efficiency (kg fruit/cm^2)	Total fruit/tree	Average fruit weight (g)	*Biennial bearing index
Chanh orange	117	1.1	238	100	0.25
Carrizo citrange	206	1.6	361	113	0.30
Hong Kim orange	154	0.6	282	103	0.31
Hong Nhieu mandarin	129	1.0	253	100	0.45
Hong Nhieu orange	124	1.1	256	99	0.32
Mat orange	178	2.0	338	103	0.22
Ta mandarin	172	1.3	374	94	0.51
Tau lime	120	1.6	248	98	0.35
Tieu Son mandarin	124	1.0	241	107	0.31
LSD	72.0	0.5	143	8.6	0.20
P=0.05	*	***	ns	**	*

*Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. *Biennial bearing index (BBI) values were calculated as per Hoblyn et al. (1936). A BBI value of 0 indicates no biennial bearing and a value of 1 indicates high biennial bearing.*

**The year wise data for yield is given in Figure 11, Appendix 1.*

Fruit quality

Analyses of the fruit size and internal fruit quality revealed significant differences between the rootstock treatments for total soluble solids, BrimA and fruit sugar:acid values (Table 10). Only Hong Kim orange had a total soluble solid value of greater than 12 °Brix. There was a correlation of 80% between °Brix values and BrimA (Table 10). Juice content and average fruit weight did not differ between the rootstocks (Table 10).

Table 10. The effect of rootstock on total soluble solids, BrimA, fruit to sugar ratios, juice content and average fruit weight of Imperial mandarin for the 2017 season. Values presented are means (n=5).

Rootstocks	Total soluble solids (°Brix)	BrimA	Fruit sugar:acid (°Brix:acid)	Juice content (%)	Average fruit weight (g)
Chanh orange	11.9	142	14.7	46	116
Carrizo citrange	11.9	139	14.0	49	119
Hong Kim orange	12.1	149	15.8	53	116
Hong Nhieu mandarin	11.5	138	14.7	47	112
Hong Nhieu orange	11.2	131	13.8	45	119
Mat orange	11.3	138	15.6	51	120
Ta mandarin	11.5	133	13.7	46	111
Tau lime	11.2	131	14.0	47	116
Tieu Son mandarin	11.5	140	15.4	47	120
LSD	0.7	10.5	1.8	-	-
P=0.05	*	*	*	ns	ns

*Mean separation within the column was tested with LSD. Non-significant (ns); *$p<0.05$.*

Eureka lemon

Tree growth

Analysis of the 2016 data for Eureka lemon showed that trees on Hong Kim orange rootstock had the largest trunk circumferences (60.5 cm) compared to trees on other rootstocks (Table 11). Tree height and tree spread were not significantly different for the trees on different rootstocks, most likely due to the hedging that was carried out to manage the size of the tree canopy.

Assessment of graft union

An overgrowth at the graft union is related to an incompatibility between the scion and the rootstock and can lead to tree decline.

Overgrowth (benching) is a serious problem in Eureka lemon trees and it is important to find a compatible rootstock that also induces high yields and acceptable fruit quality. The data collected on scion and rootstock growth indicated that there were some compatibility issues between Eureka lemon and the trial rootstocks, but this was not evident from the rootstock:scion circumference data. The visual score data indicated that apart from Carrizo citrange, Hong Kim orange and Hong Nhieu mandarin, all rootstocks had undesirable graft unions with Eureka lemon (mean visual score of 3) (Table 11).

Table 11. Effect of Vietnamese rootstocks on trunk circumference, tree height, tree spread, rootstock:scion ratios and graft union scores for Eureka lemon in the 2017 growing season.

Rootstock	Trunk circumference (cm)	Tree height (m)	Tree spread (m)	Rootstock: scion	*Visual score

Chanh orange	39.2	3.6	2.9	1.0	3
Carrizo citrange	47.6	3.7	2.8	1.0	1
Hong Kim orange	60.5	3.8	2.8	1.0	2
Hong Nhieu mandarin	48.5	3.6	2.8	1.1	3
Hong Nhieu orange	50.0	3.7	2.8	1.1	2
Mat orange	45.9	3.7	2.7	1.0	3
Ta mandarin	50.4	3.7	2.7	1.0	3
Tau lime	44.9	3.6	2.6	1.0	3
Tieu Son mandarin	57.8	3.5	2.5	1.0	2
LSD	9.8	-	-	-	1.2
P=0.05	**	ns	ns	ns	*

*Mean separation within the column was tested with LSD. Non-significant (ns); *p<0.05; **p<0.01; ***p<0.001. *Visual score of graft union: 1 smooth union; 2 rootstock slightly larger than scion; 3 scion slightly larger than rootstock; 4 rootstock significantly larger than scion; 5 scion significantly larger than rootstock.*

Cumulative yield (2013-2017)

Rootstock treatment did not induce a significant difference in the cumulative yield per tree and the average fruit weight (Table 12). Carrizo citrange could be considered the best performing rootstock, having the highest yield efficiencies, fruit per tree and fruit weight (Table 12). Hong Kim orange and Tieu Son mandarin rootstocks had the highest biennial bearing index values, indicating a strong biennial bearing tendency (Table 12).

Table 12. Effect of Vietnamese rootstocks on cumulative yield, yield efficiency, total fruit per tree, average fruit weight and biennial bearing scores in Eureka lemon trees during the 2013-2017 growing seasons.

Rootstocks	*Cumulative yield (kg/tree)	Yield efficiency (kg fruit/cm^2)	Total fruit/tree	Average fruit weight (g)	*Biennial bearing index
Chanh orange	109	0.8	207	182	0.43
Carrizo citrange	227	1.4	269	200	0.47
Hong Kim orange	111	0.4	61	187	0.83
Hong Nhieu mandarin	135	0.6	171	188	0.51
Hong Nhieu orange	158	0.6	185	186	0.43
Mat orange	164	0.8	209	188	0.54
Ta mandarin	137	0.7	160	192	0.58
Tau lime	163	0.9	222	194	0.51
Tieu Son mandarin	180	0.6	162	183	0.70
LSD	-	0.6	87.8	-	0.19
P=0.05	ns	*	*	ns	*

*Mean separation within the column was tested with LSD. Non-significant (ns); *p<0.05; **p<0.01; ***p<0.001. *Biennial bearing index (BBI) values were calculated as per Hoblyn et al. (1936). A BBI value of 0 indicates no biennial bearing and a value of 1 indicates high biennial bearing.*

**The year wise data for yield is given in Figure 12, Appendix 1.*

Fruit quality

Analyses of the fruit size and internal fruit quality revealed significant differences between the

rootstocks for total soluble solids and fruit sugar:acid values (Table 13). The levels of total soluble solids were highest for Mat orange (8.2) and lowest for Tieu son mandarin and Hong Nhieu orange (both 7.5). The lowest soluble solids (7.4 °Brix) were found in fruit produced on Hong Kim orange rootstocks. The sugar acid ratio was highest in fruit harvested from trees on Mat orange and Carrizo citrange rootstocks. There were no differences between the rootstock treatments for juice content or average fruit size (Table 13).

Table 13. The effect of rootstock on total soluble solids, BrimA, sugar to acid ratios, juice content and average fruit weight of Eureka lemon for the 2016 season. Values presented are means (n=5).

Rootstocks	Total soluble solids (°Brix)	Sugar:acid (°Brix:acid)	Juice content (%)	Average fruit weight (g)
Chanh orange	7.7	1.1	40	156
Carrizo citrange	7.9	1.2	46	198
Hong Kim orange	7.4	1.1	42	171
Hong Nhieu mandarin	7.7	1.1	45	165
Hong Nhieu orange	7.5	1.0	46	180
Mat orange	8.2	1.2	44	189
Ta mandarin	7.6	1.1	46	176
Tau lime	7.6	1.1	46	176
Tieu Son mandarin	7.5	1.1	45	176
LSD	0.4	0.1	-	-
P=0.05	*	*	ns	ns

Mean separation within the column was tested with LSD. Non-significant (ns); $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$.

Experiment 2: Evaluation of superior processing oranges for fresh juice with selected Chinese rootstocks in a semi-commercial situation

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) 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. Chinese rootstock trial established in October 2010 at Stanbridge, Leeton.

Results

Tree height

Tree growth data was analysed and the results indicated that trees on Zao Yang rootstock had slightly larger tree heights (2.0 m) compared to trees on other rootstocks (1.7 m). Across Valencia scions, Valencia 5 had the highest tree height (2.3 m) (Table 14).

Table 14. Effect of Chinese rootstocks on tree height (m) of different Valencia selections for the 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	1.9	1.9	1.7	1.7	1.7	2.3	1.8	1.9
Tanghe	1.9	1,7	1.8	1.8	1.7	2.4	1.7	1.8
Tri 22	1.7	1.6	1.6	1.7	1.8	2.2	1.7	1.8
Zao Yang	2.1	1.8	1.8	2.8	1.8	2.4	1.9	2.0
Variety	1.9	1.7	1.8	1.9	1.7	2.3	1.8	

P value <0.001 (LSD = 0.07) to compare means across rootstock

P value <0.001 (LSD = 0.09) to compare means across variety

P value <0.5 (LSD = 0.17) to compare means across rootstock*variety

Tree circumference

Tree circumference was recorded for each experimental tree. Trees on Zao Yang rootstock had the largest tree circumference (22.8 cm) compared to trees on other rootstocks (Table 15). Across Valencia scions, Valencia 5 had the largest tree circumference (25.6 cm) compared to other scions. There was no significant interaction between variety and rootstock. However, Valencia 5 trees grafted onto Zao Yang rootstock had the largest trunk circumference (26.4 cm), while small tree circumferences were recorded for Valencia 6 on Tri 22 rootstock (19.6 cm; Table 15).

Table 15. Effect of Chinese rootstocks on tree circumference (cm) of different Valencia selections for the 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	23.4	19.9	20.9	21.9	20.2	25.6	21.3	21.9
Tanghe	21.0	19.8	20.9	20.8	19.7	25.6	20.0	21.1
Tri 22	19.8	19.8	20.6	20.0	21.3	24.9	19.6	20.8
Zao Yang	22.7	21.0	23.3	22.2	21.3	26.4	22.3	22.8
Variety	21.7	20.1	21.4	21.2	20.6	25.6	20.8	

P value <0.001 (LSD = 0.64) to compare means across rootstock

P value <0.001 (LSD = 0.84) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Fruit yield

Cumulative fruit yield was significantly higher in Valencia 5 (96.0 kg/tree) compared to the control (Keenan 82.2 kg/tree) and other selections (Table 16).

Table 16. Effect of Chinese rootstocks on cumulative (2015-2017) yield (kg/tree) on different Valencia selections.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Mean
Donghai	83.8	68.8	83.3	84.8	66.1	88.9	78.4	79.2
Tanghe	84.3	70.3	85.4	81.7	73.5	99.7	76.9	81.7
Tri 22	64.4	68.8	87.8	74.4	73.8	90.8	69.1	75.6
Zao Yang	96.4	83.8	103.4	98.9	91.7	104.6	103.9	97.5
Mean	82.2	72.9	90.0	84.9	76.3	96.0	82.1	

P value <0.001 (LSD = 5.9) to compare means across rootstock

P value <0.001 (LSD = 7.9) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Generally, Zao Yang rootstock also produced higher yields (97.5 kg/tree) compared with standard Tri22 (75.6 kg/tree). Early results showed that there was no significant interaction on fruit yield across rootstocks and Valencia selection. A further two years of data is required to properly confirm these findings and this will be carried out in the new rootstock project (CT17002).

Fruit quality

Total soluble solids

The mean total soluble solids for fruit were highest on Valencia 5 trees (12.2) compared to the fruit of other varieties (Table 17). While there was no difference in the °Brix values across different rootstocks (Table 17). The interaction effect indicated that °Brix values were higher in Valencia 5-Tri22 compared to Keenan-Tri22 (12.6 and 10.5 respectively, Table 17).

Table 17. Effect of Chinese rootstocks on total soluble solids (°Brix) on different Valencia selections for the 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	11.1	10.3	11.1	11.2	10.6	12.2	10.7	11.0
Tanghe	10.7	10.7	10.5	11.6	11.2	11.8	10.3	11.0
Tri 22	10.5	10.4	11.0	11.1	10.8	12.6	10.6	11.0
Zao Yang	10.8	10.9	11.1	11.6	10.8	12.2	10.1	11.1
Variety	10.7	10.6	11.0	11.4	10.8	12.2	10.4	

P value = not significant for rootstock

P value <0.001 (LSD = 0.5) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Total soluble solids:acid ratios

The mean sugar:acid ratios for fruit of Valencia 5 was higher (13.8) compared to fruit of other varieties. Fruit from trees on Tri22 and Donghai rootstocks had higher ratios (13.8 and 13.6) compared to other rootstocks (Table 18). Valencia 5 on Tri22 rootstock gave the best results (Table 18).

Table 18. Effect of Chinese rootstocks on total soluble solids (°Brix): acid ratios on different Valencia selections for 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	13.5	14.1	13.1	13.8	13.5	14.3	13.2	13.6
Tanghe	14.2	13.7	13.7	14.4	12.4	12.5	12.5	13.3
Tri 22	14.0	13.6	14.0	14.3	13.0	14.9	12.5	13.8
Zao Yang	12.8	13.5	14.0	13.5	12.1	13.4	13.9	13.3
Variety	13.6	13.7	13.7	14.0	12.8	13.8	13.0	

P value <0.05 (LSD = 2.2) to compare means across rootstock

P value <0.05 (LSD = 2.9) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Juice content

The juice content of the fruit from Valencia 5 was higher (55%) than the fruit of other varieties (Table 19). The interaction effect between rootstocks and scions was not significant (Table 19).

Table 19. Effect of Chinese rootstocks on %juice ratios on different Valencia selections for 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	50	52	50	55	52	57	56	53.1
Tanghe	51	53	52	51	54	53	54	52.5
Tri 22	50	57	56	53	54	57	53	54.2
Zao Yang	50	52	50	53	53	53	47	51.1
Variety	50.3	53.6	51.9	52.9	53.1	55.2	52.1	

P value <0.05 (LSD = 2.2) to compare means across rootstock

P value <0.05 (LSD = 2.9) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Fruit size

Keenan produced the greatest average fruit size (279 g) and trees on Zao Yang rootstock had the highest mean weight of 275 g (Table 20). The interaction between rootstocks and scions was not significant (Table 20).

Table 20. Effect of Chinese rootstocks on average fruit weight (g) on different Valencia selections for 2016 growing season.

	Keenan	Val 1	Val 2	Val 3	Val 4	Val 5	Val 6	Rootstock
Donghai	275	242	232	258	248	231	246	247
Tanghe	272	240	253	234	258	258	258	253
Tri 22	282	227	234	258	241	248	270	251
Zao Yang	288	263	244	271	273	284	303	275
Variety	279	243	241	255	255	255	269	

P value <0.001 (LSD = 13.0) to compare means across rootstock

P value <0.001 (LSD = 17.3) to compare means across variety

Interaction effect for rootstock × variety was not significant.

Experiment 3: Establishment and evaluation of salt tolerant rootstocks

Previous research at Dareton, NSW identified some Chinese mandarin rootstock selections as having some salt tolerance (Khurshid et al. 2014). 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). An additional set of rootstock hybrids from the NSW DPI breeding program as well as hybrids from America that are reported to be salt tolerant were also included on the site. The details of rootstocks used in this trial are given in the Methodology section of this report.

Figure 2. Trees planted in April 2013 (Left) and the same trees in 2017 (Right).

Results

This trial is still in the early stages and consequently only limited data is available. However, the data is presented here to demonstrate the progress of the trial, although no conclusions can be made yet.

Tree growth

The tree growth data collected in the 2017 growing season suggests that there might be differences in trunk circumference with rootstock 3822 growing largest at 21.5 cm and Anjiang hongju the smallest at 9.4 cm (Table 21).

Table 21. The effect of different rootstocks on trunk circumference, tree height and leaf salt accumulation in Houghton navel.

Rootstock	Trunk circumference (cm)	Tree height (m)	Salt accumulation (% chloride)
3834 (Scarlett mandarin X P. trifoliata)	19.9	1.7	0.38
3835 (Scarlett mandarin X P. trifoliata)	14.7	1.5	0.61
Troyer citrange (standard)	19.9	1.9	0.43
F1 (63-199-49) (Sunki mandarin X Mars P.trifoliata)	17.8	1.7	0.26
X OP (59-24-8) (Rangpur lime X Swingle P. trifoliata)	17.3	1.8	0.20
3812 (Scarlett mandarin X P. trifoliata)	13.5	1.4	0.85
Cox (Scarlett mandarin X P. trifoliata)	17.0	1.9	0.17
F1 (63-199-31) (Sunki mandarin X Mars P.trifoliata)	17.7	1.7	0.19
3822 (Scarlett mandarin X P. trifoliata)	21.5	2.1	0.22
Zao Yang P. trifoliata	14.5	1.5	0.43
F1 (62-109-40) (Sunki mandarin X Flying Dragon P.trifoliata)	10.2	1.1	0.46
Anjiang hongju (Erythrosa type)	9.4	0.9	0.21

Tree height followed the same trends as trunk circumference, with rootstock 3822 the tallest (2.1 m) and Anjiang hongju the shortest (0.9 m) (Table 21). Rootstocks were also tested for their ability to accumulate salt. Rootstock 3812 had the highest salt accumulation (0.85% chloride) compared with the two control rootstocks of Cox (0.17%) and Troyer citrange (0.53%).

Cumulative fruit yield

Fruit yield data was combined for 2016 and 2017 and presented as a cumulative yield for the two growing seasons. So far the total fruit yield per tree was highest for the NSW DPI hybrid rootstock 3834 (39 kg/tree) compared with the controls (Troyer citrange, 34 kg/tree and Cox, 27 kg/tree). Other rootstocks F1 (62-199-31), 3822, Zao Yang, F1 (62-199-40) and Anjiang hongju) produced cumulative yields of less than 27 kg/tree (Table 22).

Fruit quality

So far there has been no difference in Brix values across rootstocks. There was 78% correlation between sugar:acid ratios and BrimA, therefore results will be presented for BrimA only. F1 rootstocks had higher BrimA values when compared with controls (Table 22). To date, rootstock selection does not appear to be significantly influencing juice content (Table 22).

Table 22. The effect of different rootstocks on cumulative yield, total titratable sugar, sugar:acid ratio, BrimA and juice content in Houghton navel.

Rootstock	Cumulative yield (kg)	Total Titratable Sugar (°Brix)	Sugar acid ratio (°Brix:acid)	BrimA	Juice content (%)
3834 (Scarlett mandarin X P. trifoliata)	39	11.0	10.1	109	47
3835 (Scarlett mandarin X P. trifoliata)	34	11.4	9.5	109	49
Troyer citrange (standard)	34	11.8	9.5	112	45
F1 (63-199-49) (Sunki mandarin X Mars P.trifoliata)	32	12.0	10.0	119	50
X OP (59-24-8) (Rangpur lime X Swingle P. trifoliata)	31	11.6	9.2	109	48
3812 (Scarlett mandarin X P. trifoliata)	28	11.6	10.2	117	46
Cox (Scarlett mandarin X P. trifoliata)	27	12.0	8.5	105	49
F1 (63-199-31) (Sunki mandarin X Mars P.trifoliata)	23	12.2	9.9	120	50
3822 (Scarlett mandarin X P. trifoliata)	22	11.4	9.0	104	48
Zao Yang P. trifoliata	21	12.1	8.9	110	48
F1 (62-109-40) (Sunki mandarin X Flying Dragon P.trifoliata)	1	12.0	10.0	119	47
Anjiang hongju (Erythrosa type)	0	na	na	na	na

While it is still too early to make any definite recommendations, on the basis of the preliminary data collected so far, it appears that the two NSW DPI hybrids (3834 and 3835) may have potential as rootstocks. As the trial continues, data collected over the next 3-4 years will enable practical conclusions to be made.

Experiment 4: Propagation and establishment of Chinese rootstock trials at grower's properties

Background

Chinese rootstocks have previously been tested in deep sandy loam soil conditions at Dareton (NSW DPI) and another trial is underway to test their performance in clay soil conditions at Leeton in the Riverina (Experiment 2). To test the performance of Chinese rootstocks in wider ranging soil and climatic conditions, trials were established on grower's properties throughout Australia. To facilitate this, an advertisement was placed in the Australian Citrus News (September 2014 issue) inviting growers to participate. A positive response was received and 16 growers were selected and registered to participate in small scale research trials. The rootstock and scion selections provided to the growers (Table 23) were decided based on their preferences for scion variety and soil type. The objective of the grower's site trials is to assess the performance of Chinese rootstocks with existing and new scion varieties in a range of soil and climatic conditions around Australia.

Propagation of rootstock seedlings

Rootstock fruit was collected from Chinese trifoliata source trees established at Dareton and the seed extracted. The Australian standard trifoliata selection (Tri22) was obtained from Auscitrus. Seeds were provided to Victorian Citrus Farms, Red Cliffs in Victoria to raise rootstock seedlings. Seeds were planted in polystyrene boxes on 14 September 2014 and germination began on 30 September 2014 (Figure 3).

Figure 3. Propagation of rootstock seedlings for rootstock trials at Victorian Citrus Farms, Red Cliffs, Victoria.

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 those with uniform health were selected for potting. Off-type seedlings (too small or large, or with an unusual leaf shape) and seedlings with deformed root systems were discarded. Selected seedlings were potted into 4 litre pots and placed in the screen house. Once they had developed to a suitable thickness (pencil thickness – 7.5 mm) they were then considered ready for grafting (Figure 4). Trees were chip budded in March 2016 with a range of scion varieties for both growers' and dwarfing trials.

After budding, trees were managed as per nursery best practice. Trees were ready for dispatch in August 2017 (Figure 5).

Figure 4. Seedling selection and potting.

Figure 5. Chip budding was used to graft one-year-old rootstock seedlings.

Trial establishment (October 2017)

Trial site preparation was carried out by the respective growers prior to the arrival of the trees at their properties. Trees were dispatched to grower's properties in five states around Australia. Trees were planted according to the experimental design outlined previously.

A research agreement between each grower and the NSW DPI is in place to ensure that milestones are met during the project. Growers will be fully responsible for trial management including fertigation, irrigation and other cultural practices. Data for tree growth, yield and quality will be collected by the NSW DPI with assistance from the growers. This trial will be evaluated under the newly funded project (CT17002, Evaluation of new rootstocks for the Australian citrus industry). The details of the trial sites are given in Table 23.

Table 23. The rootstock-scion combinations to be used in the grower's trial sites around Australia.

Grower's site	Scion type	Rootstock types
Burronga, NSW	Cara Cara	Tanghe, Zao Yang, Tri22
Curlwa, NSW	Afourer	Tanghe, Zao Yang, Tri22, Nianju
Dandaragon, WA	Afourer	Tanghe, Zao Yang, Tri22, Ghana, Nianju
Dareton NSW	Afourer	Zao Yang, Tri22, Ghana, Anjiang hongju
Dareton, NSW	Cara Cara	Tanghe, Zao Yang, Tri22, Ghana
Gayndah, QLD	Afourer	Tanghe, Zao Yang, Tri22, Nianju
Gin Gin, WA	Afourer	Tanghe, Zao Yang, Troyer citrange, Tri22, Nianju
Gunnedah, NSW	Valencia	Tanghe, Zao Yang, Tri22, Ghana
Harvey, WA	Afourer	Tanghe, Zao Yang, Tri22, Ghana
Kenly, Victoria	M7 navel	Tanghe, Zao Yang, Tri22, Ghana
Leeton, NSW	Afourer	Tanghe, Zao Yang, Tri22, Ghana, Anjiang hongju
Leeton, NSW	Valencia	Tanghe, Zao Yang, Tri22, Ghana
Leeton, NSW	Washington navel	Tanghe, Zao Yang, Tri22, Ghana
Moree, NSW	Benyenda	Tanghe, Zao Yang, Tri22
Waikeri, SA	Valencia	Tanghe, Zao Yang, Tri22, Ghana

Experiment 5: Propagation and establishment of Chinese and US rootstocks for dwarfing effect at NSW DPI, Dareton

Two trial sites were established at the NSW DPI Dareton research institute in October 2017 (Figure 6). Selected Chinese and American rootstocks were included in these trials (Figure 7). The details of which rootstocks were budded onto M7 navel and Tang Gold mandarins are listed in Table 24.

Table 24. Rootstocks used in M7 navel and Tang Gold mandarin sites at NSW DPI, Dareton.

Figure 6. M7 navel and Tang Gold mandarin trial planted at NSW DPI Dareton in October 2017.

Rootstock	Type	Source
85-25	Poncirus trifoliata	People's Republic of China
C146	Citrus sunki x Poncirus trifoliataL. Raf 'Swingle'	University of California, Riverside
C22 (Bitters)	Citrus sunki x Poncirus trifoliata L. Raf 'Swingle'	University of California, Riverside USDA Breeding Program, Indio
C54 (Carpenter)	Citrus sunki x Poncirus trifoliata L. Raf 'Swingle'	University of California, Riverside

C57 (Furr)	Citrus sunki x 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

Figure 7. Dwarfing rootstock seedlings at Victorian Citrus Farms, Red Cliffs, Victoria.

Experiment 6: Propagation and establishment of Italian rootstocks

Rootstock seedlings of Italian hybrid varieties F5P12, F6P12 and F6P13 have been introduced by ANFIC Nurseries. The trees are being maintained and will be ready to be grafted onto three scion varieties, Nectar, Tang Gold and Imperial, in October 201 (Figure 8).

Figure 8. Italian rootstock seedlings of F5 P12 at NSW DPI, Dareton

Release of new rootstocks to the Australian Citrus Industry

The primary output of the project was the release of new rootstocks to the Australian citrus industry. Six new rootstocks were released from the Chinese rootstock evaluation program on 10 May 2017 (Table 25).

Table 25. Six new Chinese rootstocks characteristics as compared to Tri22

Name	Zao Yang	Tanghe	Ghana	Donghai	Anjiang hongju	Caoshi xiangju
Type	Poncirus trifoliata	Poncirus trifoliata	Poncirus trifoliata	Poncirus trifoliata	Citrus erythrosa (mandarin)	Citrus erythrosa (mandarin)
Compati-bility	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 Mandarin	Smaller fruit for Valencia and Navelina. Sweetness is better than Tanghe for Navelina	Internal quality acceptable for Valencia and higher for imperial mandarin	Internal quality acceptable for Valencia
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

The rootstocks were released by the Hon. Niall Blair (Minister of Primary Industries) at Parliament House in Sydney. Seeds for the new rootstocks are now available for purchase from Auscitrus. The characteristics of the new rootstocks are given in Table 25 and compared to the standard Australian Trifoliata22 rootstock. The results were obtained from trial sites at NSW DPI Dareton and also from a trial site in Riverina. At Dareton, trees were planted in deep sandy loam soil (light), while the soil type in Riverina was clay loam (Heavy soil).

Information transfer and extension

The project included a comprehensive information transfer program. Trial results were presented to citrus growers, packers, processors and industry service providers at conferences and seminars in Australia and overseas. Data was also presented to local and international visitors to the NSW Primary Industries Institute at Dareton, and numerous visitors inspected the trial sites. The project team established international linkages with scientists and industry representatives during the course of the experimental program. It is anticipated that the key scientific outputs from the project will also be presented at the International Citrus Congress in Turkey in 2020.

National forums and field days

A number of presentations were made around Australia during the project. These presentations, which often included farm walks, workshops and technical forums, were organised by industry development officers or during other organised events such as Citrus Australia Limited (CAL) technical forums and NSW DPI road shows. The project team also took every opportunity to inform citrus producers about the project outcomes at meetings and other less formal events. Some of the extension activities are listed below:

- Citrus Australia Limited Forum: Rootstock presentation, release of new rootstocks, Gayndah, Queensland, 28 November 2017.
- NSW DPI Forum: Rootstock presentation, NSW DPI Road Show, Loxton, South Australia, 19 October 2017.
- NSW DPI Forum: Rootstock presentation, NSW DPI Road Show, Mildura, 18 October 2017.
- Citrus Australia Limited Forum: Citrus rootstock update, Mildura, 1 March 2017.
- NSW DPI Forum: Rootstock presentation, NSW DPI Road Show, Griffith, 17 October 2017.
- Citrus Australia Limited Forum: Citrus rootstock update, Mildura, 10 May 2017.
- Progress and update Hort Innovation: Citrus rootstocks update, Ourimbah, 1 February 2017.
- Citrus Australia Limited Forum: Citrus rootstock update to growers, Mildura, 2 March 2016.
- Citrus Australia Limited Forum: Rootstock results were presented to citrus growers, Riverina, 23 June 2016.
- Citrus Australia Limited Forum: Rootstock results were presented to citrus growers, Mildura, 21 June 2016.
- NSW DPI Field Day: Research work results were presented to the local industry during a field day at Stanbridge, Leeton, 23 March 2016.
- Citrus Australia Limited Forum: Research work results were presented to the industry, Red Cliffs, 16 March 2015.
- Citrus Field Day: Rootstock trial update and results presented, Perth, Western Australia, 4-5 June 2013.

International conference and workshops

Formal presentations were presented at the following:

- Khurshid, T. 2016. Citrus rootstock evaluation program for overseas rootstocks. Iguasu, Brazil, 16-24 September 2016.
- Khurshid, T. 2016. Citrus rootstock effects on yield, quality and tree growth. Maejo University, Chiang Mai, Thailand, 21 February 2016.
- Khurshid, T. 2014. Progress on Chinese rootstocks. University of Florida, Lake Alfred, 2 December 2014.
- Khurshid, T. 2014. Progress on Chinese and University of California rootstocks. Riverside, 5 December 2014.
- Khurshid, T., Donovan, N. J., Forner-Giner, M. A. 2014. The effect of Chinese rootstocks on tree growth, fruit yield and quality of citrus under Sunraysia conditions in Australia. 29th International Horticultural Congress, Brisbane, 17-22 August 2014.
- Khurshid, T. 2013. Data summaries and updates from the Chinese rootstock trials were presented to research scientists and staff of the Instituto Valenciano de Investigaciones Agrarias, Valencia, Spain in November 2013.
- A paper on Chinese rootstocks was presented at the International Horticultural Congress held in Valencia, Spain in 2012.

Presentations for national and international visitors at Dareton, Australia

- USA: Dr Frid Gmitter and Dr Kim Bowman 2017. Rootstock progress was presented to the overseas rootstock experts followed by a field session to show them the different rootstocks. A meeting with Dr Kim Bowman was also held to discuss the possibility of importing new rootstock varieties to Australia with potential to induce dwarfing and HLB tolerance.
- Pakistan: Rootstock updates were presented to a group of researchers and extension officers from Pakistan in August 2014. A field session was also organised for the visitors to inspect the Chinese rootstocks.
- China: A formal presentation about the latest results of Chinese rootstock trial was made to 20 growers and nursery workers from China on 21 April 2015. A field visit of the rootstock trial followed the presentation.
- Thailand: Rootstock updates were presented to Mr Kom, the owner of Thanathon orchards, on 30 June 2016. A field session was also organised to inspect the Chinese rootstocks. The Australian citrus industry is keen to export navel oranges to Thailand under the KCT (Korea, China, and Thailand) program.
- Chile: Rootstock updates were presented and a field session was given to Chilean visitors on 29 September 2016.
- Australian Centre for International Agricultural Research (ACIAR): Rootstock updates were presented to Dr Richard Markham (ACIAR, Canberra) on 24 October 2016 followed by a field session. The importation of Chinese rootstocks into Australia was carried out during an ACIAR funded project in 1992.
- USA: Rootstock updates were presented to a leading variety expert, Dr Tim Williams (University

of California, Riverside), on 7 September 2015. He also inspected the rootstocks in the field following the presentation.

- NSW DPI Management: Rootstock results were presented to the Director General, Scott Hansen, and 5 other deputy director generals during their visit to Dareton research station on 26 August 2016.

Industry and newspaper articles, radio interviews

- Rootstock article in ACIAR's Partner magazine 2018.
- Rootstock article in Australia Citrus News 2017.
- Rootstock launch article, Sunraysia Daily, 17 May 2017.
- Radio interview on Chinese rootstocks and their potential, ABC radio, 23 March 2016.
- Citrus researcher looks into overseas rootstocks, Good Fruit and Vegetables, April 2016 Issue.
- New rootstock shows potential, The Land, 14 April 2016.
- Article in Australia Citrus News, 30 September 2016.
- Research work results published in Australia Citrus News, September 2014.
- Research work results published in CitrusConnect (NSW DPI online newsletter).
- Evaluation of locally bred and imported rootstocks, Citrus Insight, submitted to HAL, 2013.

Variety Leadership Group meetings

- CAL Mildura, 14 June 2017.
- NSW DPI, Dareton, 5 December 2016.
- NSW DPI, Dareton, 24 May 2016.
- Rendezous Hotel, Melbourne, 10 November 2015.
- Mantra Hotel, Tullamarine, Melbourne, 14 October 2014.
- NSW DPI, Dareton, 3 September 2013.

Milestone reports

Khurshid, T. 2014. Milestone report 102, CT13042, submitted on 30 November to Horticulture Innovation Limited.

Khurshid, T. 2015. Milestone report 103, CT13042, submitted on 15 June to Horticulture Innovation Limited.

Khurshid, T. 2015. Milestone report 104, CT13042, submitted on 15 November to Horticulture Innovation Limited.

Khurshid, T. 2016. Milestone report 105, CT13042, submitted on 30 May to Horticulture Innovation Limited.

Khurshid, T. 2016. Milestone report 106, CT13042, submitted on 15 November to Horticulture Innovation Limited.

Khurshid, T. 2017. Milestone report 107, CT13042, submitted on 30 May to Horticulture Innovation Limited.

Khurshid, T. 2018. Milestone report 190; Final Report, CT07002, submitted on 30 March to Horticulture Innovation Limited.

Future planned activities

- Present project progress at the CAL Forum, Mildura, 2019.
- Import Spanish rootstocks from IVIA, Valencia, Spain, September/October 2018.
- Import HLB tolerant rootstocks from USDA, Florida, 2019.
- Present paper at the 14th International Citrus Congress, Mersin, Turkey, 2020.

Outcomes

- New rootstocks released to the Australian industry from the National Citrus Rootstock Improvement Program will provide growers with greater choices for matching rootstock to scion varieties and growing conditions.
- Australia is the only country with access to new Chinese rootstock varieties released from the long-term evaluation program.
    - Adoption of new Chinese rootstocks will widen scion choice for some growers; increasing industry competitiveness by opening new markets.
    - Adoption of new Chinese rootstocks will improve sustainability of Australian citrus production; it is anticipated that the new rootstocks will improve tree health and reduce tree failure from soil and disease factors by almost 15%.

- Rootstocks that impart better quality attributes to fruit of the grafted scion variety will lead to an increased proportion of large or appropriate sized fruit for export and local markets.

- Improved fruit quality due to the influence of improved rootstock varieties will lead to better pack out rates and increase profitability of the Australian industry in export markets by 20%.
- Improved competitiveness of Australian citrus growers in early markets will result from industry adoption of new rootstocks that induce better fruit quality in early maturing varieties.
- Improved productivity in Australian orchards will result from industry adoption of new rootstocks that induce greater yields in scion varieties.
- The Auscitrus propagation scheme is a non-profit industry organisation whose existence is essential for maintaining biosecurity and ensuring survival of the Australian citrus industry. The National Citrus Rootstock Improvement Program promotes biosecurity and supports the Auscitrus propagation scheme by partnering to supply the industry with seed of new rootstock releases from health tested sources.

Monitoring and evaluation

This project was monitored by a reference group; details are given below.

- Review completed by Horticulture Innovation Australia as per milestone 105 (3 May 2016).
- Industry Advisory Committee internal project review was carried out by Horticulture Innovation Australia as per Milestone 106 (15 November 2016).
- All milestones were achieved by NSW DPI and were accepted by Horticulture Innovation Australia Limited.
- The project was also monitored internally by the NSW DPI staff development program twice a year.
- Project progress was presented to the Variety Leadership Group meetings:
    - CAL Mildura, 14 June 2017;
    - NSW DPI, Dareton, 5 December 2016;
    - NSW DPI, Dareton, 24 May 2016;
    - Rendezous Hotel, Melbourne, 10 November 2015;
    - Mantra Hotel, Tullamarine, Melbourne, 14 October 2014; and
    - NSW DPI, Dareton, 3 September 2013.

Recommendations

Rootstocks have a major impact on the profitability of citrus orchards. Rootstocks can influence fruit size, yield and yield efficiency. 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 in navel oranges.

Rootstocks selected for entry to further trials

The performance of rootstock varieties in trials to date have led to the selection of a number of these for further testing in longer-term, industry-based, commercial trials.

- The rootstocks recommended for further investment are Zao Yang, Ghana, Tanghe, Donghai, Anjiang Honju and Cao Shixiangju. This recommendation is based on results with Navelina, Lane Late, Imperial mandarin and Valencia orange scions. The scions used in the trials were considered to best represent the major scions grown by industry at the start of the project. The large number of rootstocks under investigation limited the number of scion combinations that could be tested, given the cost and logistics involved. The performance of the selected rootstocks will now be evaluated with new commercial scion varieties, in trial sites comprising a diversity of growing conditions across Australia. Two Vietnamese rootstocks Mat orange and Hong Nhieu orange were identified to have dwarfing effects in sweet oranges and Imperial mandarins. Therefore, the Vietnamese rootstock varieties Mat orange and Hong Nhieu orange are recommended for further testing as an interstock on Troyer citrange and *Poncirus trifoliata* rootstocks with navel and mandarin scion varieties.

Auscitrus has been licensed by agreement to handle the distribution of seeds from any rootstocks released to the Australian citrus industry.

Future research

The work of the National Citrus Rootstock Improvement Program will continue in a new project supported by Hort Innovation (CT17002, Evaluation of new rootstocks for the Australian citrus industry). Specifically, the following activities will be undertaken in these trials.

- Salt tolerant rootstock hybrids from the NSW DPI and Californian breeding programs as well as the Chinese rootstocks selected for further testing will continue to be evaluated in a demonstration trial established at Bindoon, Western Australia. The rootstocks are propagated with Houghton navel. Yield and fruit quality data will be collected for another 4 years to identify promising rootstocks with salt tolerance.
- The evaluation of Chinese rootstocks will continue in the Riverina trial for another three years.
- Commercial trials on grower's properties of the most promising Chinese rootstocks will be evaluated for the next five years.
- A high density dwarfing trial at Dareton, with M7 navel and Tang Gold mandarin scions propagated onto dwarfing rootstocks from China and the United States, will be evaluated for the next five years.

- Italian rootstock hybrids will also be evaluated at Dareton in collaboration with ANFIC (Experiment 6). This will be the first time that these rootstocks have been tested in Australia with Tang Gold, Imperial and Nectar mandarin scions.
- HLB tolerance rootstock trial will be established, once the rootstocks (US-942 and US-802) are imported from Florida, USA.

Strategies for wider industry testing of promising rootstocks

Strategies for wider industry testing of promising rootstocks from trials conducted at NSW DPI Gosford during project CT96008 were developed.

- Eighteen selected rootstocks identified in Horticulture Australia Limited projects CT317 (1993-1996) and CT96009 (1996-1999) as worthy of further investigation have been established as seed source trees at NSW DPI, Dareton. Trees have also been budded with Atwood navel and planted at NSW DPI, Dareton for further evaluation.
- Twenty-two hybrids were selected and recommended for further testing in Queensland at Bundaberg Research Station. NSW DPI's intellectual property in these rootstocks has been protected via a Material Transfer Agreement (MTA) between NSW DPI and Department of Agriculture and Fisheries (DAF) Queensland. An agreement is also currently in place for some of the Chinese citrus rootstock accessions that were transferred to Bundaberg for evaluation in 2001. Rootstock seed source trees have been established in Queensland.
- Rootstock evaluation will be undertaken for varieties that were not adequately evaluated in a previous project (South Australian Research and Development Institute (SARDI) component of CT03025). The rootstock germplasm set out in Table 26 has been collected from SARDI's Loxton Research Station, SA, for preservation. Seeds were collected and transferred to the NSW DPI, Dareton site where they were germinated and are currently growing in a glasshouse.

Table 25. Rootstock germplasm from Loxton Research Centre, Loxton, SA.

Accession Number	Parentage
58-220-2	(Rangpur × Shekwasha 54-63-24) x OP
59-24-8	(Rangpur × Swingle P. tri. 54-61-4) x OP
59-47-3	(Rangpur × Shekwasha 54-63-46) x OP
62-109-40	(Sunki × Flying Dragon P. tri.) FI
63-199-31	(Sunki × Mars P. tri.) FI
63-199-49	(Sunki × Mars P. tri.) FI

Recommendations on the mechanism to identify other sources of potentially useful rootstocks from overseas programs

It is important that rootstock evaluation is part of a co-ordinated program aimed at meeting industry (national and regional) needs; *ad hoc* approaches consume scarce resources and have limited applicability. New rootstocks identified from overseas studies as having potential should be imported and introduced into the national program. Auscitrus imports new publicly available citrus varieties under the industry funded National Citrus Repository Program (CT15005). Greater communication and coordination of the import of rootstock varieties would reduce the likelihood of multiple imports of the same material and its trueness to type could be validated avoiding, for example, the confusion experienced recently with multiple imports of Swingle citrumelo. The import and evaluation of new rootstocks requires support; it is futile identifying potentially useful

germplasm overseas unless resources are made available to assess that material under Australian conditions. Some progress has been made in identifying and interacting with the rootstock research staff overseas. For example:

Spain: Contact has been made with Dr Maria Forner from the Spanish breeding program regarding the possibility of testing two plant breeders' rights (PBR) rootstocks (Forner-Alcaide 5 and Forner-Alcaide 13) in Australian conditions under a reciprocal research agreement. The reciprocity arrangement would mean that Dr Forner would test selected Chinese rootstocks under Spanish conditions.

South Africa: Mr Wayne Parr (Variety Access, Queensland) has imported a hybrid rootstock (Minneola × *Poncirus trifoliata*) from the South African breeding program.

United States: Contact needs to be established with Dr Kim Bowman from the United States Department of Agriculture (USDA) regarding testing of the HLB tolerant rootstocks (US-942 and US-802) in Australian conditions under a reciprocal research agreement. The reciprocity arrangement would mean that Dr Bowman would test selected Chinese rootstocks under American conditions.

Refereed scientific publications

No refereed publications

References

Bevington, K. B. 1998. Citrus rootstock improvement in Australia. Breeding and Biotechnology for Fruit trees. In: Omura, M., Hayashi, T., Scott, N. S. (Eds.), *Proceedings of the 2nd Japan-Australia Workshop*. pp. 73-77.

Bevington, K. B., Castle, W. S. 1982. Development of the root system of young Valencia orange trees on Rough lemon and Carrizo citrange rootstocks. In: *Proceedings of Florida State Horticultural Society* **95**, 33-37.

Broadbent, P. 1993. Selecting disease-resistant citrus rootstocks. *Australian Journal of Experimental Agriculture* **33**, 775-780.

Castle, W. S. 1987. Citrus rootstocks. In: Rom, R. C., Carlson, R. F. (Eds.), Rootstocks for fruit crops. Wiley, New York, pp. 361-399.

El-Zeftawi, B., Sarooshi, R., Gallasch, P., Treeby, M. 1982. Factors affecting total soluble solids of oranges used for processing. Agricultural Information Series No. 9, Agdex 221/846 (Department of Agriculture, Government of Victoria). 33 pp.

Genstat. 2017. Genstat release 17, statistics software. Laws Agricultural Trust: Institute of Arable Crops Research (IACR), Rothamsted.

Hoblyn, T. N., Grubb, N. H., Ranter, A. C., Wates, B. L. 1936. Studies in biennial bearing. *Journal of Pomology Horticultural Science* **14,** 39-76.

Khurshid. T., Donovan, A. 2014. Assessing the horticultural performance of new citrus rootstocks via short-term orchard trials. Final report submitted to Horticulture Innovation Australia Limited, Project CT07002. (NSW DPI, Dareton).

Khurshid. T., Sykes, S., Smith, M., Thompson, A. 2007. National program for screening and evaluation of new citrus rootstocks. Final report submitted to Horticulture Innovation Australia Limited, Project CT03025. (NSW DPI, Dareton).

Lehmann, J. 2003. Subsoil root activity in tree-based cropping systems. *Plant and Soil* **255,** 319-331.

Magwazaa, L.S., Opara, L.S. 2015. Analytical methods for determination of sugars and sweetness of horticultural products—A review. *Scientia Horticulturae* **184**: 179-192.

Sanderson, G. 2011. Evaluation of superior processing oranges for fresh juice with selected Chinese rootstocks. Final report submitted to Horticulture Innovation Australia Limited, Project CT07006. (NSW DPI, Dareton).

Sykes, S. R. 2011. Chloride and sodium excluding capacities of citrus rootstock germplasm introduced to Australia from the People's Republic of China. *Scientia Horticulturae* **120,** 443-449.

Webber, H. 1948. Rootstocks: Their characters and reactions. The Citrus Industry Vol. 2. Page. 70-80. University of California Press, Berkeley and Los Angeles.

Intellectual property, commercialisation and confidentiality

There is no confidential material in this report.

Acknowledgements

During the course of the research a number of staff members participated in trial establishment, 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.

Research staff

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Technical staff

I am thankful to **Jane Khurshid** who has been involved in tree growth measurements, harvesting, grading and assessing fruit quality 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 five seasons. This involved organising harvest, transfer of fruit to the station packing shed, grading the fruit and dispatch to commercial packing sheds.

Troy Witte (Technical Officer, research) for assisting in operating the grading machine and his timely help throughout the project.

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

Kevin Lacey - Technical Officer, WA Agriculture, 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.

Farm staff

Thanks are extended to Doug Carmin (Lead Farm Hand) 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 16 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.

Sincere thanks to Brad Bowes and Darren Howard, who were 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.

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Administration staff

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Extension staff

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Participating Growers

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Victorian nursery Farms

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Editorial assistance

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Appendix 1

The year wise data for Navelina, Lane Late navel, Imperial mandarin and Eureka lemons is given in the representative figures 9-12.

Navelina:

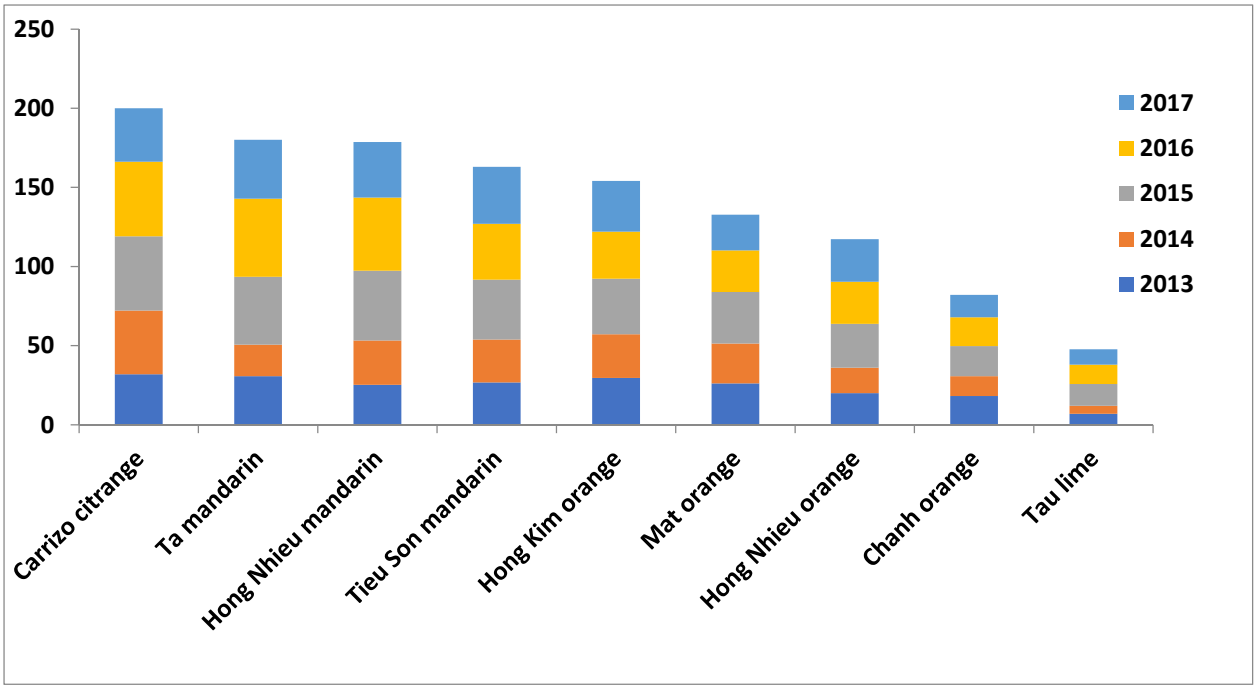

Figure 9: The effect of rootstocks on Navelina yield (kg/tree) across 5 growing seasons. The rootstocks can be compared within the years with LSD values at 5% probability. The LSD values were15.7 for 2013; NS for 2014; 16.1 for 2015; 17.9 for 2016 and 15.4 for 2017.

Lane Late:

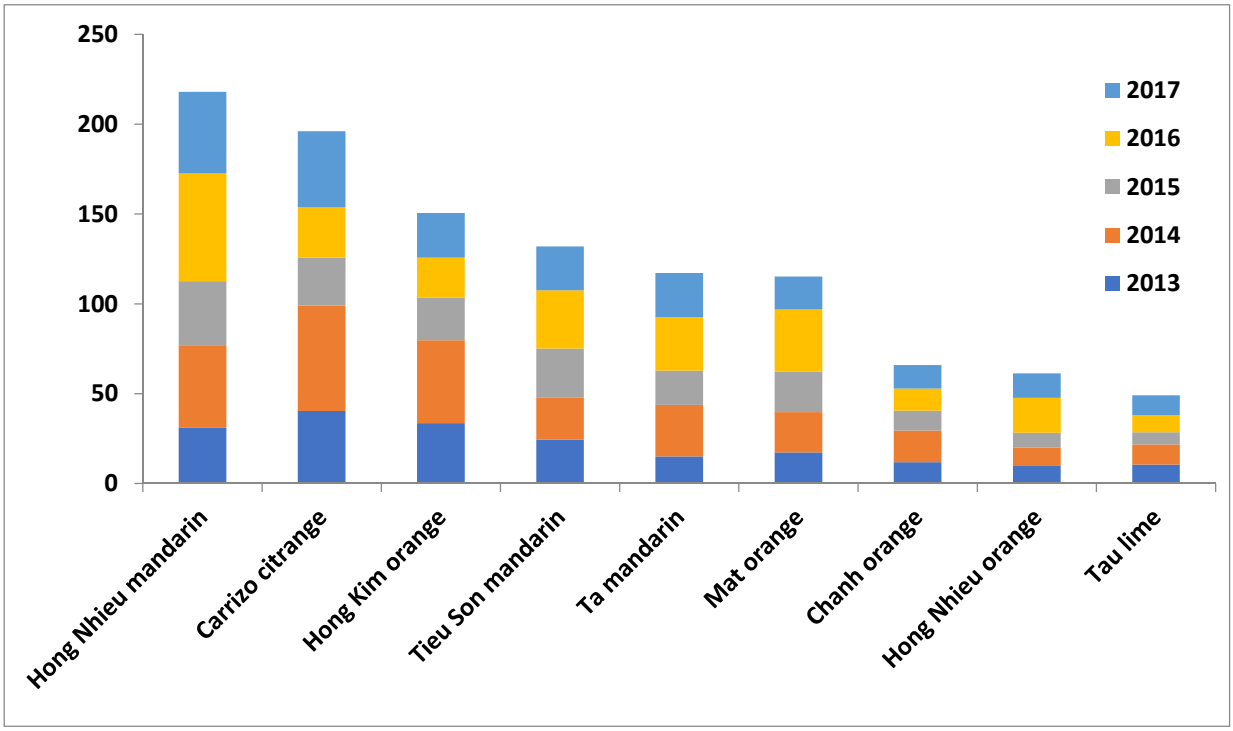

Figure 10: The effect of rootstocks on Lane Late yield (kg/tree) across 5 growing seasons. The rootstocks can be compared within the years with LSD values at 5% probability. The LSD values were16.5 for 2013; 20.2 for 2014; 18.2 for 2015; 24.9 for 2016 and 20.0 for 2017.

Imperial mandarin:

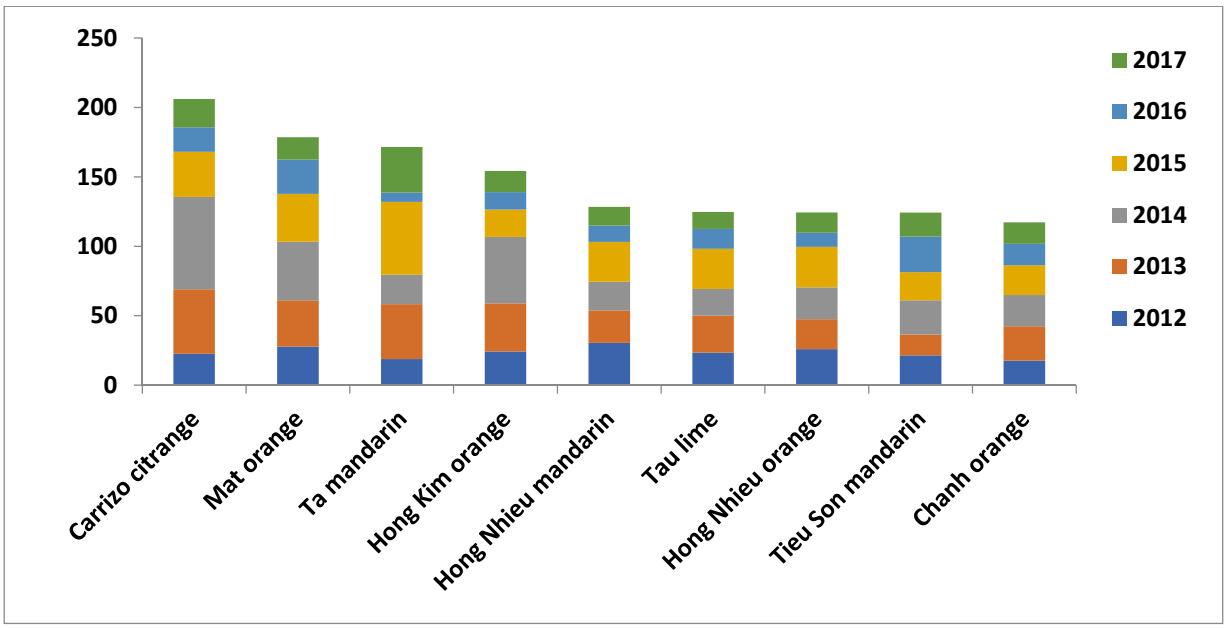

Figure 11: The effect of rootstocks on Imperial mandarin yield (kg/tree) across 5 growing seasons. The rootstocks can be compared within the years with LSD values at 5% probability. The LSD values were NS for 2012; 18.0 for 2013; 30.0 for 2014; NS for 2015; NS for 2016 and 12.6 for 2017.

Eureka lemon:

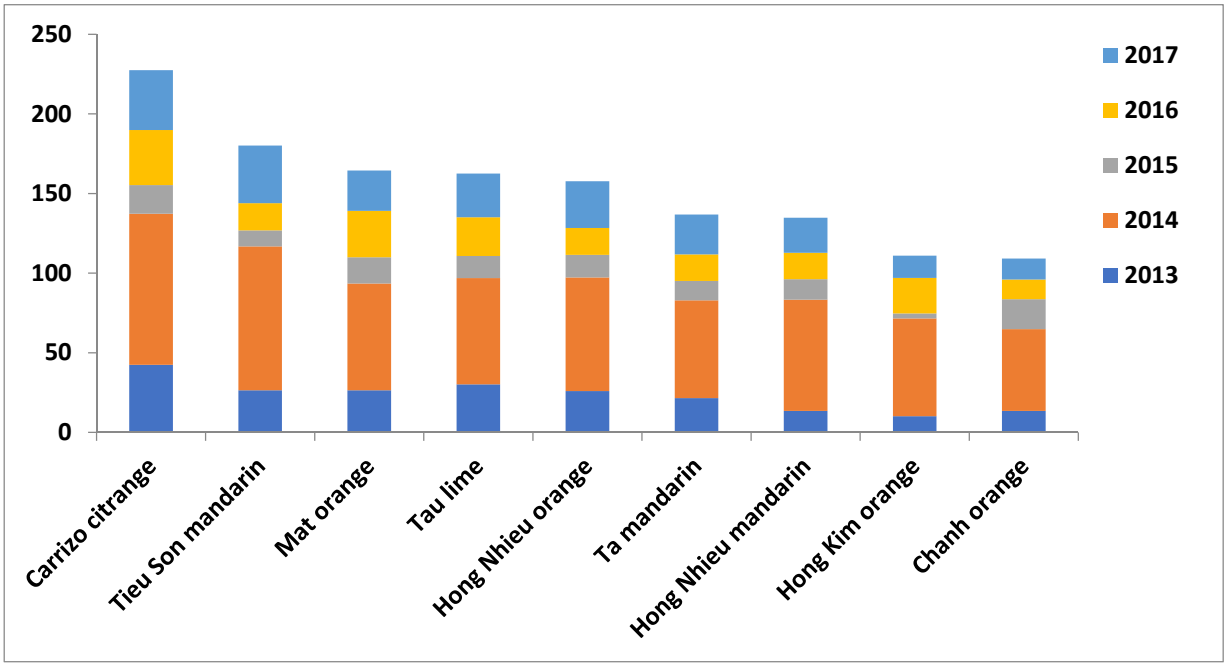

Figure 12: The effect of rootstocks on Eureka lemon yield (kg/tree) across 5 growing seasons. The rootstocks can be compared within the years with LSD values at 5% probability. The LSD values were 17.8 for 2013; NS for 2014; NS for 2015; NS for 2016 and NS for 2017.