Final Report

Tropical Stonefruit Breeding and Evaluation

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Summary

The tropical or low-chill sector of the Australian stonefruit industry produces peaches, nectarines and plums that ripen in September to November and has an annual wholesale value of $35M. The fruit is generally grown in subtropical regions. Low-chill stonefruit quality is of high importance to the wider national stonefruit industry as it sets the standard for the start of the domestic season. Consumers purchasing high quality low-chill peaches in October will continue purchasing high-chill peaches during summer. Conversely, consumers will not purchase high-chill fruit if they have bad experiences with low-chill varieties. Low-chill cultivars may have direct benefit in temperate regions as climate change reduces winter cold. Reduced insecticide availability for control of fruit fly, importation of Californian fruit and southern fruit being marketed in November are issues that have impacted on productivity and profitability. Low Chill Australia (LCA), a voluntary organization for low-chill stonefruit growers, have identified breeding as a high research priority to provide them with more profitable cultivars that ripen in October.

Controlled cross-pollination was used to combine selected parents and nearly 7,000 seed were germinated by conventional stratification and by use of embryo culture. Over 2,600 seedling trees were planted at Maroochy Research Facility (MRF), Nambour, Queensland in progeny field trials and 71 elite genotypes were selected. These were evaluated for chilling requirement, crop load, tree size and the fruit were assessed for size, colour, soluble solid content, flavour, firmness, texture, stone-freedom, skin bitterness and ripening time. The elite selections were propagated for further test at MRF and at grower trial sites. Of the 428 evaluations that were performed during the project, 64% were on peach, 33% were on nectarine and 3% were on other species including plum, apricot and interspecific hybrids.

Sixty elite peach, nectarine and plum selections were distributed for grower evaluation at 11 locations as part of the small-scale testing. The performance of these trees was evaluated at field days and at annual meetings of LCA. Results from these tests identified 11 selections of peach and nectarine that were released for large-scale evaluation resulting in 3,829 trees being planted at 13 sites. Two selections Q17-20 peach and Q32-59 nectarine have been widely planted and have part 1 Plant Breeders Rights (PBR). A further three low-chill selections ripening in the early season and with novel fruit characteristics including a flat or “peento” peach, a flat nectarine and an all-yellow peach were also protected by PBR. An all-yellow nectarine marketed as a “nectacot” remains to be PBR protected.

To increase the diversity of the breeding population we sought new sources of germplasm and have developed traits that are not common in commercial cultivars. The Mexican landrace peach ‘Nieve’ was used to develop trees with all-white fruit and altered tree architecture. Feral peaches were collected from the subtropical regions of Qld and NSW. The stony-hard flesh texture trait was introgressed from Korean germplasm and offers potential to reduce harvest costs by reducing the duration of fruit ripening.

Elite selections distributed to growers in the past four years are yet to be fully evaluated. These have been planted at 11 locations across four states and are protected by material transfer agreements. With the finish of this project, it remains for industry to complete the evaluations of commercial potential. It is likely there will be further new cultivars from these selections that will supersede those previously released by the project.

Keywords - 5-10 words

Peach; nectarine; *Prunus*; fruit breeding; genetic improvement; tree; progeny; testing; evaluation.

Introduction

The low-chill stonefruit industry is estimated in value at $35M or approx 15-20% of the national industry. The main production regions are in northern NSW and southern QLD but with production also in WA and central NSW regions. There is potential for large scale development of low and medium chill cultivars from our breeding program into warmer areas of southern Australia, such as Swan Hill and the Riverland and inland NSW and QLD regions such as Emerald. Continued climate change is seeing many of our traditional high chill regions requiring lower chill cultivars for optimum performance. If global warming predictions are correct (Henessey and Clayton Greene, 1995) then this trend will escalate.

Low-chill fruit quality is of high importance to the wider national stone fruit industry as it sets the standard for the start of the domestic stone fruit season. Consumers purchasing high quality peaches, nectarines and plums in October and November will continue purchasing during summer. Consumers will not purchase high-chill fruit if they have had bad experiences with low-chill varieties. To consumers they are all just stone fruit regardless of their production in low-chill or high-chill regions.

If global warming trends continue then low-chill stonefruit cultivars may be more widely planted in Australia. The intergovernmental Panel on Climate Change reported projected increases in global average surface temperatures of 0.80 – 2.60 C by 2050, and nighttime temperatures increasing at twice the rate of daytime maximum temperatures (Watson et al., 2001). Temperature increases of this magnitude would result in less winter chilling in many locations. Hennessy and Clayton-Greene (1995) modelled a high warming scenario of 1.5^0 – 2.0^0 C increase and found it would significantly increase the risk of inadequate chilling occurring at many temperate fruit growing regions in southern Australia. This project builds on our initial breeding work in developing new low-chill cultivars that are adapted to warmer climates.

Methodology

1. Production and evaluation of seedling populations

Hybrid seed were produced using controlled hand pollinations of selected parents. They were embryo cultured when the fruit development period of the seed parent was 80 days or less (Hamill et al, 2005). Seedlings were planted in early autumn, about five months after fruit harvest, in a fruiting nursery (Sherman et al., 1973) with mounded double-row beds at 22,000 trees per ha. Trickle irrigation was applied under plastic mulch. Trees were trained to a central leader and enclosed in netting to prevent damage by birds and bats. The trees were grown using standard commercial pest, disease and fertiliser management (Vock and Campbell, 1998).

Controlled hand cross-pollination and emasculation of peach and nectarine flowers

Tree characteristics evaluated were harvest date of first eating ripe fruit, fruit development period (FDP) in days from 50% full bloom to ripe fruit and crop load rated on a 1 (light) to 9 (heavy) scale. Chilling requirement was estimated as chill units (CU) by comparison to flowering time of known standard peach and nectarine cultivars ‘Okinawa’ (150 CU), ‘Sunred’ (250 CU), ‘Flordagold’ (350 CU) and ‘Sunlite’ (450 CU) (Sherman and Topp, 1989).

High density fruiting nursery at Nambour used for seedling progeny evaluation.

Fruit was harvested when eating ripe and rated on a 1 (least desirable) to 9 (most desirable) scale for attractiveness, amount of red blush, flavour, firmness, juiciness, amount of fuzz and stone freedom. Soluble solids were measured with a hand-held refractometer. Fruit weight was measured as the mean of 4 to10 fruit per tree

2. Performance of elites at Nambour

Each selection from the seedling population was propagated onto 'Okinawa' rootstocks in November immediately after fruit evaluation. Two trees of each new selection were planted at Maroochy Research Facility (MRF) at Nambour and these produced fruit after two to four years. Trees were evaluated for seven years using methods of Topp et al. (2012). Selections that performed well in this test were distributed for evaluation by growers.

3. Small-scale grower testing

Grower testing occurs concurrently with testing at MRS and occurs in two separate schemes, a small-scale test of one tree per selection and a large-scale test of up to 2,000 trees per selection.

Small-scale tests occurred at commercial orchard sites in Queensland and New South Wales (Topp et al., 2012). The coastal sites are all less than 50 m above sea level and have mean June temperatures ranging from 14.00C at Alstonville to 16.50C at Childers. The inland sites are elevated and have mean June temperatures as low as 11.90C at Pikes Creek. It is estimated that the warmest site, Childers, receives about 150 CU and the coldest site, Pikes Creek, about 650 CU. The growers evaluating the new material are generally members of the breeding project steering committee and provide their time voluntarily. Growers were trained in varietal evaluation to ensure uniform data collection and ratings. Grower cooperation for this testing is important in allowing wide-spread testing at low project cost over a short time. One tree of each selection was provided to the growers along with a tree of 'Tropic Beauty' peach which was used as the standard comparator. Performance of the new selections was evaluated by the growers who met annually with the breeding team to discuss which selections should progress to large-scale evaluation.

4. Large-scale testing

Large-scale field testing of elite selections generated evaluation data on which to base a general commercial release decision. Participation was available to all Australian orchardists who agree to enter the scheme. The grower was required to sign a materials transfer agreement, plant 100 to 2,000 trees of the selection, provide selection performance data and pay a testing fee. The testing fee was collected by DAF and used as a voluntary contribution which Hort Innovation matched.

5. Germplasm development

Selections with novel fruit and tree traits were developed in the breeding program using controlled cross-pollination as described in section 1 of methods. The characteristics being developed were high anthocyanin in flesh (blood peach and nectarine). absence of anthocyanin (derived from Mexican landrace germplasm), and the stony-hard and slow-melting flesh textures which are alternatives to non-melting and melting flesh textures.

To increase the diversity of our breeding germplasm, we collected feral peach budwood and seeds in subtropical regions of Queensland and New South Wales. These were propagated for future study and evaluation as potential parents.

Outputs

1. Production and evaluation of seedling populations

Nearly 7,000 seeds were prepared for germination using regular stratification and embryo culture. This resulted in field planting of 2,645 seedling trees (Table 1.1). The germination rate was highest (57%) in 2017 when no embryo culture was used. In 2017 we did not attempt to germinate seed from short fruit development period parents. Over all years the germination rate was 38%.

Embryo rescue of early ripening nectarines

Table 1.1 Numbers of seed produced by standard stratification and embryo culture and the number of seedlings established in field trials during the project.

Year pollinated	Seed number stratified in perlite	Seed number embryo cultured	Total seed number	Field planted seedlings	Year planted
2013	102	693	795	453	2014
2014	1,974	1,180	3,154	1,080	2015
2015	1,641	309	1,950	537	2016
2017	1,008	0	1,008	575	2018
Totals	4,725	2,182	6,907	2,645	

The number of seedlings selected each year ranged from 12 in 2015 to 34 in 2016 (Table 1.2). This was influenced by the size of the new population reaching maturity and by weather conditions affecting fruit set. Final selections from this population were made in the 2019 and 2020 seasons. Overall, 2.7% were selected from the original 2,645 seedling population.

Table 1.2 Numbers of seedling selected in each year of the project.

Year planted	No. planted	Year selected	No. selected	% selected
2014	453	2015	12	2.6
2015	1080	2016	34	3.1
2016	537	2017+2018	13	2.4
2018	575	2019+2020	12	2.1
Total	2645		71	2.7

The final seedling population was planted in 2018 to allow sufficient project time for the trees to commence fruiting. This seedling population was evaluated in 2019 on precocious individuals and again in 2020. Field arrangements at Nambour will allow this seedling population to be kept in 2021 until we have verified that the 12 selected individuals have been successfully propagated.

2. Performance of elites at Nambour

Elite selections from the seedling population were clonally propagated and planted at Nambour for further evaluation. A total of 428 evaluations were performed on elite selections from 2013 to 2020 (Table 2.1). Peach (64%) and nectarine (33%) were the predominant crops selected with only 3% resulting from plum, apricot, or interspecific hybrids.

Table 2.1 Number of elite evaluations categorized by crop and year of evaluation.

	No. of elite evaluations in each crop type			
Year	Peach	Nectarine	Other*	Total
2013	32	30	1	63
2014	62	24	4	90
2015	22	2	0	24
2016	52	24	6	82
2017	8	2	0	10
2018	49	21	1	71
2019	25	26	0	51
2020	25	11	1	37
	275	140	13	428

*Other includes plum, apricot and interspecific hybrids

For the peach and nectarine crops there were combinations of either yellow or white flesh and either melting or non-melting flesh texture. There were 24% melting white flesh, 18% melting yellow flesh, 15% non-melting white flesh and 38% non-melting yellow flesh. The slight emphasis on non-melting flesh types was a deliberate breeding strategy aimed at producing fruit that remained firm on the tree while developing full-ripe flavour characteristics. A few of the selections contained the stony-hard or slow-ripening flesh texture (3%) and some had red flesh (<1%). These selections are described in more detail in section 5 of germplasm development.

A visiting peach breeder, Dr Zeynep Ozdemir Eroglu, from the Ataturk Central Horticultural Research Institute in Turkey conducted a research trial at Maroochy Research Facility on the relationship among a range of phenological and agronomic characteristics in our low-chill peach breeding population. Her report is attached in Appendix 1.

The study was conducted in 2016 and 2017 and evaluated 85 genotypes with a range of the three flesh types (melting, non-melting and stony-hard). There were many interesting results from the study. Comparing melting and non-melting flesh genotypes indicated there was no significant difference in the duration of the flower period, flower bud density, duration of the harvest period, or amount of red skin blush on fruit. Non-melting flesh genotypes were significantly firmer and sweeter and smaller than melting flesh types. It is likely that the increased sweetness of the nonmelters was related to the ability to harvest fruit closer to full maturity compared to the melters. The firmer flesh of the nonmelters allows this delayed harvest without consequent loss of yield due to soft fruit damage. The non-melting flesh resulted in a shorter harvest period of8.6 weeks mean harvest duration compared to the 10.4 week mean for melters, but this difference was not statistically significant. The duration of flowering was positively correlated with harvest duration (r=0.55). Both melters and non-melters in this experiment had long flower duration (34 and 36 days respectively) and this was a major determinant of the harvest duration. Selection of trees with more compact flower duration will result in reduced harvest period. The higher firmness of non-melting flesh genotypes means that growers can harvest less frequently within the ripening period of each genotype.

The stony-hard flesh type is a trait we have recently introduced into our lowchill breeding. We introgressed this trait from the highchill Korean cultivar 'Yumyeong'. Only two selections were available at MRF for this study, and both need a further generation of breeding to improve their adaptation to the subtropics. For these reasons, the stony hard trait was not compared in this study. Both stony-hard selections flowered and ripened later than our adapted material and had longer fruit development periods. It was interesting to note that the harvest duration was less than 3 weeks for both selections. This indicated there is potential for use of stony-hard flesh type for reducing harvest duration which is an important trait in improving profitability.

3. Small-scale grower testing

Elite selections were distributed to 11 growers for small-scale testing from 2013-2020 (Table 3.1). The purpose of this testing was to allow evaluation across a wide range of industry locations. Testing occurred in New South Wales (n=3), Queensland (n=6), South Australia (n=1) and Western Australia (n=1). Details of the small-scale test locations and the partitioning of selections by test location are provided in Appendices 2 and 3, respectively.

Table 3.1. Distribution of elite selections for small-scale testing.

State	No. of growers	No. of selections
NSW	3	46
QLD	6	100
SA	1	41
WA	1	13
	11	200

A total of 60 selections of peach (n=33), nectarine (n=20) and plum (n=7) were distributed for grower test from 2013 to 2020. Multiple trees of each genotype were sent to the 11 test sites which resulted in a total of 200 genotype shipments (Table 3.1). Details of the fruit and tree characteristics are provided in Appendix 4.

Growers require a spread of white and yellow flesh peach cultivars for both peach and nectarine through the whole season. For this reason, we provided a range of elite selections that combined these flesh characteristics (Table 3.2). Of the elite peach and nectarine selections, 60% were yellow flesh, 40% were white flesh; and 45% were melting and 55% were non-melting flesh. The white flesh nectarine 'Polar Lite' is planted in large numbers and so there is an oversupply of white flesh and currently a demand for yellow flesh nectarines in the October and early November period.

Table 3.2. Classification of the small-scale test nectarine and peach selections by flesh colour and texture.

	Colour	Texture		
		Melting	Non-melting	
NECTARINE	White	5	4	9
	Yellow	3	8	11
PEACH	White	10	2	12
	Yellow	6	15	21
TOTAL		24	29	53

Feedback from growers was combined with performance data at Nambour to determine selections for the next stage of testing, the large-scale test.

Field day in 2015, with growers from Qld, NSW and WA inspecting the low-chill breeding plots at Nambour.

4. Large-scale grower testing

A total of 3,829 trees were tested in the large-scale evaluation program from 2014-2020. The 11 selections were tested by 13 growers in Queensland (n=3) and New South Wales (n=10). Details of the large-scale testing locations are provided in Appendix 5. Release of 11 selections for large-scale testing exceeds the minimum of six selections originally planned for the project.

The 11 selections of peach and nectarine combined the flesh characteristics of white or yellow, melting or non-melting texture and acidity ranging from low to moderate (Table 4.1). The chilling requirement varied from 100 chill units for Q32-59 nectarine to 400 chill units for GB566-15 nectarine. Images and grower comments on these selections are provided in Appendix 6.

Table 4.1. Summary description of elite selections planted in large-scale testing 2014-2020

Clone	Crop	Flesh colour	Flesh texture	Flesh acidity	Chill (CU)	Remarks
32059	N	Y	M	M	100	early and large; uneven crops; requires 'Retain'
58070	N	Y	NM	M	150	early but after 'White Satin'
68064	P	Y	M	M	225	performs well at Atherton tablelands
113021	P	Y	M	L	150	Early, attractive; only medium size, requires 'Retain'
131051	P	W	M	H	250	early but develops tip that softens
135015	N	Y	NM	L	200	very clean skin finish; high eating quality
217002	P	Y	NM	L	200	Large and attractive but too late in season
221053	P	W	M	L	250	early and good eating but small
223020	N	W/R	NM	M	150	very attractive and eats well but too late
223045	N	W	NM	M	150	very attractive and eats well but too late
GB566015	N	Y	NM	L	400	attractive fruit; high quality; for medium chill regions

Crop N-nectarine, P-peach; Flesh colour W-white, Y-yellow; Flesh texture M-melting, NM-non-melting; Flesh acidity L-low, M-moderate, H-high; Chilling requirement of tree estimated in CU-chill units

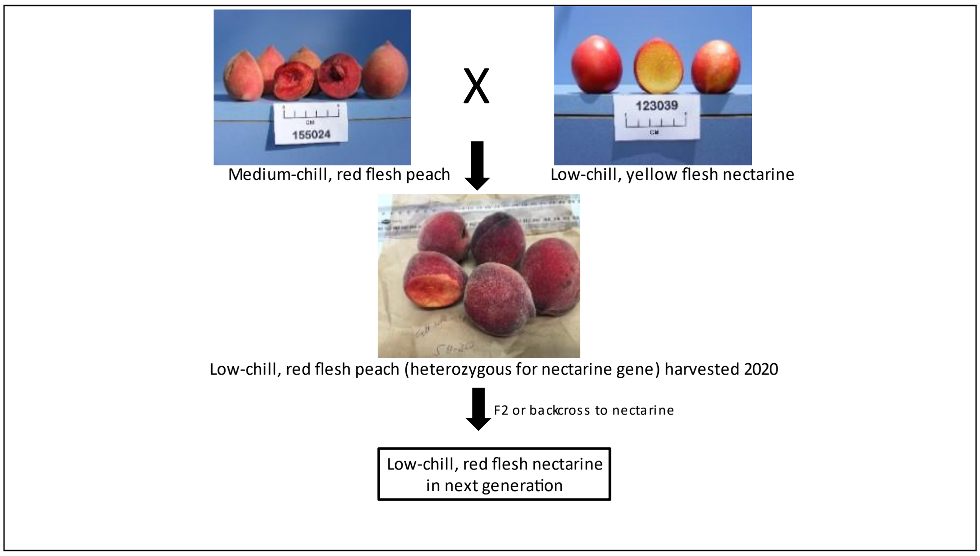
Elite selections were also tested by Rusticas del Guadalquivir of the Royal fruit company (https://royal.es/es/produccion/seleccion.html) in Seville under a materials transfer agreement. The annual payments from Royal were used as voluntary contributions that assisted in funding the project. Evaluations at the Rusticas test orchards provided information on performance under Mediterranean cool winter and hot dry summer environments. Evaluations from Royal were compared to those from Nambour for six elite selections (Appendix 7). None of our low-chill selections have been planted commercially by Rusticas but several are performing at a commercially acceptable standard. The top performers in Spain based on a selection index of all traits from 2017-2020 were Q316-2, Q315-77, Q315-73, and Q315-9 (see Appendix 4 for descriptions). It is interesting to note that one of these selections, Q315-9 peach, was rated with potential in South Australia where it ripened in mid-November. At Gatton, the peach Q315-77 was rated as one of the best in recent small-scale test. It would be useful to have growers evaluate all four selections in large-scale test.

5. Germplasm development

A small portion of this project was devoted to developing germplasm which may assist industry in responding to changing market and farm requirements. The novel fruits developed in previous breeding (see SF07003 final report) are being commercialized by the Qld Department of Agriculture and Fisheries and Mr Ross Stuhmcke. The flat peach Q73-50, the all-yellow peach Q74-30, the "nectacot" Q74-69 and the flat nectarine Q108-65 are all being test marketed and showing promise. Plant Breeders Rights (part 1) was obtained for three of these selections in 2018. Descriptions of these three selections are provided in Appendix 8. The "nectacot", an all-yellow, non-melting flesh nectarine coded Q74-69 should also be considered for PBR protection. The "nectacot" name has been trademarked by Mr Ross Stuhmcke and this may influence protection decisions.

Some selections have been developed during the current project but have not been released for either small or large-scale testing. These are from recently created seedling populations that have only been observed to fruit in the past year or are building blocks that can be used for further breeding. These include the following:

Q503-33 nectarine is a selection with slow-melting flesh which allows the fruit to stay firm and yet still develop a melting texture. It ripens from mid-late October at Nambour and produces fruit with yellow, firm flesh and a sub-acid flavour. Trees were distributed to growers in 2020 and should be monitored for field performance.



Q511-20 is a blood-flesh peach that first fruited in 2016 and has been propagated at Nambour. It requires 150 chill units to break dormancy and so is well adapted to low-chill regions. However, it requires further breeding to increase the flesh firmness and reduce the prominent tip.

Q253-7 is an interspecific hybrid that is 75% plum and 25% apricot. This required four generations of breeding and has resulted in an attractive, small (34g), dapple skin coloured fruit with firm, sweet (tss=16%) flesh. It requires 350 chill units to break dormancy and so is suited to medium chill regions. It should be sent for grower test but would benefit from another generation of breeding to improve fruit size.

Nieve' is a landrace Mexican peach which has the desirable fruit traits of high flesh sugar, firm non-melting flesh and an all-white appearance. These traits would be useful in our breeding to produce visually distinctive fruit that consumers could associate with a pleasant, sweet flavour. We imported 'Nieve' seed from Mexico and used two elite seedling selections as parents. We selected pollen parents that were very low-chill and had short fruit development periods; both traits lacking in the 'Nieve' OP elites. We evaluated a hybrid seedling population in 2015 and selected two elite genotypes. These selections were propagated and used to create an F2 population by selfing. Q410-57 peach is a selection that was derived from this 'Nieve' population. It carries a recessive allele of a constitutively expressed gene that blocks anthocyanin production. Homozygous individuals show no red pigmentation in leaves, flowers, bark, or fruit. A full description and pictures of 'Nieve' and its off-spring are provided in Appendix 9.

Peaches grow wild in Australia along roadsides, creek-beds and at sites of human habitation. Some of these feral peaches may be derived from seed imported by Chinese goldminers in the 1800s and may provide a unique source of germplasm for future breeding The field collection for the feral peach study in cooperation with the University of Florida was completed in 2016. Over 47 feral accessions were collected from Coraki, NSW to Rockhampton, Qld. The accessions have been propagated at Applethorpe Research Facility. When funding is available, it is planned to extract DNA and compare the genetic diversity of these Australian feral peach populations with modern cultivars. There may be genes available in this feral germplasm that have not been captured in modern cultivars and no longer exist in China. We will advertise this research as a student project.

Q313-28 peach has the stony-hard flesh texture which provides very firm flesh with the freestone characteristic. It produces a heavy crop of large fruit but has a prominent tip and ripens in early November and so is not commercially viable. Further breeding is required to shorten the fruit development period and remove the tip.

Q314-30 peach produced its first crop on a budded tree in 2015. It is a low-chill selection that requires only 150 chill units each winter to break dormancy. At Nambour, it produces fruit that are very attractive with a bright red blush covering 80% of the skin; the flesh is white, melting, firm and juicy and has a low-acid pleasing flavour and high sugar content (16% soluble solids content). This selection is now in small-scale grower evaluation. It was reported in South Australia to have potential and to ripen at the start of December with fruit of 68mm diameter, 12% SSC, good appearance, and good flavour.

Outcomes

1. Production and evaluation of seedling populations

The target of producing 2,000 seedlings during the project was exceeded by over 30% despite significant reduction in budget. Maroochy Research Station was an excellent location for the primary screening of seedling populations. It received about 150 chill units each winter which allows selection for adaptation to the current subtropical breeding locations. The insect-proof netting at MRF allowed peach production without fruit-fly sprays and thus allowed harvesting without withholding periods.

2. Performance of elites at Nambour

A phenological study of the elite selections at MRF illustrated the importance of gummosis control in the subtropics. High levels of gummosis were associated with increased duration of flowering and off-season flowering that reduced yield. Non-melting flesh has been used in this breeding program to increase fruit firmness and allow harvest at close to physiological maturity. The study found that non-melting flesh selections were firmer and sweeter than melting types; they also had smaller fruit indicating that further breeding is required to consolidate this trait.

3. Small-scale grower testing

The small-scale grower testing has allowed wide-spread testing of our elite selections at low project cost. Growers have met at orchards during the season to view the new selections and discuss their commercial potential. The annual meeting of Low Chill Australia has provided another forum where variety performance has been compared from different locations.

4. Large-scale grower testing

There has been wide uptake of two releases from the breeding project. Q17-20 peach and Q32-59 nectarine (unofficially named as 'QFire' by growers). These are trees with a low-chilling requirement that allows production in the subtropics. Their fruit is sold in October when prices are high on the Australian market. This is the time when importation of Californian fruit has ceased and production from southern Australian temperate regions has not commenced.

Q17-20 peach packed for distribution to market.

The novel fruits developed in the previous project are being commercialized but have not been widely planted. Three promising varieties have obtained part 1 Plant Breeders Rights.

Q73-50 flat or "peento" peach packaged in clam shells

The novel peach cultivar Q73-50 is being successfully marketed by our commercial partner Blackboy Ridge. Q73-50 is a low-chill peach variety that produces distinctively flat shaped or "peento" fruit which are being well received in the market. The fruit have white, non-melting, firm flesh with a balance of sugar and acid and good flavour. Currently 1,000 trees are in commercial production at Gatton. The fruit are sold in 300g punnets (see Figure 1).

Nearly 4,000 trees of 11 elite selections were distributed for large-scale testing. Feedback from these tests will determine the economic viability of obtaining Plant Breeders Rights protection. In the previous SF07003 project we distributed over 21,000 trees in large-scale test. The reduction in number in part reflects the decline in the number of low-chill growers. Low-chill orcharding in high fruit-fly regions such as coastal southern Qld and northern NSW has become more difficult since the removal of fenthion (previously used as a cover spray for fruit fly control). The marketing window has also been compacted with the importation of Californian fruit during winter and spring and the earlier production from southern Australian regions. Now October is the clear month of profit for low-chill growers.

5. Germplasm development

This project successfully obtained new and potentially useful sources of peach germplasm from Mexico and feral trees in Australia. Increasing the diversity of germplasm should be a major goal of all peach breeders given the very narrow base currently in modern cultivars. This is a major reason why all the peaches and nectarines in our supermarkets look and taste similar. Breeding for the novel fruit types we have released for commercialization and with the different flesh textures such as stony hard offer routes of providing consumers with improved eating experiences.

Monitoring and evaluation

This project commenced prior to the development of the Hort Innovation monitoring and evaluation schedule requirements. Instead, we monitored the project through direction obtained by a project steering committee formed of Low Chill Australia (LCA) members. The LCA committee met regularly during the project and concluded each year with an Annual General Meeting in December at which time the performance of new selections was reviewed by growers and researchers. Extension activities for the project are listed in the following sections.

Scientific journal articles

Russell, D., Bignell, G., Neal, J., & Topp, B. (2015). Testing low chill peaches and nectarines in subtropical and temperate Queensland, Australia. *Acta Horticulturae, 1084*, 357-360.

Topp, B., Perez, S., Krolow, D., Correa, E., Russell, D., & Neal, J. (2015). Use of the Mexican peach 'Nieve' for breeding new cultivars in Australia. *Acta Horticulturae, 1084*, 119-123.

Industry publications

Nectacots show great potential in Australia. Fresh Plaza 12 Jan 2014

(http://www.freshplaza.com/article/131902/Nectacots-shows-great-potential-in-AU)

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Conferences

8th International Peach Symposium, June 2013. Oral presentation titled "Use of the Mexican peach 'Nieve' for breeding new cultivars in Australia".

Meetings and workshops

Field day to exhibit new selections was conducted at Bangalow, NSW on 17 October 2014.

An update on the breeding program provided to growers at the Annual General Meeting of Low Chill Australia on 16 December 2014.

On 19th March 2015, Professor Jian Quan, the Director of Peach Germplasm and Breeding at the Institute of Pomology and Forestry, Beijing Academy of Agriculture and Forestry Sciences, visited MRF. He was accompanied by Mr Zuo Ligang, the General Manager of the Beijing Chia Tai Fruit Industry Company Ltd, and representatives of Sinogreen Biological Technology Company, Mr Stephon Sexton and Ms Linda Gao. We held discussions on peach breeding and the future use of Australian and Chinese peach cultivars.

Seminar on breeding at University of Queensland, St Lucia, 23 June 2015.

Grower field day on the breeding project at Maroochy Research Facility hosting growers from the Perth Hills Orchard Improvement group as well as local east coast growers; 29 July 2015.

Grower evaluation of new selections field day at Coopers Shoot test site; 20 October 2015.

Commercial visit of Mr Jean Clement Marcaillou, Director of Research for Royal Fruit Company Spain (Royal have a testing agreement with DAF); 3-5 November 2015. Mr Marcaillou evaluated our new material at MRF and at grower test sites and expressed Royal's desire to continue our collaboration.

Presentation on breeding project at Low Chill Australia annual general meeting, 11 December 2015.

Field evaluation of new selections for growers at Coopers Shoot on 7 October 2016.

Provided email and teleconference advise to Summerfruit Australia Manager John Moore on taxonomic classification of Prunus.

Low Chill Australia and project steering meetings were held at the Rocklea markets on 18 July 2016 and by phone on 21 September and 29 November 2016.

A report on the breeding project was presented to growers at the LCA annual general meeting at Bangalow on 7 December 2016.

Update on breeding project to LCA executive via teleconference on 8th August 2017.

An international presentation of our stonefruit breeding program was made on 10th October 2017 to the Fruit Crops Department of the Liaoning Academy of Agricultural Sciences at Shenyang, China. Dr Topp was invited as an expert by the Chinese Government who paid all expenses for the travel.

Presentation on lowchill stonefruit breeding to LCA annual general meeting at Bangalow, NSW on 13th December 2017.

Presentation on the stonefruit breeding project was made to scientists from the Chinese Academy of Tropical Agricultural Sciences at the Maroochy Research Facility on 18th December 2017.

A summary report on the performance of promising selections was presented to the Low Chill Australia annual general meeting held at the Brisbane Fruit Markets on 22 November 2018

Report to annual general meeting of LCA, December 2019.

Report to annual general meeting of LCA, December 2020.

Recommendations

New cultivars should target early ripening, compact harvesting, and small tree size.

The low-chill industry has the month of October as its target production season. The industry requires reduced production costs to maintain profitability. From a genetic perspective, this can be achieved by developing early ripening cultivars with more compact harvest seasons and with reduced tree size. The combination of early ripening to meet the October harvest window, compacted ripening to reduce the number of harvests and smaller trees to reduce pruning and picking costs will deliver increased profits for growers.

Many of our selections, released during this project for small-scale test, contain the non-melting flesh trait which reduces the harvest season. The stony-hard flesh and slow-melting flesh types should also be used to reduce harvesting costs and improve consumer experience through delivery of more mature fruit.

IP management of elite selections currently on grower test

The elite selections that are currently on small- and large-scale grower test are protected by material transfer agreements. Many of these selections are less than four years-old and so their commercial potential is yet to be determined. It is likely that some of these selections will be identified by the grower testers as being of use in their region. The IP manager for this project is DAF. Their responsibility will be to monitor these MTAs and to respond to industry requests for expansion in the use of material currently on test.

Propagate recent elite selections for grower test

The most recent elite genotypes that have been selected in the primary seedling progeny trials in 2019-2020 have not been distributed for regional grower testing. These should be propagated and distributed before the seedling trials are removed from the Maroochy Research Facility. It will be important to distribute these elites to high-chill as well as subtropical regions. The high-chill, temperate regions are seeking early ripening cultivars and global warming is reducing the amount of chilling they receive each winter. Our low-chill selections can offer solutions for both these problems. Generally, orchard sizes are larger in temperate than in subtropical regions and thus uptake of cultivars from this project is likely to be in larger numbers if they find a niche in temperate regions.

Send recent elite selections for test in Spain

Our overseas partner, Rusticas, has provided important financial voluntary contribution to the project and excellent feedback on performance of selections in Spain. The most recent selections should be sent to Rusticas for evaluation at their trial sites to allow determination of their potential for commercial use in their operation. The possibility of future collaboration with Rusticas should also be explored.

Protection of novel fruit cultivars

Three of the novel fruit cultivars, being commercialized by Blackboy Ridge Pty Ltd, have been identified as having commercial utility and have been protected by Plant Breeders Rights (part 1). The sales of trees should be monitored by DAF to determine if part 2 of PBR should be completed. A fourth elite, Q74-69 which is a “nectacot”, may also require PBR protection in future. Additionally, the potential for retail sale of these novel cultivars should be explored. The flat nectarine, Q108-65 has been PBR protected and is being sold via the Australian Nurseries Fruit Improvement Company (ANFIC) for home-garden use. Similar demand may exist for the other novel cultivars.

Low-chill peaches for protected cropping

There has been expansion and increased interest in protected cropping of horticultural crops. Hort Innovation, QAAFI, DAF and others are increasing their investment in research in this area. Lower chilling requirement would be a pre-requisite for stonefruit to be grown in this system of management. In Japan and China, there is breeding for low-chill cultivars exclusively for this purpose. The low-chill cultivars developed in this project should be tested by DAF, QAAFI and others in future research in protected cropping.

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Intellectual property, commercialisation and confidentiality

This project commenced prior to the development of the Hort Innovation Technology Exploitation Plan template. A draft plan was written in 2019 and was delivered to Hort Innovation in milestone 112. A second version of the plan has been sent to QAAFI and DAF for signature.

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Appendices

Appendix 1. Evaluation of relationship of phenological and agronomic characteristics in a low-chill peach breeding population

The Evaluation of the Relationship between Phenological and Agronomical Characters in the Low-Chill Peach Breeding Population

Zeynep Ozdemir Eroglu[1], Bruce Topp[2] , Edward Howell[2]

Abstract

Breeding efforts to develop low chill peach varieties are increasing to expand peach growing into mild-climate regions and to benefit from high market prices as well as to avoid from the effect of global climate change. In the present study, phenological and agronomical characters of 8 commercial cultivars and 77 experimental genotypes were evaluated to determine the relationships between these characters. Significant differences for flowering and harvesting duration among the genotypes were observed. The flowering duration varied from 5 to 69 days for genotypes with the majority of the genotypes flowering for longer than 4 weeks. Flowering duration correlated positively with fungal gummosis, tree age and harvest duration. On the other hand, flower bud density was not found to be associated with gummosis or tree age. The difference in mean fruit weight, blush, fruit firmness and soluble solids content (SSC) of the genotypes according to the flesh colour (white or yellow) were not significant statistically. The influence of flesh texture (melting or non-melting) on flowering and harvest duration, bud density and blush were not seen, however, fruit weight, firmness and SSC were effected significantly by flesh texture.

Introduction

Controlled peach breeding, which began in the late nineteenth century, provided considerable progress in improving fruit quality traits, such as fruit size, blush, better background colour, and increased flesh/pit ratio, etc. (Sansavini et al., 2006; Bassi and Monet, 2008; Hancock et al., 2008). The harvesting schedule has been extended from 2-3 months up to 4-5 months and the chilling requirement has been gradually reduced to allow further expansion to subtropical climate regions (Byrne, 2002; Sansavini et al., 2006). Worldwide peach breeding efforts have provided many options for growers to grow the varieties which harvested over a long period of time, adapted to a wide range of ecological conditions and fulfilled consumer demands. However, there are still important requirements and they are thought to be even more critical over time. Changes in biotic and abiotic stress factors are also taking place due to climate change that began to be felt more and more in every region of the world over the years. In addition, global marketing opportunities, changes in eating habits of people in different societies, increasing demand for organic products particularly in developed countries, changes in some strains of disease and pest, to be identified of high-priority new targets by breeders is require.

The chilling requirement refers to the period of cold required to provide normal growth for vegetative and flower buds in fruit trees during winter. It is measured by several models e.g. the Chilling Hours Model as in hour below 7.2 ^{o}C (Weinberger, 1950), the Utah Model as in chill units (CU) (Richardson et al., 1974) and the Dynamic Model as in

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chill portions (Fishman et al., 1987; Erez et al., 1988). However the former two models developed under temperate zone conditions have not been accurate under warm climate. Positive Chill Units modified the Utah model and the Dynamic Model have given better results in chilling estimates in warm temperate and sub-tropical climates (Linsley-Noakes et al., 1995; Dennis, 2003; Perez et al., 2008). Furthermore, Sharpe et al. (1990) reported that to determine peach/nectarine varieties well adapted to Florida should take into account mean temperature of the coldest months [(mean daily maximum + mean daily minimum)/2]. Breeding programs are being carried out to develop varieties with particularly low chill (50-400 CU) to expand peach growing regions into sub-tropical areas to benefit from high market prices. The main aims of these programs are to develop cultivars with short fruit development period (FDP), to increase the density of the flower buds, to improve the quality of the fruits, and resistance some diseases and pests. Peach breeding in this area is heavily concentrated in countries such as the USA, Brazil, Mexico, Australia, Taiwan and Thailand (Byrne, 2003; Topp et al., 2008).

Uniform flowering in peach is an important agronomic trait in low-chill peach breeding as well as flowering time since it may influence the length of harvest duration. In peach, the fruits of even the most uniform flowering genotypes can ripe at different times because they will be exposed to the sunlight at different ratios. However, this difference is quite large in non-uniform blooming. Therefore, it is important to select the uniform flowering genotypes.

In order to minimize multiple harvests, the breeders may wish to develop varieties with compact flowering period and that will resist fruit abscission on the tree after ripening. Some efforts have been made to obtain genotypes with different fruit flesh texture that resist rapid fruit deterioration on the tree, and suit harvest and post-harvest handling and transport.

As mentioned above, to develop the varieties with different flesh textures is one of the purposes of many peach breeding programs. Peaches can be divided two major phenotypes into melting flesh (M) and non-melting flesh (NM) according to fruit softening behaviour. The vast majority of table peaches are in the M structure, showing a significant softening in the last stage of fruit development. Varieties vary in softening rate and are grouped as soft, medium and hard. The varieties in the hard group show a very slow softening and longer shelf life. (Haji et al., 2005; Bassi and Monet, 2008). Varieties in the NM phenotype have a hard texture at full ripening stage and slowly soften when they mature, but they do not show a state like those in the melting state and are usually used for processing. The melting and non-melting character are controlled by a single gene and the M flesh texture is dominant to the NM (Sherman et al., 1990; Scorza and Okie, 1991; Haji et al., 2001; Haji et al., 2005; Bassi and Monet, 2008). Another phenotype that has been identified in recent years for flesh texture is the "stony-hard" (SH) type, which is very hard. Varieties with this type of flesh may be white or yellow flesh, and be M or NM,. However, these types differ from NM types because there is virtually no ethylene production. This trait is controlled by the recessive gene called Hd. The SH character is linked to the character of the clingstone (Haji et al., 2005; Bassi and Monet, 2008).

Despite the high cost of fruit thinning, high flower density is desired by breeders to secure some crops after frost damage. In warm-climate areas, however, this is not be necessary, because late spring frost never occurs or occurs rarely. It may be better to select or develop genotypes with moderate flower bud density for these areas to avoid high labour costs of fruit thinning.

In many low-chill peach breeding programs, another objective is to develop of genotypes with short FDP. These genotypes are especially important for low-chill regions to benefit from high market prices for early-season fruit. However, many undesirable properties in peaches such as clingstone, inadequate blush, small fruit size, less firmness and low flavour are linked with short FDP.

The quality of the fruit as well as the main objective in the breeding programs is absolutely necessary. For example, a cultivar with resistant to any given disease will not increase its demand and also fruit quality are required to be high. In this respect, fruit shape, size, colour, firmness, SSC, taste and aroma are the important fruit quality traits which have a big impact on consumers purchasing decision (Fideghelli et al., 1998; Byrne, 2002; Dosba, 2003; Sherman and Beckman, 2003; Byrne, 2005).

Majority of commercial cultivars have round or elongated fruit shape. The cultivars with flat (saucer) shape that is dominant over round/elongated have attracted attention in last decade. Fruit shape can be effected by temperature, especially, in terms of stylar tip and suture bulb (Topp and Sherman, 1989; Wert et al., 2007). Protruding tip and/or deep suture cavity for round/elongated fruit shape and, any cracking on stylar tip and deep cavity for flat shape are undesirable traits by both breeders and consumers.

Average fruit weight ranges from 80 to 680 g, while fruits of early varieties usually have 80 to 110 g. It has been accepted as 180-230 g in commercial standards, depending on the fruit development period, for medium and late varieties (Bassi and Monet, 2008). Fruit weight are controlled by more than one gene and its heritability are low (Sansavini et al., 2006). In addition, genotype x environmental interactions are generally effective, because, it is associated with quantitative inheritance (Quilot et al., 2002).

The red over skin colour (blush) in fresh market peach varieties is a very important quality attribute, influencing notably preference of consumer (Yue et al., 2014). The formation of blush is transferred quantitatively or qualitatively to the generations. The quantitative character is influenced by light, whereas qualitative character only appears in the epidermis and is not affected by environmental conditions (Beckman and Sherman, 2003, Bassi and Monet, 2008). Findings from a research on consumer preferences showed that varieties with a content of SSC below 10% are generally not demanded. However, to develop the early varieties with high SSC content is difficult due to the negative correlation between fruit size, early ripening and SSC, while for mid and late-season, it can be relatively easy (Byrne, 2003).

The fungus *Botryosphaeria dothidea*, which causes peach tree gummosis was first appeared in Georgia in 1960 (Weaver, 1974) and then observed in the southern US, eastern China, Taiwan, Japan and Australia. Disease symptoms are associated with lenticels, and gum formation on trunks, scaffold limbs and branches and shoots dieback. Little is known about this disease and cultural measures such as removal of dead trees and infected shoots are recommended for control of the disease. An effective fungicide application has not yet been found. Although a few genotypes have a high resistance, most of peach cultivars appear very susceptible (Ko and Sun, 1992; Byrne, et al., 2000; Beckman et al., 2003; Adaskaveg et al., 2008; Wang et al., 2011)

The purpose of the present study was to determine the relationship between flesh texture, and some agronomic and phenological characters in the low-chill peach population. Also, to select the best genotypes with compact flowering and harvest duration, and good fruit traits for a future breeding program was objected.

Materials and Methods

The trial was carried out at an experimental orchard in Nambour, Queensland, AU (lat.26° 37' S, long.152° 57'), in 2016. Weather data were obtained from Nambour Daff – Hillside (station 040988) http://www.bom.gov.au/climate (Table 1). Phenological, agronomical and fruit characters were evaluated for 85 genotypes (8 standard cultivars and 77 advanced selections) which 8 out of 85 had flat fruit shape. Tree age of genotypes was between 2 and 10 years and they were planted 1.5 x 4 m in spaces as two trees for each genotypes. The estimated chilling requirement of genotypes varied from 100 to 400 CU.

First, 50% and last blooming, and harvesting dates were recorded for each genotypes when 5%, 50% and the last few flower buds were opened and when fruit ground skin colour turned from green-yellow to yellow in the firm-ripe stage, respectively. The data of blooming were also recorded in the following year (2017).

Flower bud density was determined following two way: a) Early winter in 2016, it was subjectively determined on whole tree and scored a scale from 1 to 9 (1= least and 9= most). b) The density was detected before flowers opened when it was easy to recognize flower buds from vegetative buds on one year-old shoots from around the canopy at the beginning of April in 2017. Shoot length, number of nodes, and number of flower buds were determined as six shoots for each genotype. Bud density (flower buds/node and flower buds/cm) and internode length (length/nodes) were calculated (Okie and Werner, 1996).

The fruit development period (FDP) was calculated as the number of day between 50% blooming and first harvest date.

For evaluation of fruit quality characteristics randomized 10 fruit sample per genotype were selected. The agronomic characteristics such as peach or nectarine, white or yellow flesh and melting or non-melting were recorded for each genotype. The fruit characteristics of size, skin blush, fuzz density, firmness, soluble solids content (SSC) and attractive were evaluated as follows. Skin blush was visually evaluated and scored as the percentage of red skin colour. Fruit attractiveness was scored from 1 (least) to 5 (most). Fruit size as average fruit weight was measured in grams. SSC was measured with a digital hand refractometer and data given as percent (%). Flesh firmness was measured by removing a 1 cm in diameter piece of skin on the opposite cheeks of each fruit and then using a penetrometer fitted with an 8 mm diameter probe and expressed in $kg.cm^{-2}$. Density of pubescence were determined based on 0-5 scale (0: none-nectarine, 1: very sparse, 2: sparse, 3: medium, 4: dense and 5: very dense).

Rating of fungal gummosis was evaluated according to the following scale of 0-5 (Beckman et al., 2003).

0. No gum or lesions
1. 1-2 gum sites on trunk/scaffolds
2. 3-10 gum sites on trunk/scaffolds
3. 11-25 gum sites on trunk/scaffolds
4. 26-50 gum sites on trunk/scaffolds
5. >50 gum sites on trunk/scaffold

Data analysis

The statistical analyses were performed using SPSS 10.0 for Windows (Chicago, IL). Correlation between traits to reveal possible associations was calculated using Pearson correlation coefficient at p = 0.05 and p = 0.01. The relationship between some characters and fruit type, flesh texture and flesh colour were compared by Independent Samples Test.

Table 1. Average monthly min and max temperature in the 2016 and the 2017 of months given for Nambour. Data from Nambour Daff – Hillside (station 040988) http://www.bom.gov.au/climate

Year	Dec 2016		Jan 2017		Feb 2017		Mar 2017		Apr 2017		May 2017		Jun 2016		Jul 2016		Aug 2016	
Mean (°C)	19.7	30.3	21.6	31.0	20.7	31.3	20.6	29.0	16.3	26.0	14.9	24.4	12.2	21.5	11.1	22.3	11.5	22.8
Min	15.6	25.4	17.1	25.9	18.8	27.5	16	26	11.5	22.6	10.8	19.9	3.9	18.1	6.0	16.4	7.0	19.3
Max	23.6	35.6	26.0	36.6	23.9	39.6	24	34	19.6	30.6	18.1	27.9	18.1	28.6	19.4	30.0	19.1	26.7
Rain (mm)	79.5		89.0		70.1		385.9		26.6		68.0		288.0		40.2		39.0	

Results

Blooming of genotypes occurred an extended period from early June to mid-September and the significant differences were observed among genotypes for the beginning-50%-end of the blooming (Figure 1). There were approximately 2.5 months between the initial flowering dates of the earliest and the latest blooming genotypes. The flowering duration varied from 5 days to 69 days for genotypes and this duration for the majority of the genotypes (app. 65%) lasted longer than 4 weeks (Fig 1). In addition, some blooming of many genotypes occurred in April and May. However, the comprehensive flowering status was not recorded for the mentioned months of 2016. In 2017, early flowering (autumn flowering) was more severity than the previous year. In the third week of April, the flowering rate was between 0% and 40%, and this rate for 39% of the genotypes was 5% or more. The number of genotypes that bloomed over 5% in the first week of May was 58% and a flowering rate for some genotypes was as high as 90%. Flowering duration was not effected due to peach or nectarine of fruit type (Table 2) and melting or non-melting of flesh texture (Table 3).

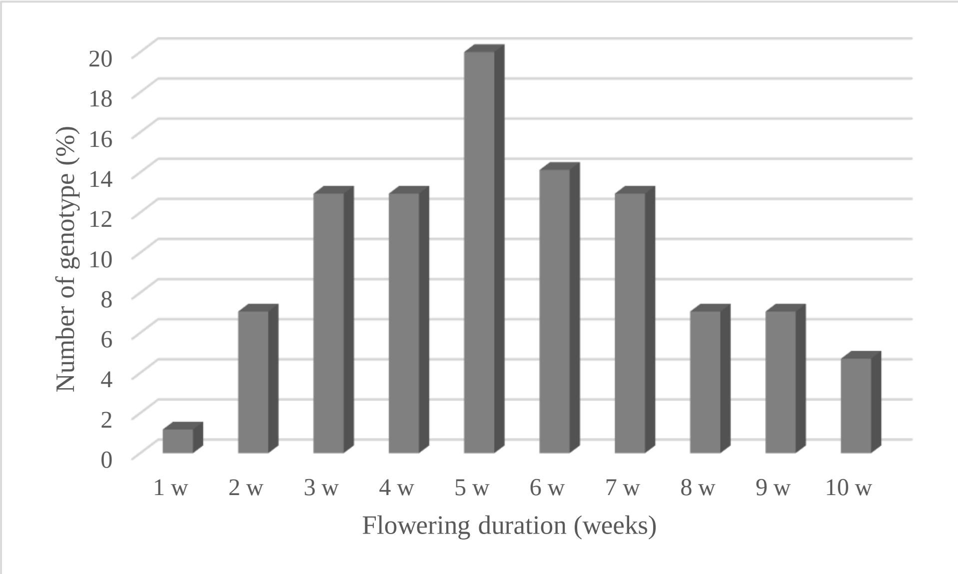

Figure 1. The number of genotypes (%) according to the length of the flowering period. The data were recorded from early June to the end of September in 2016.

Flower bud density for the genotypes studied is shown at Fig 2 and 3. According to Fig 2, bud density from at the beginning of June to mid of September in 2016 was scored 4 ≥ for 76% of genotypes. According to the measurements made in the first week of April in 2017, it ranged from 0.36 to 1.20 buds/cm for 85 genotypes and between 0.79 and 0.92 buds/cm for about 33% of genotypes (Fig 3). Internode length and shoot length measured ranged from 1.25 to 2.53 cm and from 16.20 to 54.24 cm, respectively. The bud density per node varied between 0.62 and 1.98 (data not shown). Bud density was not effected due to fruit type (Table 2) and flesh texture (Table 3).

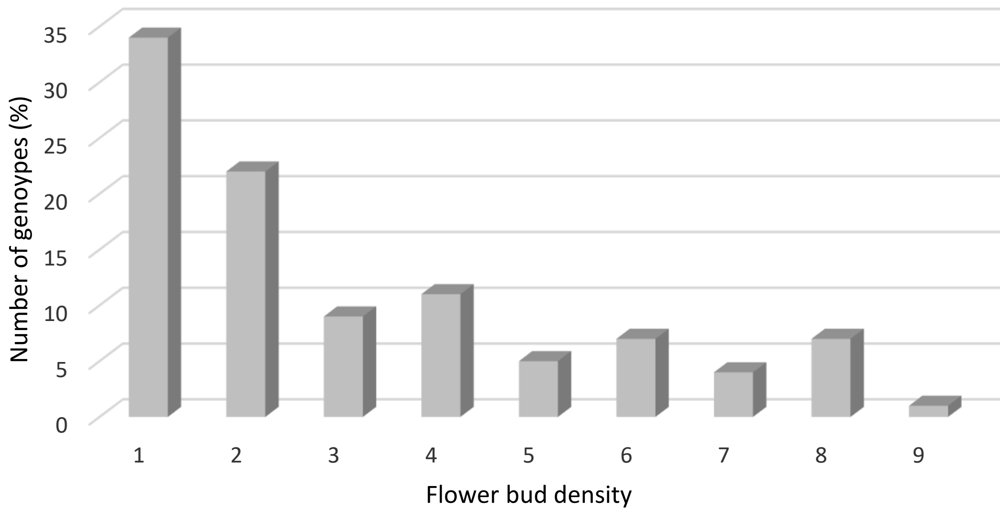

Fig 2. Number of genotypes (%) according to density of flower bud on scale 1 (least)-9 (most). Evaluation made in June 2016.

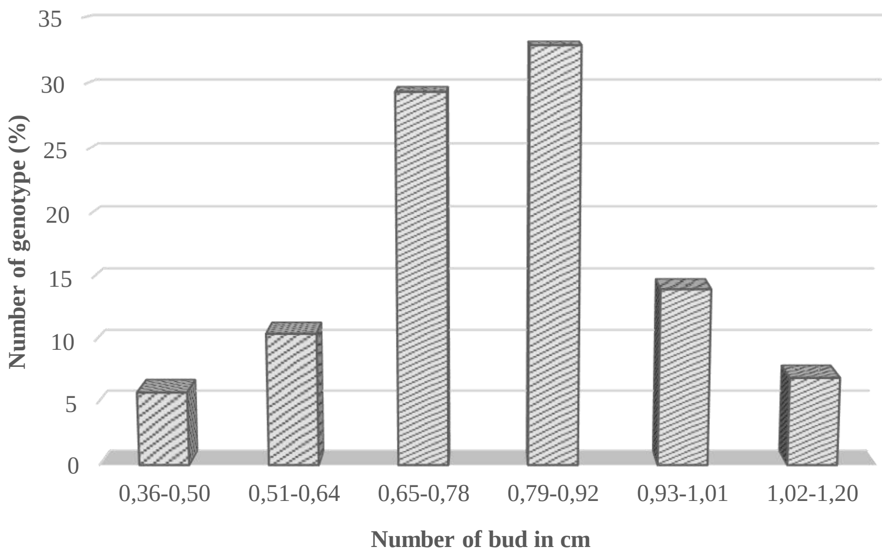

Fig 3. The percentage of genotypes according to the flower bud density (buds/cm). Evaluation made in April 2017

The mean harvest duration for each genotypes varied between 1 and 30 days and harvest continued from the first week of October to the last week of November, while FDP ranged from 75 to 123 days. Harvest duration was positively correlated with flowering duration (r = 0.549), gummosis (r=0.443) and tree age (r=0.377) (Table 3). The harvesting period of genotypes with long flowering duration was generally long. However, this duration was not effected neither because the genotypes were peach or nectarine nor melting or non-melting (Table 2 and 3).

Table 2. The change of some characters according to peach or nectarine

Variables	Peach or Nectarine	n	X ± SD	t*	p
Flowering duration (days)	P	51	36.47±15.08	0.745	0.458
	N	34	34.00±14.82		
Flower bud density buds.cm^{-1}	P	51	0.79±0.16	-0.899	0.371
	N	34	0.82±0.20		
Harvest duration (weeks)	P	51	10.29 ± 7.21	1.430	0.156
	N	34	8.21±5.53		
Fruit weight (g)	P	51	92.73 ± 37.37	2.326	**0.022****
	N	34	75.00±29.39		
Fruit firmness (kg.cm^{-1})	P	51	2.29 ± 1.21	-0.200	0.842
	N	34	2.34±1.05		
SSC (% Brix)	P	51	14.11 ± 2.28	-4.630	**0.000****
	N	34	16.96±3.07		
Blush (%)	P	51	56.57 ± 26.80	-1.433	0.156
	N	34	65.74±31.82		

Table 3. The effect of flesh texture on some phenological and fruit traits

Variables	Flesh texture	n	X ± SD	t*	p
Flowering duration (days)	M	40	34.10 ± 12.44	-0.817	0.416
	NM	45	36.71 ± 16.90		
Flower bud density (buds.cm$^{-1)}$	M	40	0.81± 0.16	0.415	0.679
	NM	45	0.79± 0.19		
Harvest duration (weeks)	M	40	10.40 ± 7.63	1.237	0.220
	NM	45	8.62 ± 5.56		
Fruit weight (g)	M	40	94.23 ± 34.00	2.160	**0.034***
	NM	45	78.00 ± 35.06		
Fruit firmness (kg.cm^{-1})	M	40	1.66 ± 0.99	-5.876	**0.000****
	NM	45	2.89 ± 0.94		
SSC (% Brix)	M	40	14.25± 2.62	-3.097	**0.003****
	NM	45	16.14 ± 2.98		
Blush (%)	M	40	58.88 ± 27.47	-0.405	0.687
	NM	45	61.44 ± 30.70		

Table 4. Correlation matrix among the variables studied

	Flower bud density	*Flowering duration*	*Gummosis*	*Tree age*	*Harvest duration*
Flower bud density		-0.030	-0.142	-0.041	0.018
Flowering duration			0.438**	0.438**	0.549**
Gummosis				0.667**	0.443**
Tree age					0.377**
Harvest duration					

*. Correlation is significant at the 0.05 level
**. Correlation is significant at the 0.01 level

Fungal gummosis moderately effected flowering duration (r=0.438) and harvest duration (r=0.443) which the disease caused the prolongation of both these periods (Table 4). In addition, as tree age increased, the effect of gummosis was also increasing (r=0.667). Although fungal gummosis, which is in this region effects the tree health adversely (Fig 4), a correlation between gummosis and bud density was not found (r=-0.142) for the 85 genotypes studied (Table 4).

Fig 4. Fungal gummosis on peach tree

Fruit weight of the genotypes tested ranged from 27 g (flat nectarine) to 213 g (round peach). Fruit weight was more in the peaches with average 92.73 g than nectarine (Table 2). Besides, fruit size of the genotypes with melting flesh was also higher (Table 3).

Fruit firmness varied from 0.5 to 7.6 $kg.cm^{-2}$ and this character was higher than 2 $kg.cm^{-2}$ for 82% of the genotypes which was effected due to flesh texture (Table 3). Although the influence of flesh colour on firmness was not important as statistically in this population (Table 5), firmness for the genotypes with yellow flesh colour was slightly higher.

Table 5. The effect of flesh colour on some fruit characters

Variables	**Flesh colour**	**n**	**X ± SD**	**t^***	**p**
Firmness (**$kg.cm^{-1}$**)	Y	56	2.5 ± 1.0	1.854	0.067
	W	29	2.0 ± 1.3		
SCC (% Brix)	Y	56	15.2 ± 3.1	-0.243	0.808
	W	29	15.4 ± 2.8		
Blush (%)	Y	56	60.2 ± 28.6	-0.025	0.980
	W	29	60.3 ± 30.5		

SSC varied from 8% to 22.4% which only three genotypes had lower SSC than 10% (data not shown). It was influenced by the genotype of peach or nectarine (Table 2) and from flesh texture (Table 3) which were higher in nectarines and genotypes with NM. There was no effect of flesh colour on SSC (Table 5), however, a significant correlation between SSC and fruit weight (r = -0.501) was found (Table 6).

In this population, the occurrence of red skin colour in fruits was very high and 74% of genotypes showed blush formation over 50% (Fig 5).

The number of genotype showing large stylar tip was 24, however 10 out of 24 produced smaller protruding tip. In addition a few genotype had fruit with large suture bulge and pubescence of over 2 scored (data not shown).

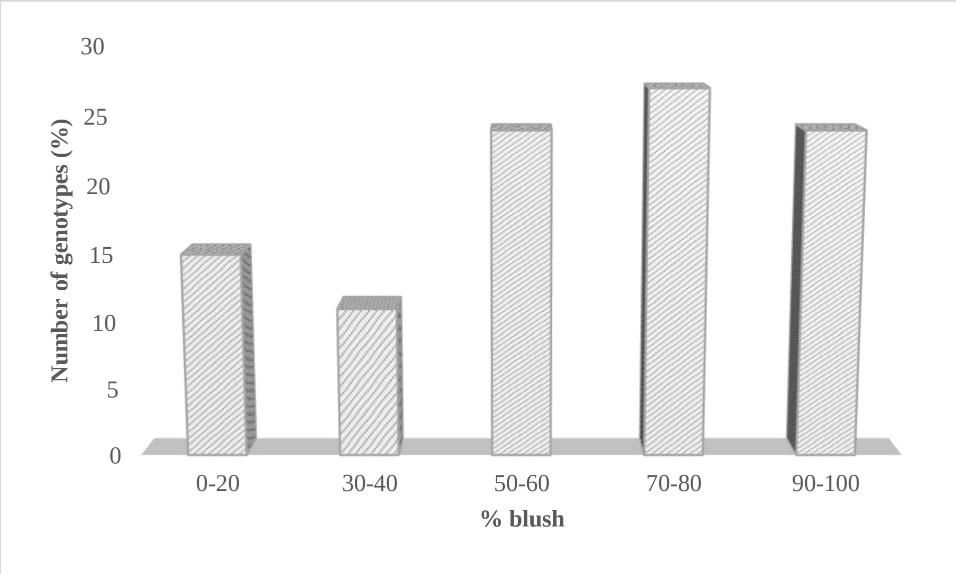

Fig 5. The number of genotypes (%) according to formation of blush.

Table 6. Correlation among the variables studied

	FDP	*Fruit weigh*	*Fruit firmness*	*SSC*
FDP		-0.074	0.283**	0.205
Fruit weigh			-0.213	-0.501**
Fruit firmness				0.245*
SCC				

Discussion

Compact flowering is wished in peach cultivation, especially in the growing of low-chill cultivars, because it also effects harvest duration. In this study, flowering duration of the genotypes usually was very long and therefore ripening over an extended period. The length of this period was effected from fungal gummosis (r= 0.438) and tree age (r= 0.438) (Table 4). Flowering duration in younger aged trees took place in a shorter time. This may have been due to the low density of flowers in young trees, despite, there was no a significant correlation between flowering duration and bud density.

First blooming time of genotypes was very different and there were approximately two and a half months between the first and last flowering genotypes in blooming date. This is because blooming time is considered a quantitative trait in peach, however, its heritability is high (h^2>0.65). The difference in flowering time of peach cultivars in the same land is due to genotype differences for the winter chilling requirement and accumulation of heat units. (De

Souza and Byrne, 2000; Bassi and Monet, 2008; Topp et al., 2008). Furthermore blooming date and duration for a cultivar will vary depending on the amount and time of chilling it receives (Okie and Blackburn, 2011). In this trial, the chilling requirement of genotypes studied varied from 100 to 400 CU. Fig 1 represents the values from June to September when the observations for flowering were taken. However, the majority of genotypes started to bloom in April. In 2017, this situation became more pronounced. Blooming began at the end of March and the flowering reached 90% in some genotypes at the beginning of May, while the others bloomed less than 5% or only few flower. Flowering began with the opening of the flower buds at the top of the shoots and continued down to the shoot. This is agree with indicated by Okie and Blackburn (2011) which the chilling requirement of the flower buds for a given cultivar vary. According to Erez (2000), dormancy development in axillary buds are gradually due to apical dominance, and the intensity of this may vary depending on the variety within the species. If the terminal bud continues to grow in warm climates, the chilling requirement of the lateral buds may be affected. In addition to flowering, apical shoot growth also continued in some genotypes. Some genotypes completely fell their leaves off, while some had leaf between 1% and 70% at the end of April. Erez (2000) stated that high autumn temperatures cause flower buds of low-chill cultivars not to enter endodormancy or enter very slowly and if bud break is stimulated by loss of leaves, irrigation after a long period of drought or dormancy-breaking chemical sprays, autumn blooming may be quite plenty. In our population, some genotypes had neither leaf nor flower, while the others had both leaf and high amount of flowers. Therefore defoliation and flowering intensity do not seem to be related. In March-May, which are autumn months, the average monthly min-max temperatures ranged 20.6-29.0 ^{o}C, 16.3-26.0 ^{o}C and 10.8-18.1 ^{o}C respectively. Since the temperature was relatively lower in May, the flowering was slower but not stopped. Viti et al. (2010) have recommended that temperature fluctuations between day and night and the time of chilling fulfilment (late autumn, early winter or mid-winter should be take into account to satisfy the chilling requirement a variety.

The reason of autumn flowering is not clear which further work is needed to clarify it and we cannot explain this phenomena. However, the resulting fruits will face with problems such as fall off, malformation, inadequate size, colouring and low sugar content due to shortage of carbohydrates. Besides, flowering in autumn causes sparse blooming in spring. On the other hand, since the flowering will continue in winter and spring, and flowering period is quite long and therefore harvest duration is also long. This seems to be a negative. But is it possible to turn it into a positive one? These genotypes that bloom very early season can be assessed by protected culture in areas where frost is not occur such as this region. Thus, their harvest time for specific periods may be adjusted by easily manipulating flowering.

Flower bud density is a sign of productivity. It has been reported that the density of flower bud is highly dependent on the variety (Okie and Werner, 1996), and that the level of heritability is moderate (h^2 = 0.41-0.48) (Topp et al., 2008). Mowrey and Sherman (1986) reported that there is a positive correlation (r=0.65) between the average number of flower bud and the number of fruit-bearing individuals in hybrid combination. In this study, flower bud density ranged from 0.36 to 1.20 buds/cm and buds per node were between 0.62 and 1.98. When compared to other works (Werner, et al., 1988; Perez-Gonzalez, 1993; Okie and Werner, 1996), the density for the majority of genotypes was high. However, because of the above-mentioned abnormal flowering condition, there was a decrease in the amount of flower buds to be opened at the usual time for early-bloomed genotypes (Fig 2). As a result, the yield of most genotypes was as low as 1-2 kg/tree. Since fruitfulness is one of the most important traits of a variety for breeders and producers, it is important to determine fruiting potential of parents prior to the start of hybridization studies. Because progeny of the parents with high flower bud can also have high flower bud. In addition, varieties with high flower bud tend to be fruit-bearing after being budded on a rootstock and in a shorter time than those with low flower bud (Sherman and Lyrene, 1983; Burgos et al., 2004). In this region, late spring frost is not a problem, in this connection, it may be appropriate that the density of the flower buds of the cultivated varieties is moderate in order to avoid fruit thinning costs. Besides in term of fruit size, mean fruit size is generally correlated with crop load as negative (Naor et al. 1999).

Since the time of fruit maturation is transferred to the new generation with quantitative inheritance (Abbott et al., 2008), the harvest time of seedlings to be obtained by hybridizing parents with different harvesting times is unpredictable. However, in the selection of parents, their average harvesting time should be taken into account (Hesse, 1975), because, Souza and Byrne (2000) have reported that the maturation time is highly inherited (h^2= 0.84). In this study, the first harvest time and FDP of genotypes was between the second week of October and the middle of November, and 75-123 days, respectively. The 50% flowering estimate due to the extended flowering was very difficult, so the length of FDP for some genotypes may had been calculated longer than normal. The gradual harvest which it can be normally seen in peach was quite pronounced in this region which it may be possible to see some ripe fruits, fruitlets and flowers together on the same tree during the flowering period. The reason for this was unusual blooming (autumn flowering) which a moderate significant correlation (r= 0.549) was found between flowering and harvest duration (Table 4). The harvest duration of the genotypes with no flowers or a few flowers in autumn was shorter and they had more yield than others. Early-harvest is important to take advantage from high market price in this region.

Bigger fruits, usually desired by consumers, are easier to sell and at higher prices in many of world markets. Although, the development of varieties with large fruit is more difficult for the early season due to a strong positive correlation between the FDP and fruit size, the selection of the genotypes with large fruit is one of the objectives in breeding programs (Souza and Byrene, 2000; Souza et al, 1998). Previous study showed that fruit size is related to quantitative inheritance and is controlled by more than one gene (Quilot et al., 2002). In addition, these genes may have spread throughout the genome and transferring this character to the progeny depends on interactions such as epistatic or additive gene expression (Sansavini et al., 2006). However, when the parents with differing in fruit size and their progenies are assessed, hybrids may be expected to be towards large size (Monet et al., 1996). Although normally there is a strong correlation between FDP and fruit size in high-chill peach cultivars, a correlation between the FDP and the fruit weight was not found in this study (Table 6). The fruit weight of genotypes studied varied a wide range, because, in this population, there were the genotypes with flat and round in fruit shape. FDP of peach is highly dependent on the genotype, however, post-blooming temperature in spring has an influence on the harvest time.

Flesh firmness is a very important trait that should be taken into consideration in terms of reducing of losses due to mechanical damage during harvest and post-harvest period and transport of fruits to distant markets. Firmness may vary depending on the fruit size, texture, varieties, climate conditions and cultural practices (Crisosto, 1994; Crisosto and Valero, 2008). Peaches with fruit firmness below 1.8 $kg.cm^{-2}$ are generally reported to be more exposed to injury during the harvest and post-harvest period (Crisosto et al., 2001; Valero et al., 2007; Cantin et al., 2010). At the time of minimum maturity, early varieties of peach and nectarine are less firm than late ones. Generally at this stage the peaches have firmness of 4.08-4.54, 4.99-5.44 and 5.90-6.35 $kg.cm^{-2}$. However, when they are harvested after this period, they become more delicious as the amount of sugar increases, the amount of acid decreases and the accumulation of aroma compounds increases. Sales of fruit with firmness of 2.6-3.6 $kg.cm^{-2}$ and fruit with 0.9-1.4 $kg.cm^{-2}$ are considered to be the most suitable for consumption (Crisosto, 1994; Cantin et al., 2010). In this study, the genotypes with NM were average 2.9 $kg.cm^{-2}$ of firmness to compare ones with M (1.6 $kg.cm^{-2}$). NM peaches/nectarines show a hard texture at full maturity and can stay on tree for a longer time which this character can lead compact harvest duration. Although, a variety with white flesh is generally low firmness, the effect of flesh colour on firmness was not found in this study, since some of the genotypes with white flesh had NM character.

Off flavour is one of the most common complaints by consumers. Although peach flavour is complex which affected the content of organic acid, sugar, TA i.e. in fruit and the taste sensation varies from community to community and from region to region. To measure flavour usually is used sugar and acid content as well as the ratio between these (Crisosto et al. 2008). In this study, SSC of genotypes was usually higher than 10% which is considered as the minimum level in yellow flesh peaches (Fideghelli, 2003; Crisosto and Crisosto, 2005), although SSC of the early ripening genotypes with short-FDP is usually low due to an association between short FDP and low SSC. SSC varies depending on variety, fruit size, firmness, flesh texture and colour. There was a negative correlation between fruit size (weight) and SSC (r = -0. 501; Table 6) which the fruit size decreased while SSC increased. Indeed, in a previous study, 2/3 of the fruit size measurements were found to be negatively associated with SSC (Hesse, 1975). Normally, when fruit firmness is decreased, SSC is expected to increase. However, we obtained findings in the opposite which a positive correlation between SSC and firmness was found (r=0.245) but not high. This was because many of the genotypes studied were NM flesh texture which allows the fruits to mature with higher SSC and to keep firmness. Various studies on the inheritance of SSC have shown that this trait is quantitative (Dirlewanger et al., 1999; Quilot et al., 2004) and moderately heritable with estimate of 0.45 (Souza and Byrne, 2000). Therefore it can be possible that the hybridization of parents with high SSC will increase the chances of success to achieve a progeny with high SSC.

One of the problems faced in low-chill peach production is a fruit with prominent stylar tip. In commercial peach growing, the fruit with round shaped, non-pronounced suture and -prominent stylar tip are preferred due to storage convenience and for consumer acceptance. Fruit shape is moderately heritable (Souza et al. 1998) but the changes can occur according to locations and years. Some genotypes are round in cold locations, however, they suffer somewhat from pointed in warm locations (Hesse, 1975; Topp and Sherman, 1989; Wert et al., 2007; Topp et al., 2008). It may be considered that if a genotype has round fruit with pointed tip-free or pronounced suture-free when grown in warm, its seedlings can be also rounded. In our population, the number of genotypes with larger tip and/or bulge was very low, despite, this region is warm climate. Therefore, through the use of the parents of the individuals to be selected from this population, a progeny with good fruit shape can be obtained.

Fruit colour is an important quality factor which affects appearance of fruit and consumer acceptance. The expression of red skin colour can be inherited both quantitative that is controlled by polygene action and has a high degree of light exposure interaction (Scorza and Sherman, 1996; Bassi and Monet, 2008) and relatively high inheritable (h^2 = 0.65) (Souzo and Byrne, 2000) and qualitative that there is no environmental interaction and is controlled some recessive genes for red skin colour (Beckman and Sherman 2003; Beckman et al., 2005). In our population which composed of genotypes with different flesh texture and colour, 74% of genotypes had between 50-100% of blush. The formation of blush was quite high, even thought FDP was short. Blush expression can be affected temperature, tree training, and light intensity (Lewallen and Marini, 2003; Wert et al., 2009)

All trees had the disease of fungal gummosis at different rates and it was noted that this disease increased as the tree aged. The severity of the disease was not seem to be affected by difference in genotype. However it is needed to more comprehensive work to determine the resistance ratings of the genotypes. Because previous work showed that no cultivar was immune but the susceptibility varied among 25 cultivars from the most to the least (Beckman and Reilly, 2005) and also a few peach lines have some resistance (Adaskaveg et al., 2008). While some trees in our population produced strong shoots over the diseased trunk, some had very little growth. The correlation between the disease and the density was not significant statically (Table 4), however, symptom severity had a slight negative affect on bud density (r=-0.142). Beckman et al. (2003) has reported that both trunk diameter and fruit yield were negatively correlated with the disease.

Conclusion

The blooming duration of the genotypes studied ranged from one to ten weeks and was longer than four weeks for most of the genotypes. Blooming duration correlated positively with gummosis (r= 0.438), tree age (r=0.438) and harvest duration (r=0.549). Since many genotypes bloomed in autumn, the number of their flowers opened in usual time (winter-spring) was very low. Therefore, to determine the uniform flowering genotype, the duration of flowering and the density of flowers should be considered together.

The FDP of the majority of genotypes was below 100 days which provides the opportunity to benefit from early high market prices.

The length of harvest duration for many genotypes was very long despite most of the genotypes having NM flesh texture which a genotype with NM flesh can stay on the tree until fully ripe.

Fruit quality traits such as fruit size, blush, firmness and pubescence of the genotypes were generally satisfactory.

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Appendix 4 Descriptions of selections sent for small-scale test 2013-20

Clone	Crop	Skin colour	% skin blush	Shape	Flesh Colour	Flesh texture	Flesh acidity	Flavour	Stone Freedom	Chill (units)
9039	J	Med red	9	Round	Y	M	med	mild	semi-cling	350
10020	J	Med red	8	Oblong	R	M	high	bal	cling	250
17020	P	Med red	70	Ovate	Y	NM	med	bal	cling	200
32059	N	Med red	70	Ovate	Y	M	med	bal	cling	100
43027	J	Med red	9	Round	Y	M	med	bal	cling	350
43050	J	Med red	6	Round	Y	M	low	bal	free	400
52018	P	Light red	70	Round	W	M	med	mild	cling	150
53004	P	Med red	70	Round	Y	M	med	bal	cling	150
58070	N	Med red	90	Round	Y	NM	med	bal	cling	150
68064	P	Mot red	70	Round	Y	M	med	bal	cling	150
74069	N	Yellow	0	Round	Y	NM	med	bal	cling	150
78002	N	Light red	70	Oblong	Y	NM	high	bal	cling	250
79036	P	Mot red	80	Round	W	M	high	bal	semi-cling	250
85037	N	Light red	50	Oblong	Y	M	med	bal	free	150
86049	P	Med red	70	Ovate	Y	M	honey	mild	cling	350
115067	P	Med red	90	Ovate	W/R	NM	honey	sweet	cling	250
127066	P	Light red	90	Round	Y	NM	honey	mild	cling	250
135014	N	Light red	80	Ovate	Y	NM	med	bal	cling	250
135015	N	Dark red	80	Round	Y	NM	honey	sweet	cling	150
157028	P	Mot red	70	Oblong	Y	NM	honey	sweet	cling	250
162017	J	Black	9	Round	Y	M	med	bal	cling	350
181077	N	Med red	80	Round	W	M	low	sweet	semi-cling	250
212024	J	Black	9	Round	O	M	med	bal	cling	250
215036	P	Med red	90	Ovate	Y	M	med	bal	cling	100
217002	P	Med red	70	Ovate	Y	NM	low	mild	cling	200
218007	P	Light red	80	Round	W	M	honey	sweet	cling	150
219020	P	Light red	70	Ovate	W	NM	med	bal	cling	200
219025	N	Light red	80	Ovate	W	NM	med	bal	cling	150
221053	P	Med red	80	Round	W	M	honey	sweet	cling	250
223015	N	Med red	80	Round	W	M	med	bal	cling	250
223020	N	Bright red	90	uneven	W	NM	med	bal	cling	250
223031	N	Med red	80	Round	W/R	NM	high	bal	cling	150
223041	N	Light red	80	Round	W	M	high	bal	free	150
223045	N	Bright red	80	Round	W	NM	med	bal	cling	150
223052	N	Bright red	80	Round	W	M	med	bal	semi-cling	100
228039	N	Light red	80	Round	W	M	med	bal	cling	150
254051	J	Yellow	0	Oblong	deep Y	M	high	bal	cling	250
302063	P	Med red	90	Round	Y	NM	honey	sweet	cling	150
305052	P	Light red	60	Round	W	M	med	mild	semi-free	150
307011	P	Yellow	0	Round	Y	NM	high	bal	cling	150
309031	P	Light red	80	Ovate	W	M	med	bal	free	150
311004	P	Med red	80	Oblong	W	M	honey	sweet	cling	200
314030	P	Light red	80	Round	W	M	honey	sweet	semi-cling	150
314032	P	Med red	90	Round	Y/R	M	med	bal	cling	150
315009	P	Bright red	90	Ovate	Y	NM	med	bal	cling	250
315012	P	Mot red	70	Round	Y	NM	med	bal	cling	250
315062	P	Med red	60	Round	Y/R	NM	med	bal	cling	250
315073	P	Dark red	90	Round	Y/R	NM	med	bal	cling	250
315077	P	Dark red	90	Round	Y	NM	low	bal	cling	150
316002	P	Med red	90	Round	Y	NM	med	bal	cling	150
316075	P	Bright red	80	Round	Y/R	NM	med	bal	cling	150
316076	P	Bright red	90	Round	Y	NM	low	sweet	cling	100
503033	N	Med red	80	Round	Y	M	honey	sweet	semi-cling	150
504011	P	Med red	90	Round	W	M	med	bal	semi-free	250
505010	P	Med red	80	Round	W	M	honey	sweet	semi-cling	150
602055	P	Med red	80	Round	Y	M	med	bal	free	150
GB561027	N	Med red	80	Oblong	Y	NM	honey	sweet	cling	350
GB561065	P	Dark red	80	Oblong	Y	NM	honey	sweet	cling	350
GB566014	N	Med red	80	Ovate	Y/R	NM	honey	sweet	cling	350
GB566015	N	Dark red	80	Round	Y	NM	honey	sweet	cling	450
Crop: J Japanese plum; N Nectarine; P Peach										
Flesh colour: O orange; R red; W white; Y yellow										
Flesh texture: M melting; NM non-melting										

Appendix 6 Grower comments on large-scale selections

SELECTION	GROWER COMMENTS
<u>Q32-59 nectarine</u>  	Yellow, melting flesh nectarine Test marketed as 'QFire' Fruits are large and picked early in the season and command high prices. The tree is difficult to manage. Fruit drop can be severe. Growers have reported that a combination of minimal pruning and picking fruit at the end of laterals may assist. Retain sprays are used to improve fruit firmness.
<u>Q58-70 nectarine</u> 	Yellow, non-melting flesh nectarine Test marketed as 'QSweet' Early ripening and firm flesh. Overlaps in picking with Q32-59 and receives lower prices. Fruit size is too small, and cropping varies across years. Ripens after 'White Satin'.
<u>Q68-64 peach</u> 	Yellow, melting flesh peach It has performed well in north Queensland on the Atherton Tablelands. Consistent production of early to mid-season fruit of good eating quality.

Q113-21 peach 	Yellow, melting flesh peach Test marketed as 'QRose' Ripens after 'UFSun' and at same time as Q17-20. Very attractive appearance with low fuzz and even shape. Crop was a bit light in 2019 but okay in 2020. Flavour is good. Some growers are using 'Retain' to improve firmness
Q131-51 peach 	White, melting flesh peach Ripens early season and produces attractive fruit for the time slot. Can have prominent tip and flesh softens quickly. Only one grower is testing this selection.
Q135-15 nectarine 	Yellow, non-melting flesh nectarine Planted in large-scale test in 2020 so no report back yet. It produces very attractive fruit with high eating quality. Its outstanding feature is the clean skin finish. Downside is that it is only medium size for its late October ripening time slot at Nambour.

<table>
<tr><td><u>Q217-2 peach</u>
</td><td>Yellow, non-melting flesh peach

Selected primarily for its large fruit size. Fruits are also firm and attractive. Downside is ovate rather than round shape and ripens late in the season; picked at Nambour in late October and early November.</td></tr>
<tr><td><u>Q221-53 peach</u>
</td><td>White, melting flesh peach

Early ripening and attractive skin colour. Only on test at one property. No reports back yet.</td></tr>
<tr><td><u>Q223-20 nectarine</u>
</td><td>White, non-melting nectarine

We produced seven selections in the Q223 series. All have excellent skin colour, size, firmness, and taste.

This is one of the earliest of the series and ripens before Q223-45 but still considered too late.</td></tr>
</table>

<u>Q223-45 nectarine</u>  	White, non-melting nectarine “Nice and big. Easy to handle. Bit too late.” This sums it up. Growers like the fruit but the squeeze in the season with southern fruit reducing prices from mid-November onwards means that selections like this ripen too late for economic production. It ripens at the end of “Richen White’ season.
<u>GB566-15 nectarine</u> 	Yellow, non-melting flesh nectarine It cropped very well at Bangalow one year and was picked up for trial by a local grower. It requires 300-400 chill units to break winter dormancy and so is more suited to medium-chill regions. Fruit quality is excellent in appearance, size, firmness, and flavour. Ripens in November which is too late for coastal growers.

Appendix 7 Performance of low-chill peach in Spain 2017

Performance of Low-chill Peach Selections in Spain 2017

Peach and nectarine selections from the Hort Innovation SF13004 stonefruit breeding project are currently under evaluation at the Royal fruit company orchards about 16 kms north of Seville, Spain. This report provides information on six peach selections that have performed well at Seville and compares them with results at Maroochy Research Facility, Nambour, Queensland.

Materials and methods

Data was collected in Seville from four year old trees in 2017 and in Nambour on three and four year old trees in 2011 to 2015. Trees were rated for date of harvest of first eating ripe fruit, FDP (fruit development period) the number of days from flowering to harvest and chilling requirement (chill units) based on comparative flowering dates of standard cultivars. The traits of yield, shape, colour, firmness and taste were rated on a 1(low) to 9 (high) scale with most desirable traits being high yield, round and even shape, full red skin colour, firm flesh and high flavour. Fruit size was rated on a 1 (small) to 9 (large) scale at Seville and as mean fruit weight (g) on a 5-10 fruit sample at Nambour. Soluble solids (^{0}Brix) were measured on a two fruit sample using a hand held refractometer.

Results and discussion

The earliest and latest ripening selections at both sites were Q316-2 and Q218-7 respectively (Table 1). At Seville there was a 54 day difference in ripening dates compared to only 30 days at Nambour. Subtropical peach orchards in northern NSW and southern Queensland rely on early ripening fruit to remain viable. Most growers prefer to finish fruit harvesting by the first week in November. After this time, southern temperate peaches reach the market and prices fall dramatically. Q218-7 is therefore marginal in its fruit ripening category. The remaining five selections ripen in October when the subtropical peach industry is at its peak.

All selections were rated in Seville as having commercially acceptable fruit size, shape, colour, firmness and taste (Table 2). The soluble solids varied from 9-10 Brix for Q315-73 up to 13-14 Brix for Q218-7 (Table 2). The high sugar content for Q218-7 is related to its long FDP and hence time on tree in which to develop higher eating quality. Compared to Q315-73 it had a 49% longer FDP.

The following paragraphs provide a detailed description of the selections and include comments from the evaluators on the good and bad traits of each selection.

Q221-53 white peach. Fruit are round with low fuzz, bright red skin blush covering 80% of surface and have white melting flesh with low acidity. It can ripen as early as mid-September at Nambour and should be trialled in low-chill and temperate regions for early season production. In Seville it was noted that it was of high eating quality with a good load of fruit but small size.

Q218-7 white peach. Fruit are round, with very low fuzz, light red skin blush and white melting, low acid flesh. Selected at Nambour as a high quality peach for late season subtropical Australia. In Seville it was noted as having enough sugar to cause sugar speckling, a balanced flavour with good firmness and texture but size was too small. At Nambour the fruit averaged 133g which is an acceptable size for this harvest time.

Q305-52 white peach. Fruit are round, 60% light red blush with white, melting flesh and a balanced flavour. Selected at Nambour despite its light crop because of the high fruit quality and sent to growers for testing its yield in different locations. In Seville it was noted that both the fruit size and the yield were high; skin colour was not sufficient for their markets and the flesh melted too easily.

Q315-9 yellow peach. Fruit are round to ovate, 80-90% medium mottled light red skin blush with yellow, non-melting flesh with balanced flavour. At Nambour noted that fruit size was good (123g) for the crop load (8); considered the best peach in 2015. At Seville noted that it had very good size and high productivity, the fruit was a bit acid but okay; ranked second best, behind Q316-2.

Q315-73 yellow peach. Fruit are round, 80-90% dark red skin blush with yellow, non-melting flesh with balanced flavour. At Nambour noted that it had even shape and attractive skin colour but may be too small. At Seville the size was rated as 8 of 10 and therefore considered above commercial standard; the shape went from round to oblate (flattened) and noted to have good colour, high productivity, the flesh was very firm, contained some red and was acid. Noted as interesting.

Q316-2 yellow peach. Fruit are round to ovate, 80% mottled red skin blush with yellow, non-melting flesh with balanced flavour. At Nambour it was selected despite the light crop because of its early ripening; has ripened as early as mid-September. At Seville it was noted as highly productive indicating that its cropping may depend on management or location. It had very good firmness and was ranked as best of the selections.

Conclusions

Five of the six selections have been sent to Australian growers for test from 2012 to 2015. The selection Q315-73 originally was not sent for Australian testing because of poor fruit size at Nambour. Considering the Seville fruit size results we sent Q315-7 to our small-scale evaluators. All six selections should be tested widely in Australia.

Table 1. Tree characteristics of six peach selections evaluated at Seville, Spain and Nambour, Australia.

Clone	Location	Year	Harvest date	Yield (1-9)*	FDP** (days)	Chill Requirement (chill units)
Q221-53	Seville	2017	12-May	8	86	
	Nambour	2012	18-Oct	6	80	200
Q218-7	Seville	2017	3-Jul	7	149	
	Nambour	2011	3-Nov	7	122	200
Q305-52	Seville	2017	16-May	8	93	
	Nambour	2013	14-Oct	1	105	150
Q315-9	Seville	2017	12-May	9	96	
	Nambour	2015	15-Oct	8	87	250
Q315-73	Seville	2017	18-May	9	100	
	Nambour	2015	15-Oct	7	87	250
Q316-2	Seville	2017	10-May	9	97	
	Nambour	2011	4-Oct	2	92	150

*Yield rating scale is 1 light to 9 heavy with 7 a commercially acceptable crop
** FDP Fruit Development Period

Table 2. Fruit characteristics of six peach selections evaluated at Seville, Spain and Nambour, Australia.

Clone	Location	Year	Size (1-9)*	Soluble Solids (Brix)	Shape (1-9)	Colour (1-9)	Firmness (1-9)	Taste (1-9)
Q221-53	Seville	2017	8	11-12	8	9	7	8
	Nambour	2012	103	12.5	8	8	7	7
Q218-7	Seville	2017	7	13-14	8	8	9	9
	Nambour	2011	133	13	9	8	8	8
Q305-52	Seville	2017	9	10-11	8	7	7	8
	Nambour	2013	140	13	8	7	8	8
Q315-9	Seville	2017	8	11-12	8	8	8	8
	Nambour	2015	123	14	7	9	8	8
Q315-73	Seville	2017	8	9-10	8	8	9	7
	Nambour	2015	90	11	7	7	8	7
Q316-2	Seville	2017	9	10	8	8	9	8
	Nambour	2011	129	12	8	8	8	7

*All 1-9 rating scales have 7 as the minimum commercial threshold
Size at Nambour (g)

Appendix 8. Description of novel varieties submitted for PBR 2018

Q73-50 peento (flat), white-fleshed peach

FRUIT *Ripening time*: Ripens early, around 4 days later than Tropic Beauty and 10 days earlier than UFO. Harvested in mid to late October at Nambour, about 80-90 days after bloom. *Size*: Small to medium size for season; averages from 45 to 55g per fruit. *Shape*: Flat. *Skin colour*: Light red *Flesh*: White, non-melting flesh that has balanced sugar and acid, pleasant flavour and TSS averaging 12%. *Stone freedom*: Clingstone

TREE *Vigour*: Vigorous growth; with a semi-upright growth habit. *Yield*: Sets light to moderate crops. *Flowering period and chilling*: Bloom period is 18 days later than Tropic Beauty peach and is rated at approx. 250 chill units. Blooms in mid to late July at Nambour.

SUMMARY This is a low-chill, flat peach with white, non-melting flesh. It is potentially useful commercially because of its flat shape, white flesh, early ripening period and low chilling requirement.

Q108-65 flat nectarine

FRUIT *Ripening time:* Ripens early, around 1 day later than Tropic Beauty and 13 days earlier than UFO. Harvested in mid to late October at Nambour, about 90-100 days after bloom. *Size*: Medium size for season; averages from 60 to 70g per fruit. *Shape*: Flat. *Skin colour*: Bright red. *Flesh*: Yellow, non-melting flesh that has balanced sugar an 13%. *Stone freedom*: Clingstone

TREE *Vigour*: Vigorous growth; with a semi-upright grow *Yield*: Sets light to moderate crops. *Flowering period and chilling*: Bloom period overlaps with Tropic Beauty peach and is rated at approx 150 chill units. Blooms in early to mid July at Nambour.

SUMMARY This is a low-chill, flat nectarine with yellow, non-melting flesh. It is potentially useful commercially because of its early ripening period and low chilling requirement.

Q74-30 all-yellow peach

FRUIT *Ripening time:* Ripens around 4 days later than Tropic Beauty, in mid to late October at Nambour, about 90-100 days after bloom. *Size*: Medium size for season; averages from 75 to 85g per fruit. *Shape*: Ovate to round shape. *Skin colour*: Yellow skin; no red blush observed. *Flesh*: Yellow, non-melting flesh that has balanced sugar and acid, pleasant flavour and TSS averaging 13%. *Stone freedom*: Clingstone

TREE *Vigour* Vigorous growth; with a semi-upright growth habit. *Yield* Sets moderate crops that will require thinning. *Flowering period and chilling* Bloom period overlaps with Tropic Beauty peach and is rated at approx. 150 chill units. Blooms in early to mid July at Nambour.

SUMMARY This is a low-chill peach that produces all-yellow fruit with yellow, non-melting flesh. It is potentially useful commercially because of its attractive yellow skin, early ripening period and low chilling requirement.

Appendix 9 Details of the Mexican germplasm 'Nieve'

USING MEXICAN PEACH FOR BREEDING NEW CULTIVARS IN AUSTRALIA

Bruce Topp[1], Dougal Russell[2] and Edward Howell[1]

[1]The University of Queensland, QAAFI

[2]Department of Agriculture and Fisheries

The industry low-chill peach breeding program in Queensland seeks to use a range of parents in order to provide a wide population for response to changing market demands. 'Tropic Beauty' peach is the industry standard and has been used extensively as a parent in the early generations of our breeding. More recently, non-melting parents have been incorporated, including 'UFSun' and 'UFRoyal' from the University of Florida and a number of selections from Brazil.

Increasing the diversity of our base breeding population allows incorporation of new traits in future cultivar development. This paper describes the introduction, evaluation and use in breeding of 'Nieve', a Mexican landrace peach.

Origin and characteristics of 'Nieve' peach

Landrace peaches have been grown in Mexico for centuries. The conquistador Pedro de Alvarado is reported to have carried peach seeds into the Central American highlands in 1524. Since that time peaches were cultivated by planting and re-planting orchards from seed, with each new orchard planted using the seed from the best trees. Over generations, these landraces of peach developed distinct varietal characteristics that were favoured by the local consumers and were adapted to the region. Nieve' was selected from a seedling population that was grown at San Juan del Rio, Queretero, Mexico at an elevation of 2,100m (latitude 20^0 23'N longitude 100^0 00'W). The mean temperature of the coldest month is 12.7^0C corresponding to about 340 CU.

The "Nieve" landrace develops low to medium-chill, semi-dwarfing trees that produce large, white flesh peaches with high flavour and aroma characteristics. A distinct characteristic is the white petals (Figure 1). The one-year old wood also lacks any red pigment and so is distinct from our regular selections whose wood turns red on the sun-exposed side. It appears that the "Nieve" germplasm has a mutation that blocks anthocyanin production throughout the plant. This lack of red pigment may be a useful trait in the fruit where red streaked through the flesh or around the stone are undesirable.

Figure 1. White petals and green wood of 'Nieve' indicate a lack of anthocyanin production in the plant.

We imported 100 seed of open pollinated (OP) "Nieve" via the Australian Quarantine and Inspection Service. The resulting seedlings were planted at Nambour which has a mean coldest monthly temperature of 15.0^{0} C corresponding to 200 CU.

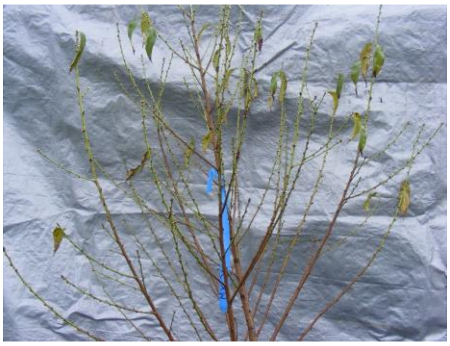
Performance of budded selection 'Q311-29'

The 'Nieve' OP family first fruited in 2011 when the seedlings were two-years-old. 'Q311-29' was selected because it was the earliest ripening seedling and had very sweet fruit. It was harvested on 22 November and produced a light crop with white skin, and white, non-melting flesh. The fruit were round with a slight tip, small (58g), sweet (TSS 20%), low-acid, clingstone, moderately dry and had an acceptable level of pubescence (Figure 2). The fruit did not develop any off-flavours after 2 weeks of cold storage.

Figure 2. 'Q311-29' peach selected at Nambour from 'Nieve' OP seedling family. The fruit and tree lack red colour development.

There was a complete lack of anthocyanin development in any part of the plant, including the fruit, flowers and branches. This corresponds to the white flower phenotype previously reported as controlled by a single recessive allele symbolised as w. This differs from the highlighter phenotype also a single recessive allele (h), which is characterised by lack of red in the skin, flesh and around the stone at fruit maturity but with red on the branches and petals. The highlighter phenotype can develop some red as the fruit becomes over-mature. In this regard the white flower phenotype may be more useful in producing non-red peach cultivars in that the red does not develop under any conditions.

As a budded tree on Okinawa rootstock, 'Q311-29' had a distinctly different tree growth habit to the standard 'Tropic Beauty'. The trees were bushier due to higher sylleptic shoot development, with 'Q311-29' having 115% more sylleptic shoots (Figure 3). 'Tropic Beauty' shoots grew 29% faster than 'Q311-29'. Leaves of 'Q311-29' were smaller than those of 'Tropic Beauty'. So 'Tropic Beauty' produced fewer but faster growing shoots than the 'Nieve' selection. The slower growth rate of the 'Nieve' selection is a desirable trait but the increased branching would be an added cost requiring increased pruning. The influence of this type of tree architecture on light penetration and subsequent fruit quality should be investigated.



(a) 'Nieve' selection

(b) 'Tropic Beauty'

Figure 3. High sylleptic shoot development on (a) 'Nieve' compared with (b) 'Tropic Beauty' produces a more bushy appearance.

Seedling 'Nieve' OP family compared to local families

'Nieve' seedlings were smaller, had higher chilling requirement and lighter crops than the local seedlings (Figure 4). Small trees are desirable in subtropical peach locations because excess tree vigour requires costly control with the use of growth regulators and regular pruning.

Figure 4. Local peach seedling population in the foreground followed by the 'Nieve' seedling population. Note the smaller tree height and denser foliage of the 'Nieve' population.

The desirable fruit traits in the 'Nieve' family were the high TSS, firm, non-melting flesh, and the all-white appearance. These traits would be useful in our breeding in that they may allow the production of cultivars which produce visually distinctive fruit that consumers associate with a pleasant, sweet flavour.

The 'Nieve' family has the undesirable fruit traits of late ripening, long FDP, small pointed fruit, dry flesh and high fuzz. This means that several years of selection are required to develop acceptable cultivars. However, the heritability of many of these traits is moderate to high and so reasonable progress is possible. We have started on this process and in 2014 planted the first generation of hybrids of 'Nieve' with short FDP and low-chilling parents. In 2015 we selected two elite seedlings which are now being used as parents to recover the all-white fruit characteristics.

In Mexico, 'Nieve' has been crossed with cultivars from Arkansas, Brazil, Valencia, California, Korea and Canada resulting in the production of selections in the range of 250 to 450CU with non-melting flesh and TSS of 18-20%. 'Nieve' has also been reported to have some tolerance to leaf rust. The complete lack of red, and the firm flesh, high TSS, with tree health and small tree size are valuable traits that we will attempt to incorporate into our breeding populations.

ACKNOWLEDGEMENTS

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University of Queensland. It has been part-funded by voluntary contributions from Low Chill Australia. Dr S. Perez kindly supplied seed of 'Nieve'.

Any grower wishing to obtain information on our low-chill selections or on the breeding program should contact Bruce Topp at the Maroochy Research Facility, phone 07 54535973 or fax 07 54535901 or email b.topp@uq.edu.au.