Procado®: A New Australian Avocado Rootstock

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Phytophthora root rot (*Phytophthora cinnamomi* Rands) has arguably the greatest impact on the field-loss of avocado production worldwide. Trees in all countries commercially growing this crop are now affected to a greater or lesser extent with this disease, which, left untreated, becomes fatal. Effective chemical management of Phytophthora root rot (PRR) in high disease pressure environments is available via phosphonate-based and metalaxyl/mefenoxam fungicides. Phosphonates are applied at key phenological stages preventatively and curatively (Lisa – link to video and recent TA article), while application of metalaxyl/mefenoxam is generally only cost effective at planting. Growers should not rely solely on fungicides to manage PRR but embrace a holistic approach to manage this disease.

Resistance or tolerance amongst rootstocks to PRR in avocados has been a key selection trait for the past 35 years with varying levels of success. The Californian program identified that the "Duke" series of rootstocks were moderately resistant to Phytophthora, and Duke 7 was released as a clonal rootstock in the mid-1970s. Since then, Dusa, from the South African selection program, has become the international benchmark for resistance and has been planted in Australia for a number of years. Velvick, a Queensland selection, is also extensively planted as a seedling rootstock in Australia, and is a vigorous rootstock that performs well under high PRR disease pressure. None of these rootstocks are completely resistant to PRR, but rather form an important component of an effective management package to control PRR in trees under high disease pressure.

Procado®

In the early 2000s a healthy "escape" avocado tree (Hass grafted to an unidentified seedling rootstock) was noticed growing in an orchard at South Kolan near Bundaberg, where the condition of surrounding trees had significantly declined due to Phytophthora root rot. The tree was cut below the graft union in spring, leaving only the rootstock to regenerate shoots. Once the new growth had sufficiently hardened, scion wood was cut and vegetatively propagated using the micro-cloning technique described by Ernst (1999) and Ernst *et al.* (2012). The rootstock was given the accession code of SHSR-04 and was grafted with Hass in preparation for field evaluation for resistance to Phytophthora root rot.

To secure the Intellectual Property a second set of trees was prepared with SHSR-04 grafted to seedling Velvick rootstock and planted in a commercial orchard in North Queensland, to provide descriptive data for Plant Breeders Rights (PBR). An application was made for PBR under the name of SHSR-04 and given preliminary approval on the 24th August, 2019. This immediately provides IP protection through until the application is finalised, which is expected by August 2021. More recently (October 2020), a Trade Mark was granted for the rootstock and the name Procado® was successful, which will be used for marketing purposes.

From data collected to-date we know that Procado® is predominantly of the Guatemalan horticultural race with fruit maturing mid-season (May/June). The tree has a semi-upright growth habit of moderate vigour and despite the "A" type flower, crop load at the PBR experimental site has been low since fruiting began. This has no reflection on it being used as a rootstock where it induced a high level of precocity

Figure 1. Procado® fruit showing thick, pebbly skin.

in trees grafted to Hass planted in Central Queensland in their first flowering season (developing fruit were removed to maximise vegetative growth in their first year of establishment). Obviously, more cropping data is required to support these early observations.

Procado® fruit has a thick, pebbly skin and very palatable flesh with a rich nutty flavour. The fruit has a flesh recovery of about 80% with a mean size of about 345 g (Figure 1). Fruit characteristics are required for PBR and Plant Patent descriptions but are irrelevant for its use as a rootstock. Procado® seeds have been grown as rootstocks and grafted with Hass then tested for PRR resistance but gave no commercially useful protection.

DNA fingerprinting was kindly provided by Prof Iñaki Hormaza (Institute of Subtropical and Mediterranean Horticulture, Malaga, Spain), utilising 12 simple sequence repeat (SSR) molecular markers, that demonstrated Procado® was different to all the other genotype profiles held in the collection in Spain, which include Velvick and the South African and Californian rootstocks.

Evaluation of SHSR-04 (Procado®) for resistance to Phytophthora root rot

A series of replicated trials to evaluate SHSR-04 (Procado®) and other rootstocks, were undertaken between 2006 and 2014 in a field at Duranbah, NSW, which had previously grown avocados that were removed due to PRR decline. Soil sampling and lupin baiting confirmed the presence of high levels of *Phytophthora cinnamomi*.

Trial 1. Replicates of 11 rootstocks propagated as seedlings and/or clones and grafted to Hass were planted in May 2006. At planting all nursery trees were assessed as having a health rating of 1, i.e. full health. To assist with the field establishment, Ridomil® (metalaxyl) granules were spread around trees at planting, and a full phosphonate program (pre-planting Agri-Fos® pot drench and post-planting bark-painting with Agri-Fos®) was applied for the first 12 months. In May 2007 all PRR control management was withdrawn from the trees. Regular disease assessments were started in November 2006 and continued through to March 2008 using the 1 -10 rating scale where 1 = healthy and 10 = dead. Trunk girth circumferences were measured in April 2008 as a secondary indicator of tree health.

Full details including statistical analyses are available in Smith *et al*., (2011), and are represented here as simple plots of health over time for each rootstock. Health of all trees declined when rated 6 months after planting despite support from the metalaxyl and phosphonate program (Figure 2). This may be partly due to trees being rated after winter and before new summer growth had occurred.

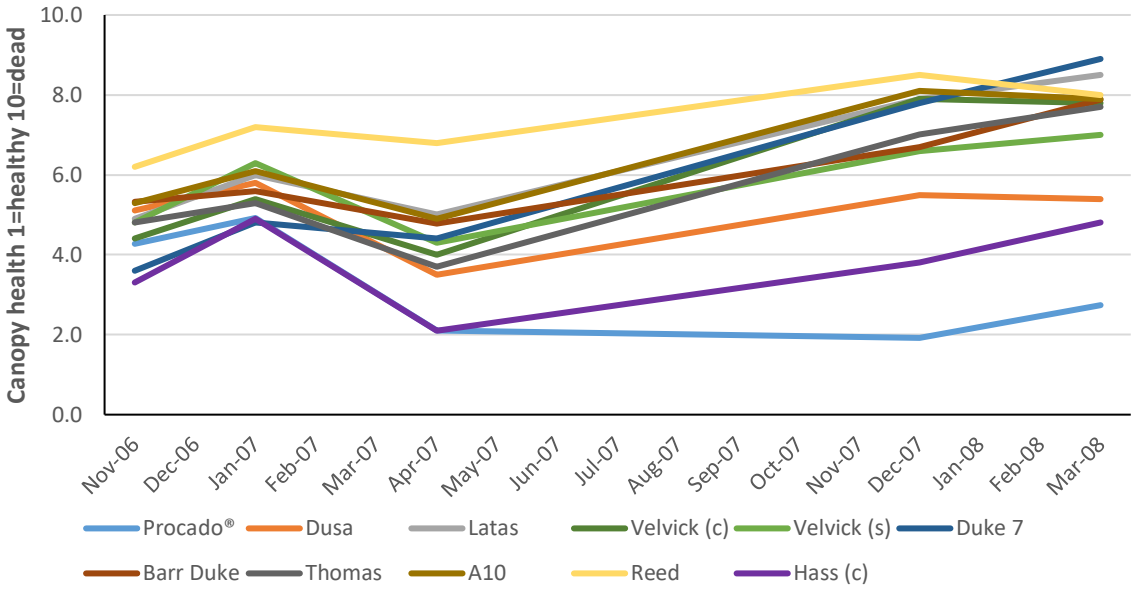


Figure 2. Average health of Hass trees grafted to different rootstocks 6-22 months after planting at Duranbah in May 2006 (Trial 1). Assessed using a rating scale of 1–10, where 1 = healthy and 10 = dead.

Figure 3 Dr Ken Pegg with Hass grafted to SHSR-04 (Procado®) at Duranbah, 2008.

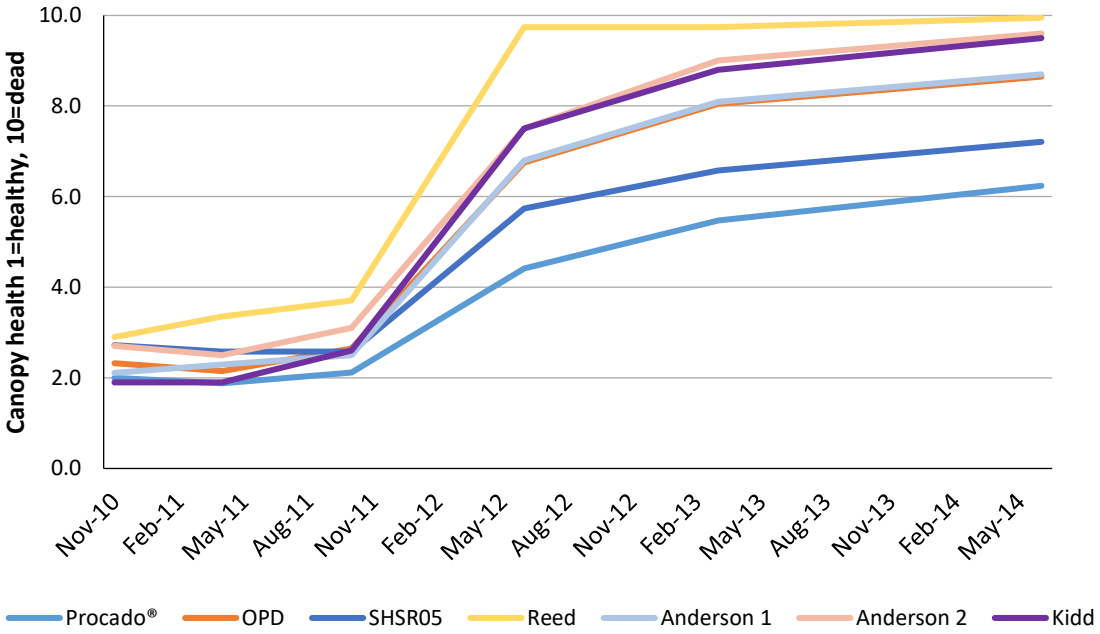
At the end of the first summer (11 months after planting) Hass, SHSR-04/Procado®, Dusa and Thomas had the lowest health ratings, i.e. were the healthiest trees but not statistically different to some of the other rootstocks. Most rootstocks declined significantly in health 19 and 22 months after planting, the exceptions being SHSR-04 (Procado®), Hass and Dusa (Figure 2). Of these three, SHSR-04 (Procado®) (Figure 3) had a significantly better health rating than Dusa but was not different to Hass, which at this point in time performed strongly. The clone of Hass has no graft union since it's basically a rooted cutting and this may be that reason for its "pseudo-resistance" to PRR as beyond the scope of this data these trees declined rapidly in health and succumbed to root rot. Girth data (Table 1) largely mirrored the health ratings. The exception was Hass grafted to Thomas, which had the greatest trunk circumference when measured despite the trees being in significant PRR decline. Observations from other rootstock experiments in the HAL AV08000 project showed that the Hass/Thomas tree combination is particularly vigorous and these trees generally grew faster than any other of the rootstock combinations. In this instance, it is likely that Thomas rootstock trees put on greater growth than other trees during the first year after planting when all were protected by fungicides and before Phytophthora decline set in. Several years after the trial was planted, 70% of Procado®, Dusa and clonal Hass trees were still alive, while most other trees of other rootstocks had died in that time (Table 1).

Table 1 Average trunk girth and percentage survival of trees grafted to different rootstocks planted at Duranbah in May 2006 (Trial 1). Trunk girth measurements were taken immediately above the graft union 2 years after planting. Tree survival is the % of living trees compared with total numbers planted. Mean values followed by the same letter are not significantly different at $P = 0.05$. Girth data are from Smith *et al.,* 2011.

Rootstock	Girth (mm) at 2 years		Tree survival % at 6 years
Latas	128	bcd	30
Dusa	112	bcd	70
Velvick clonal	125	bcd	20
Velvick seedling	99.0	d	50
Duke 7	108	cd	10
Barr Duke	132	abcd	30
Thomas	179	ab	30
A10	83.7	d	0
Reed	78.4	d	10
SHSR-04 (Procado®)	179	a	70
Hass	143	abc	70

Trial 2. Replicates of 7 rootstocks propagated as seedlings or clones and grafted to Hass were planted at the same site in Duranbah in April 2010. In addition to SHSR-04 (Procado®) and Reed (as the known susceptible control), the rootstocks included SHSR-05 (seedlings) from a tree north of Bundaberg, seedling Kidd and two selections from Anderson Horticulture, assigned here Anderson 1 and Anderson 2. The trial also included trees grafted with an open-pollinated seedling Dusa (OPD). These seed were sourced from a Shepard orchard where the Dusa rootstock in several trees had been allowed to escape and fruit. While the maternal parent of each seed is known to be Dusa, the pollen donor (father) could be either Dusa or Shepard. A year after planting, trees on Procado® were significantly healthier than all other rootstocks, except those grafted with Kidd or Anderson 2 (Figure 4). Reed rootstock is considered extremely susceptible and declined more rapidly than other rootstocks after planting. Canopy health continued to decline over time, and at three years after planting, trees grafted with Procado® and SHSR-05 were the healthiest (Figure 4). At the conclusion of the trial, approximately 4 years after planting, more than 50% of trees grafted to Procado® were alive, 40% of SHSR-05 and 30% of OPD and Anderson 1. There was only 5-10% of trees on other rootstocks still alive. It is noted that the OPD rootstock planted in this trial is not a true clonal Dusa and likely did not perform as well as Dusa would have, in terms of tree health over time and survival. This demonstrates why it is important to protect the integrity of these superior proprietary rootstocks by licences and non-propagation agreements. They simply do not perform as seedling rootstocks, due to the genetic variability introduced by the outcrossing.

Figure 4. Average health of Hass trees grafted to different rootstocks 7-50 months after planting at Duranbah in April 2010 (Trial 2). Assessed using a rating scale of 1–10, where 1 = healthy and 10 = dead.



Trial 3. Surviving trees from previous trials were removed and a third experiment to evaluate resistance of seedling or cloned rootstocks to PRR was planted into the same sites at Duranbah in May 2013, and similarly protected from PRR for the first year following planting. SHSR-07 and SHSR-08 were cloned from seedling trees surviving under high PRR disease pressure in an earlier rootstock trial, planted in 2007. SS3-1 was from the Canary Islands PRR selection program. As the population of Pc varies according to the availability of roots to infect, the new plantings were grouped according to the health of their previous occupant, i.e. empty for about 3 years or tree removed 2 months prior to planting the new trial.

After two years from planting, rootstocks indicating the highest tolerance to PRR were SHSR-08, SHSR-04 (Procado®) and Velvick however, they are not significantly different to Dusa and SHSR-07. Reed, SS3-1 and Zutano were the worst affected and in significant decline when assessed less than a year after planting. (Figure 5).

Approximately 18 months after planting, counts of developing fruit were higher on the healthiest trees (Table 2), and at the end of the data collection period, nearly two years after planting, tree survival was greatest on Velvick, SHSR-04 (Procado®) and SHSR-08. Despite the severe PRR decline, there was still a reasonably high survival rate of trees on Zutano and Reed.

An interesting link to the planting site history was revealed, where the majority of tree deaths occurred at sites where live trees had been removed only 2 months prior to planting, compared with those which were planted into sites which had been cleared for a few years. This shows the benefit of a period of fallow for replant orchards to allow *P. cinnamomi* inoculum in the soil to decline.

Figure 5 Health of Hass trees grafted to different rootstocks 6 – 22 months after planting at Duranbah in May 2013 (Trial 3)**.** Tree health is rated on a scale where 1 = healthy and 10 = dead.

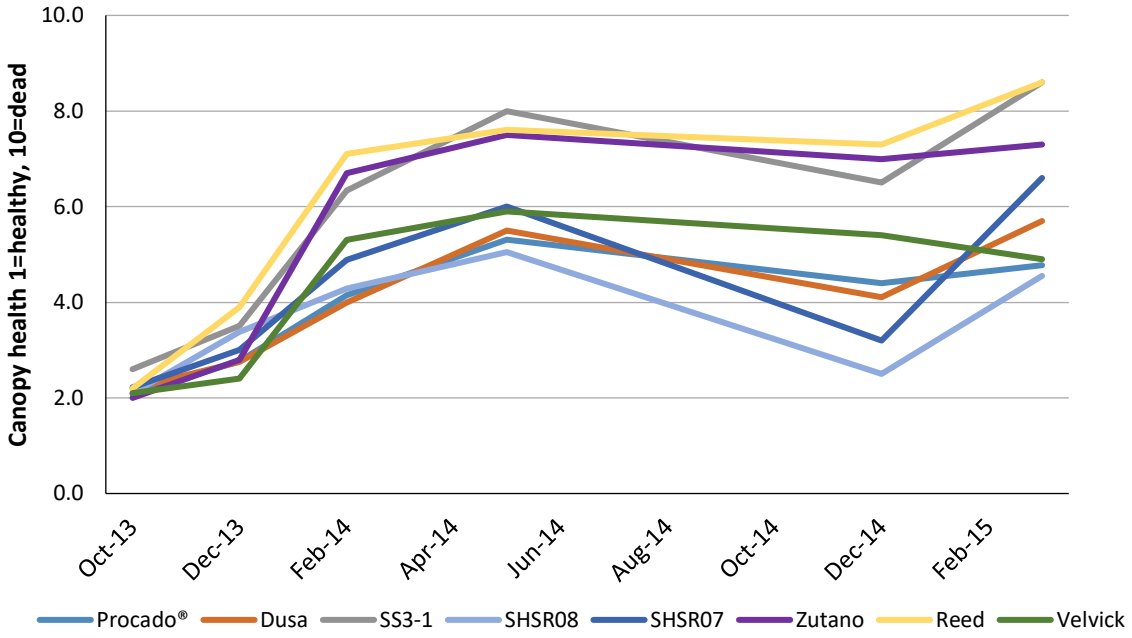


Table 2 Fruit counts and % tree survival of trees grafted to different clonal rootstocks 19-22 months after planting at Duranbah in May 2013 (Trial 3)**.** Tree survival is the % of living trees compared with total numbers planted. Means followed by the same letter are not significantly different ($P \leq 0.05$).

Rootstock[1]	Fruit counts/tree 19 months		Tree survival % 22 months
SHSR-08 (clonal)	18	abc	91
SHSR-04 (Procado®) (clonal)	23	ab	79 (85)[2]
Dusa (clonal)	32	a	64
Velvick (seedling)	11	bcd	100
SHSR-07 (clonal)	25	ab	60
Zutano (seedling)	3.8	cd	90
Reed (seedling)	2.0	d	70
SS3-1 (clonal)	3.3	bcd	23

[1] SHSR-07 and SHSR-08 were cloned from seedling trees surviving under high PRR disease pressure in an earlier rootstock trial, planted in 2007.
[2] One of the three tree deaths was due to *Phellinus noxius*, not PRR. If this death is not included, the tree survival is 85%

Commercial planting of Procado®

The first commercial planting of 600 Hass grafted to Procado® was made near Childers in July 2020 (Figure 6), in a replant orchard block that was replaced because of significant tree decline due to Phytophthora root rot. Tree spacing is at 7.5 x 3 m (443 trees/ha), which is somewhere between a commonly used commercial spacing and a true high density orchard. The reason for this is the same block as trees planted on the more vigorous rootstocks of Dusa and Velvick and the spacing used provides greater opportunity to manage all rootstock/scion combinations with strategic pruning and PGR application.

Figure 6 Newly planted block of Hass grafted to Procado® near Childers, July 2020.

Despite the drier than average spring and summer conditions that followed, trees have established well (Figure 7). A full program of Phytophthora suppression was implemented starting from soil preparation through to fungicidal treatments that were continued after planting. Tree height and diameters were recorded 2 weeks after planting along with measurements from similar aged Hass trees planted on Dusa and cloned Velvick rootstock, so that comparative growth rates can be tracked with age. These will be reported as data is accumulated.

Figure 7 Nine-month-old Hass on Procado® growing in a replant orchard near Childers, March 2021.

Early observations on tree vigour and yield

Whilst Procado® produces a tree of moderate vigour when grown as the scion (variety), when used as a rootstock it appears to produce smaller trees, at least in its early years. This is illustrated in Figure 8, where Shepard was grafted to 3 different cloned rootstocks, Velvick seedlings, Velvick mother tree and Procado®. Velvick has long been recognised as producing vigorous growing trees when grafted to Hass and Shepard so it's not surprising that Shepard grafted to cloned Velvick seedlings (seedlings from where the tip was removed and rooted as a cutting for rootstock use) has produced the largest trees (24.6 m^3) over the 2.5 year period since planting. Shepard grafted to rooted cuttings from the Velvick mother source produced the second largest trees at 20.2 m^3, while the Shepard trees grafted to Procado® were less than half the size of trees on the other two rootstocks at 8.9 m^3 (yield data not available at the time of publication).

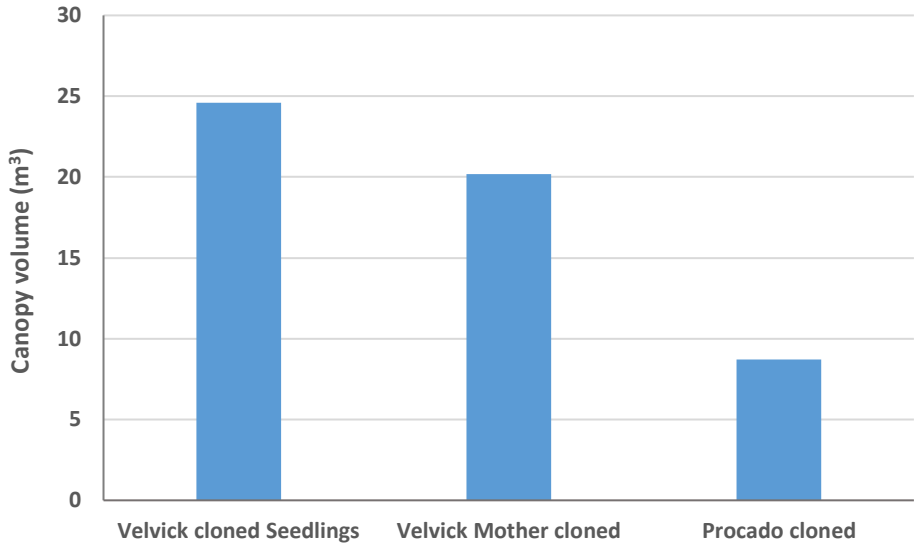


Figure 8. Canopy volume (m^3) of Shepard trees grafted to cloned rootstocks of Velvick seedlings, Velvick mother and Procado®. The 2.5-year-old trees were growing in an orchard at Walkamin, NQ and were planted within 4 months of each other. Data are mean values of 10 trees for each rootstock/scion combination. Shepard trees on cloned Procado® are significantly smaller than Shepard on cloned seedling and cloned mother Velvick ($P<0.001$).

Figure 9. A hillside, high density avocado orchard in Chile where tree size is managed by strategic pruning and fertigated PGRs.

The implication from this "lower vigour" trait of the Procado® rootstock is the potential to grow high density orchards with tree height capped to 2-3 m with less reliance on plant growth regulators (PGRs). Chile has been the leader in moving from low to high density avocado production as a matter of necessity to avoid damaging frost, where orchards have been increasingly planted on steep mountain slopes with use of mechanisation limited. Orchards are planted at several densities depending on location and management skills of the growers but range from 555 to 1000+ trees/ha (Figure 9). By comparison, standard tree densities in most avocado orchards across Australia are somewhere between 166 to 200 trees/ha. Tree height in Chilean high density orchards is contained to 1.5-2 m using soil-applied PGRs and hand pruning, which are assisted to some extent by climatic and edaphic factors (Whiley *et al.* 2012). However, most nursery trees are propagated on seedling Mexicola rootstocks that impart moderate to high tree vigour. Hass is the main variety grown and well-managed high density orchards consistently achieve between 15 to 25 t/ha, albeit there are years when yield crashes due to inclement weather affecting flowering/fruit set.

Closer to home, for a number of years the senior author has been assisting with the development of high density avocado production in the Far North of New Zealand, where an orchard has been planted on the slopes of ancient sand dunes. With much of the planted area not suitable for machinery access, a decision was made to plant at high densities, initially at 3.5 x 3.5 m (814 trees/ha) then later at 5 x 3 m (825 tree/ha) to provide inter-row access for small orchard vehicles (Figure 10). Most of the orchard has been planted with Hass grafted to seedling Zutano rootstock, which is quite a vigorous growth combination. Some Hass grafted to cloned Dusa were also been planted, which has produced trees with greater vigour than Hass on seedling Zutano, thereby increasing the difficulty of managing smaller trees. The aim is to contain tree height at 2.5 m since hydraulic ladders can't be used due to the sloping terrain. Pesticides and pelletised fertiliser are applied by helicopter. It's been a steep learning curve with blocks escaping from tree size control in the early years as management techniques were being developed. Success comes to those who persist and tree height in blocks planted more recently are being controlled with production over the past 4 years averaging around 18 t/ha, that is, consistently carrying heavy crops. It's noted that the most successful blocks in the orchard are those where tree vigour has been suppressed by soil conditions. Both Chile and the New Zealand orchard documented in this article use polliniser trees throughout the orchard and introduce bee hives during flowering to maximise pollination opportunities, since flowering for Hass often occurs during periods of inclement weather for floral dichogamy to operate successfully. This provides an additional layer of "insurance" over all other management inputs given prior to the flowering/fruit set event.

Figure 10. High density orchard in New Zealand's Far North where tree size is managed with strategic pruning and fertigated PGRs.

Chilean and New Zealand production conditions differ from most of Australia's growing regions with both labour and agronomic factors that make high and ultra-high density orchards viable for them. However, both countries are having to deal with relatively high-vigour rootstocks. The concept of producing economic yields from smaller trees is universal across all fruit tree crops and for many fruits has been made possible by the use of genetic combinations (rootstocks/scions) developed from 100+ years of targeted breeding and selection programs, that reduce tree vigour and growth, e.g. apples and citrus. Smaller tree canopies increase the efficiency of light interception to the total orchard canopy, generally resulting in yield improvements through greater cropping efficiency per cubic meter of canopy (Figure 11). When tree vigour is controlled an increased percentage of energy is diverted from shoot growth to fruiting (Wolstenholme *et al.*, 1990). While we are still learning the growth and cropping habits of trees grafted to Procado®, the data to date suggest that this rootstock could be a very useful tool in

Figure 11. Crop load on a 2 m high tree in a high density orchard in New Zealand's Far North managed with strategic pruning and fertigated PGRs.

managing growth in high density orchards in Australia as the key features it provides are reduced vigour and good field resistance to Phytophthora root rot.

Evaluation of the yield capacity of SHSR-04 (Procado®)

To evaluate preliminary yield performance of SHSR-04 (Procado®), 10 trees of this rootstock were clonally propagated together with 10 trees of Velvick, each as a seedling or cloned rootstock giving a total of 30 trees. Velvick was chosen as the standard for comparison since it is widely used across the Australian avocado industry and has been shown to be one of the most productive rootstocks used in Australia (Whiley *et al*., 2013). The trees were planted in February 2007 in a Phytophthora-free site at Hampton in southeast Queensland. Yield data was first recorded in 2010 which was the first crop the trees had set and carried to maturity, and subsequently measured in 2011 and 2012. The HAL Project AV08000 concluded in 2012. Yield is reported in mean kg/tree and t/ha for three years (Table 3). Yield data was collected for SHSR-04 (Procado®) in 2013 but not for Hass on Velvick rootstock trees.

Table 3 Yield, and cumulative yield of the SHSR-04 (Procado®) cloned rootstock in comparison with seedling and cloned rootstocks of Velvick growing in a Phytophthora root rot-free site at Hampton in south east Queensland. Values in columns followed by different letters are significantly different ($P \leq 0.05$) and are the mean of 10 trees for each rootstock/scion combination.

Rootstock[1]	**Yield (kg/tree)**				**t/ha[2]**				**Cumulative Yield (kg/tree)**
	2010	**2011**	**2012**	**2013**	**2010**	**2011**	**2012**	**2013**	
SHSR-04[C]	6.8	30.6 b	3.6	58.9	1.3	5.7	0.7	10.9	41.0[4]
Velvick[S]	5.3	61.2 a	10.1	-	1.0	11.3	1.9	-	56.4
Velvick[C]	7.3	32.7 b	1.8	-	1.4	6.0	0.3	-	41.8
	ns[3]		**ns**						

[1] C = cloned rootstock and S = seedling rootstock.
[2] t/ha is based on 185 trees/ha (9 x 6 m orchard spacing).
[3] ns = non significant ($P > 0.05$).
[4] 2013 data for SHSR-04/Procado® has not been added to this total.
Data are from Whiley *et al*., 2013.

There were no significant differences between rootstock yield in 2010, however, in 2011 yield of Velvick seedling rootstock was significantly ($P \leq 0.05$) greater than either the cloned Velvick or SHSR-04 (Procado®) rootstocks. The crop across the whole orchard was low in 2012 due to inclement climatic conditions during flowering and fruit set in the preceding 2011 spring, and there were no significant differences between rootstock yield this year (Table 3).

When comparisons are made with the seedling and cloned Velvick rootstocks in this experiment against the same rootstocks planted at Hampton in 2004, it's noted that the Velvick seedling rootstock outperformed the Velvick cloned rootstock in the early years of the experiment but after five fruiting cycles there was no significant difference between the two rootstocks. From Table 3 data it's too early to predict the comparative yield performance of SHSR-04 (Procado®) in a Phytophthora-free site. However, more recent growth data with Shepard as a scion, indicates that Procado® produces trees with lower vigour than other rootstocks in common use (Figure 8) and comparative yields should be made on a canopy efficiency basis (kg/m^3) since when growing high density orchards, the number of individual canopies/ha can be 3-4 times greater than in conventionally planted orchards.

Conclusions

Procado® is an Australian developed rootstock with a level of commercially useful resistance to Phytophthora root rot, which used with other disease management practices, will assist in maintaining orchard health. The rootstock belongs to the Guatemalan race of avocados differentiating it from the South African and Californian rootstocks with Phytophthora root rot resistance that are predominantly of Mexican race origin. The Horticulture Australia Ltd (HAL) project *Rootstock Improvement for the Australian industry – Phase 3* (AV08000) project clearly demonstrated that under most Australian production conditions Guatemalan and Guatemalan x West Indian race hybrids outperformed Mexican race rootstocks. Establishment and performance of trees grafted to Procado®, under additional stressful conditions, for example, salinity, will continue to be evaluated. With current knowledge, it appears the lower tree vigour induced by the Procado® rootstock will be more suited to higher density orchards than those currently planted by Australia growers and thus row and tree spacings should be carefully considered for a more timely return on investment per hectares planted.

Where to buy trees grafted to Procado®

Propagation licenses have been signed with Andersons Horticulture Pty Ltd, Duranbah, NSW, Flemings Nurseries Qld, Nambour, QLD and Turkinje Nursery, Walkamin, QLD. Future license agreements with other ANVAS nurseries are expected.

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