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New Cultivars from the Australian Almond Breeding Program

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The almond [*Prunus dulcis* Miller (D.A. Webb)] breeding program of the University of Adelaide began in 1997, with the objective of creating new superior cultivars with high productivity, good kernel quality, and self-fertility (Wirthensohn and Sedgley, 2002). The aim of self-fertility is, in part, due to the potential incursion of Varroa mite (*Varroa destructor* and *Varroa jacobsoni*) into almond-growing regions that would greatly affect bee hive performance at the critical time of flowering (Queensland Government Department of Agriculture and Fisheries, 2017). It also allows growers to have single-block orchards to facilitate more efficient orchard management. Scion cultivar improvement is acknowledged by the Almond Board of Australia as a high priority in their Industry Strategic Plan (ABA, 2018). Australian growers are mainly reliant on cultivars from overseas, mostly from California, but with a small representation of old Australian cultivars such as Johnston's Prolific, Chellaston, and Keane. The Australian industry requires new varieties to expand its planting choices.

The breeding program has produced more than 34,000 seedlings and in 2016/2017, the first six cultivars were released commercially to the Australian almond industry. 'Capella', 'Carina', 'Maxima', 'Mira', 'Rhea', and 'Vela' all outperform the benchmark cultivar Nonpareil in yield, with four being self-fertile. The earlier flowering cultivars offer a replacement for 'Price', and the later flowering cultivars offer a replacement for 'Carmel', which is showing symptoms of noninfectious bud failure. All have been registered with the Plant Breeders Rights (PBR) office of Intellectual Property Australia (IP Australia) and US Plant Patents.

Origin

'Capella', 'Carina', 'Maxima', and 'Mira' were derived from a cross between 'Nonpareil' and 'Lauranne'. 'Nonpareil' was chosen as the female parent due to its high-quality kernel characteristics, and 'Lauranne' was chosen mainly as a source of self-compatibility (Grassely, 1991). 'Rhea" was derived from a cross between 'LeGrand' and the Australian variety 'Keane'. 'LeGrand' was chosen as the female parent because it was partially self-fertile, and 'Keane' was chosen as the male parent due to its kernel characteristics. 'Vela' was derived from a cross between the Australian variety 'Chellaston' and breeding selection 1bT47 (a breeding selection from a cross of 'Nonpareil' × 'Lauranne'). 'Chellaston' was chosen as female parent due to its kernel size and 1bT47 was chosen as male parent on the basis of kernel quality and self-fertility.

Description

'Capella' is a slightly open tree with medium vigor. Flowering buds occur on both spurs and 1-year old shoots. Flowers are medium to large, with abundant pollen. The stigma is lower than or level with the anthers, which is highly beneficial for self-pollination because 'Capella' is self-compatible, showing up to 56.2% fruit set after self-pollination. The *S*-alleles are S_7S_f making it a universal pollinator for all trees that flower coincidently. It flowers 1 d after 'Nonpareil' and harvests shortly after 'Nonpareil'. The nuts of 'Capella' are hard, and the kernel is medium to large (1.33–1.48 g; Table 1), rounded in shape with light kernel color.

The 'Carina' tree is open to spreading with low to medium vigor. Flowering buds occur on both spurs and 1-year old shoots. Flowers are medium in size, with medium to many stamens. The stigma is below the anthers, which facilitates its self-compatibility (*S*-alleles S_7S_f). 'Carina' flowers 1 to 4 d before and harvests slightly before 'Nonpareil'. The nuts are semi-hard and the kernel has a medium weight (1.2–1.5 g) with light kernel color and similar shape to 'Nonpareil'.

'Maxima' is a spreading tree with medium vigor. Flowering buds occur on both spurs and 1-year old shoots, but mainly spurs. Flowers are large with many stamens. 'Maxima' flowers 3 to 6 d after 'Nonpareil' and is half cross-compatible because its *S*-alleles are S_3S_8. Its harvest time is early to midseason, along with 'Nonpareil'. The kernels are large (1.81–2.05 g) and the skin is pale; the nut is semi-hard.

The tree of 'Mira' has a slightly open habit with high vigor. It is self-compatible and flowers 4 to 6 d after 'Nonpareil'. The nuts are semi-hard and the kernel is small to medium (1.28–1.5 g). The hull of 'Mira' flares open fully which makes hull rot less likely. Harvest time is similar to that of 'Nonpareil'.

'Rhea' has an upright to slightly open habit with medium to strong vigor. Flowering buds are mostly on spurs and flowers occur 3 to 4 d earlier than those of 'Nonpareil'. The nut is a papershell and the kernel has a small to medium weight (1.1–1.28 g) with a strong almond flavor. 'Rhea' is self-incompatible and is half cross-compatible with 'Nonpareil'.

'Vela' is an upright to spreading tree with medium vigor and demonstrates very high and regular production of softshell nuts with kernels with an excellent flavor. The kernel size is large (1.7–1.8 g), and harvest maturity is medium to late. 'Vela' is self-compatible and flowers up to 4 d before 'Nonpareil'. Figure 1 shows the nuts and kernels of the six new varieties.

Performance

Field evaluation occurred on a grower's property in the Riverland region of Victoria (lat. 34°10′S, long. 141°02′E, elevation 59 m) over 10 years. The climate is warm temperate, with little rain during the summer months. Annual rainfall average is 251 mm. The soils are sandy loam over a limestone layer. The evaluated trees were grafted onto 'Nemaguard' rootstock with between 5 and 10 replicates of each variety. Reference and comparator varieties were planted randomly within the trial for PBR purposes. Data were collected yearly on flowering and harvest time and kernel quality. At each harvest, 100 fruit were collected from each variety and measured in the laboratory. Larger tertiary trials (100 trees each) are planted in all major almond-growing regions in Australia (Riverland, Sunraysia, and Riverina). Table 1 shows the main traits of each of the new cultivars.

Chemical composition of the kernels was analyzed for 4 years to determine variation and specificity of each selection. Chemical analysis was performed according to Zhu et al. (2015). Briefly, almond lipids and fatty acid measurements were based on methanol-chloroform extraction and gas chromatograph with flame ionisation detector analysis, and almond tocopherol measurements were based on alkaline saponification, hexane extraction, and high-performance liquid chromatography with diode array and fluorescence analyses. Twenty kernels of each variety were weighed before processing to determine the kernel size. Thereafter, the kernels were dried at 50 °C for 48 h, ground to a fine powder using a coffee grinder, sieved through a 1000-μm mesh, and then used for analysis. The results in Table 2

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Table 1. Main traits of 'Carina', 'Capella', 'Maxima', 'Mira', 'Rhea', and 'Vela' almonds.

Characteristic	Capella	Carina	Maxima	Mira	Rhea	Vela
Pedigree	Nonpareil × Lauranne	Nonpareil × Lauranne	Nonpareil × Lauranne	Nonpareil × Lauranne	LeGrand × Keane	Chellaston × 1bT47
Self-compatibility	Yes	Yes	No	Yes	No	Yes
S-genotype	S_7S_f	S_7S_f	S_3S_8	S_7S_f	$S_8S_?$	S_3S_f
Flowering time	Nonpareil + (0–2 d)	Nonpareil – (1–4 d)	Nonpareil + (3–6 d)	Nonpareil + (4–6 d)	Nonpareil – (3–4 d)	Nonpareil – (4 d)
Harvest season	Early-mid	Early	Early-mid	Mid	Mid	Mid-late
Kernel weight (g)	1.33–1.48	1.2–1.5	1.81–2.05	1.28–1.5	1.1–1.28	1.7–1.8
Shell hardness	Hard	Semi-hard	Semi-hard	Semi-hard	Paper	Soft
Double kernels	0%	0%	0%	0%	0%	0%
Kernel taste	Sweet	Sweet	Sweet	Sweet	Semi-bitter	Sweet
Growth habit	Slightly open	Spreading	Spreading	Slightly open	Upright to slightly open	Upright to slightly open
Nut location	Spurs and 1-year-old wood	Spurs and 1-year-old wood	Mainly Spurs	Spurs and 1-year-old wood	Spurs and 1-year-old wood	Spurs and 1-year-old wood
Bacterial spot tolerance	Very good	Very good	Fair to good	Good	Very good	Good
Yield (kg·ha^{-1})[z]	3,872	3,614	4,071	3,750	3,388	3,569

[z]Yield results are data collected from the fourth leaf tertiary trial in The Riverland region in 2019.

Fig. 1. Kernels and nuts of 'Capella', 'Carina', 'Maxima', 'Mira', 'Rhea', and 'Vela'.

Table 2. Chemical composition of the new cultivars in comparison with 'Nonpareil'.

Cultivar	Fat (% dry wt)	Oleic acid (% oil)	α-tocopherol (mg/100 g oil)
Nonpareil	54.2	62.2	45.4
Capella	49.7	65.0	44.6
Carina	53.0	60.3	49.5
Maxima	55.2	56.3	39.0
Mira	58.3	59.8	52.83
Rhea	54.4	65.9	33.8
Vela	55.8	63.4	41.0
Significance	NS	NS	NS

NS = not significant at $P < 0.05$.

Table 3. Average percentage fruit set obtained after bagging in four almond selections over 5 years.[z]

	Fruit set (%)[z]			
Yr	Carina	Capella	Mira	Vela[y]
2009	52.7 a	16.6 b	31.9 b	—
2010	36.8 b	56.2 a	8.9 c	—
2011	20.7 a	18.3 a	11.4 a	—
2012	62.7 a	54.8 a	30.1 b	—
2014	42.1 a	42.3 a	16.7 b	32 ab

[z]Differences within each row followed by different letters are significant at the 0.05 level (least significant difference).
[y]Vela trial was planted in 2010; the first record was in 2014.

Fig. 2. (**A**) 'Carina' almond tree enclosed in insect-proof mesh before flowering. (**B**) Fruit set on 'Carina' resulting from self-fertilization.

show the average across 4 years. The results were not significantly different for all traits measured; however, across the years studied, 'Mira' showed a trend of higher values for oil content than 'Nonpareil', although it was observed that 'Carina' and 'Maxima' showed higher oil content than 'Nonpareil' during 2 of the 4 years. 'Rhea' showed a trend of consistently higher oleic acid levels than 'Nonpareil', which is important because it has health benefits for humans and is important for oil stability. Levels of α-tocopherol were only measured in 2015 and 2017; however, 'Carina' and 'Mira' showed a trend of having higher levels than 'Nonpareil'; overall, the selections showed very high amounts of α-tocopherol when compared with some European cultivars such as Marcona and Desmayo Largueta (46.33 and 30.43 mg/100 g oil, respectively) (Kodad et al., 2006).

Results determined from bagging branches in the field to test for self-fertility are presented in Table 3 and Fig. 2. Five trees of each variety were bagged to exclude pollinators. Unopened flowers were counted and open flowers were removed. After 12 weeks, the number of fruits were counted and the percentage of fruit set was calculated. There was a large amount of variation between the years, which may have been caused by climate differences between the years (2009 had the highest average maximum and minimum temperatures for August, whereas 2010 had the lowest average maximum temperature and 2014 had the lowest average minimum temperature; Australian Government Bureau of Meteorology, 2017); however, there did not seem to be a clear pattern. As a control, 'Nonpareil' was also bagged in 2014 and set an average of 1.7% fruit. It is possible that small insects such as thrips may be able to get into "insect-proof" nets and move pollen between flowers.

Chemical and fruit set data were analyzed by an analysis of variance using GenStat (14th Edition, VSN International Limited, Herts, UK). Mean comparisons