Almond Variety Development

Project No.: **14-HORT1-Gradziel**

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Objectives:

Develop (1) improved pollenizers for Nonpareil, and ultimately, (2) varieties that possess self-fertility and improved market value and resistance to disease, insects and environmental stress. Specific objectives for 2014-15 include:

1. Identify effective predictors of yield potential (annual and cumulative) to assess opportunities/limitations of traditional and new biotech approaches including molecular marker-assisted-selection (MAS).
2. Generate 12,000 new seedling progeny. Prioritize traits in partnership with growers, handlers and processors. Evaluate and reduce by an additional 30% the ~26,000 progeny trees currently in breeding trials through development/implementation of low-input/high-throughput breeding efficiency strategies.
3. Finalize 2014 patenting and release UCD2-19E as a late flowering and very productive *Nonpareil*-type cultivar. Evaluate advanced selections in regional trials including the new Regional Variety Trials (RVTs).

Interpretive Summary

The California almond industry is in a historic period of transformation driven by increased Central Valley acreage along with increasing environmental and market requirements, reductions in resources such as water, agrochemicals, and natural pollinators, as well as the uncertainties of a changing climate. While almond represents a diverse and highly adaptable species, commercial production in California is dependent almost entirely on the variety Nonpareil and a relatively few closely-related pollenizers, most of which have Nonpareil and Mission as direct parents. A long-term emphasis of the UCD almond breeding program has been the identification and incorporation of new and diverse germplasm. Genetic solutions to emerging production challenges are now becoming available from this improved germplasm, including regionally-adapted selections expressing high productivity, self-fruitfulness, and increased insect, disease and environmental

stress resistance. Improved breeding lines also offer opportunities to expand market demand by optimizing phytonutrients in new cultivars, such as the high heart-friendly oleic acid content in the recently released Sweetheart variety (see Reference 1), while minimizing potential health and marketing risks including aflatoxins, allergens and salmonella. This past year saw the establishment of a new set of Regional Variety Trials (RVT) which includes a large number of UCD selections derived from genetically diverse pedigrees. The diversity has been introduced to allow the capture of the greatest genetic contributions to orchard yield, kernel quality and disease/pest/stress resistance in future California orchards. Ongoing studies in the newly established as well as previous RVT's are demonstrating significant opportunities for improving disease and stress resistance, kernel quality and tree and orchard productivity.

Following long-term RVT and grower testing in all major California production regions, the UCD breeding program has released the *Kester* almond variety. This variety is the result of a cross between *Tardy-Nonpareil* (a late-flowering mutation of *Nonpareil*) and *Arbuckle*. *Kester* is fully cross-compatible with *Nonpareil* as well as other late-bloom pollenizers and blooms approximately 4 days after *Nonpareil* and so is less vulnerable to damage by early spring frosts. *Kester* kernels are similar to *Nonpareil* but with well-sealed, worm resistant shells. The variety produces low frequencies of double kernels and twin embryos. Harvest is 4 to 7 days after *Nonpareil*. Trees are upright to spreading and moderately vigorous, being about 80% of *Nonpareil* size at maturity. The *Kester* variety has consistently been among the most productive of all evaluated selections and varieties in over 16 years of Regional Variety Trials. Long-term regional testing also showed no Noninfectious Bud-failure or pronounced susceptibility to commercially important diseases and pests. This variety is now available under license from the Regents of the University of California. Budwood of the new variety has been subjected to the virus indexing program of Foundation Plant Service (FPS), University of California at Davis, CA. All indices have proven to be negative for viruses and Foundation trees of this genotype are presently being maintained at FPS under the designation 'Kester' or the UCD Breeding designation 'Kester 2-19E'.

Release UCD2-19E as *Kester*, a later flowering yet very productive Nonpareil-type cultivar

Advanced UCD breeding selection 2-19E has now been fully released to the California industry as the later Nonpareil-bloom pollinizer '*Kester'*. Virus-tested and certified true-to-type foundation stock has been made available to all interested nurseries. The Kester variety results from a long-term effort to develop a later-flowering pollenizer for Nonpareil which is comparable to Nonpareil in nut quality and yield (**Figure 1**) while having a flowering time approximately 3-5 days after Nonpareil and developing a smaller, more compact tree than Nonpareil. The later bloom would allow Kester to cover the peak Nonpareil bloom as well as the more straggling later bloom becoming common with warming winter temperatures. A key goal of the later bloom, however, was its greater protection from damaging spring frosts which are becoming more prevalent in California owing to changing climate/weather patterns which have encouraged unusually early Nonpareil flowering times as well as increasing aberrant cold fronts and associated inversion frosts later in the season. Kester is the result of several thousand crosses to Tardy-Nonpareil (**Figure 2**), a budsport of Nonpareil which maintains all the positive kernel and disease resistance attributes of this variety while flowering approximately 1 week later. Because the genetic change leading to later flowering was also linked with lower yield potential (see reference #6) a large number of crosses were required using a genetically diverse array of pollen parents to break the linkage and so optimize all cultivar attributes (**Figures 1 & 3**). The pollen parent was the heirloom California cultivar *Arbuckle*, which contributed to the final high productivity but may have also slightly increased final susceptibility to hull-rot disease.

Figure 1. Nut characteristics of the variety *Kester* compared to adjacently planted *Nonpareil* from the 2014 McFarland RVT.

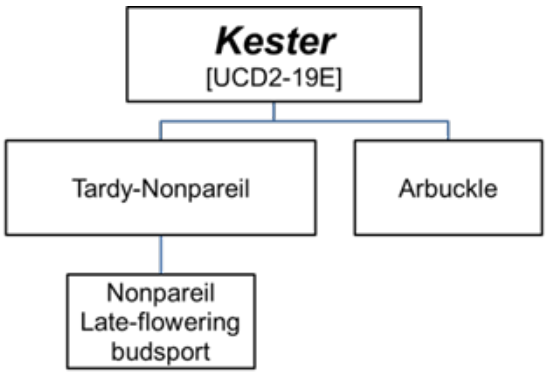

Figure 2. Parentage of the Kester almond.

A crucial prerequisite of all UCD variety releases is a long term (10+ years) testing in all regions of potential plantings prior to patenting and release. Because almond typically takes this long to come into mature production, such long-term testing is required to identify any deficiencies prior to large-scale grower investment in plantings. Over the last 15 years, the UCD variety Kester has been successfully tested (as breeding line UCD2-19E) in all current regions of Sacramento and San Joaquin valley production. A high productivity with kernel and shell characteristics similar to Nonpareil combined with low susceptibility to important almond diseases have been demonstrated in these long-term regional trials (**Table 2**).

High yields have been consistently been achieved despite a ~20% smaller tree size (**Figure 3**). Multiyear and multi-cultivar results from the ongoing Kern County trials are presented in **Table 1**. Detailed data are contained in Bruce Lampinen's McFarland Regional Variety Trial (RVT) annual reports. Similar performance summaries for earlier trials in Butte, Stanislaus, Fresno and Kern counties, where similar high kernel qualities and productivity were similarly demonstrated have also been documented in earlier RVT reports. Because of its high productivity yet smaller tree size, Kester is susceptible to alternate bearing cycles if adequate water and nutrients are not provided to sustain seasons of high crop. The smaller tree size and more concentrated fruiting spur density make Kester more productive than even Nonpareil during the 1st 6-8 years of production (**Table 1**) before shading from the adjacent Nonpareil rows limits final yield potential (see **Figure 3**). In a mature orchard, the compact tree size allows more light and so greater yields on the more valuable Nonpareil rows while still maintaining high productivity because of its high spur density and improved tree structure. These characteristics also appear to make it more compatible to the higher density orchard plantings being promoted as having greater water use efficiency. Bloom time at the McFarland RVT has averaged 3-5 days after Nonpareil in terms of bloom initiation, full bloom, and petal fall, thus providing consistent pollenizer coverage for the later Nonpareil bloom (**Figure 4**). Pollen is fully cross-compatible with Nonpareil. Average hull split at the McFarland RVT begins approximately 7-9 days after Nonpareil but because of the more compact tree size is complete approximately 5 days after Nonpareil (**Figure 4**) and so often harvested with Nonpareil at this site. The early maturity, concentrated hull-split timing and good shell-seal also contribute to low navel orangeworm damage, being comparable to Nonpareil. Susceptibility to major diseases, including scab, Alternaria and hull rot has been low (**Figure 5**) being comparable to Nonpareil. A higher, though still moderate level, of hull rot was observed in 2013 (a high disease year) which was attributed to a very heavy nut set with insufficient water to maintain the crop.

Figure 3. (Top) More compact Kester tree between 2 Nonpareil almonds at McFarland RVT. (Bottom) Strong bloom and nut set characteristic of the variety *Kester*.

Table 1. Performance of Kester relative to Nonpareil and other pollinizers in the McFarland RVT from 2006 to 2014.

Year	Planted 2004				Kernel pounds per		
	Variety	No. of nuts/tree	Average kernel wt (g)	Shelling percentage	Tree	Acre	Cumulative kernel yield (lbs/acre)
2006	Kester	6852 a	0.94 g	53.0 d	14.2 a	1718 a	1718 a
	Nonpareil-70	3848 bc	1.07 cde	64.6 ab	9.1 bcd	1101 bcd	1101 bcd
	Nonpareil-J	3717 bcd	1.08 cde	64.0 abc	8.8 bcd	1066 bcd	1066 bcd
	Chips	3623 bcd	1.02 f	53.8 d	8.1 bcde	985 bcde	985 bcde
	Kochi	3134 cd	1.16 b	59.9 c	8.0 cde	965 cde	965 cde
	Nonpareil-7	3288 bcd	1.08 cde	65.1 a	7.8 de	941 de	941 de
	Kahl	3139 cd	1.06 ef	47.8 e	7.4 de	889 def	889 def
2007	Kester	13149 a	0.78 e	54.3 d	22.8 a	2756 a	4474 a
	Nonpareil-70	9340 cde	0.92 bc	66.3 a	18.9 abcd	2291 abcd	3393 b
	Kahl	9594 cd	0.91 bc	47.6 e	19.3 abcd	2332 abcd	3222 bcd
	Nonpareil-J	9137 cde	0.89 bcd	65.5 a	17.8 bcde	2152 bcde	3218 bcd
	Chips	7681 defg	0.87 cd	54.4 d	14.7 ef	1780 ef	2766 bcd
	Kochi	6006 g	1.08 a	59.4 bc	14.3 ef	1729 ef	2694 de
2008	Kester	13472 a	0.93 g	54.3 d	27.4 cd	3321 cd	7795 a
	Nonpareil-70	12506 bcd	1.17 cd	66.3 a	30.7 b	3714 b	7106 bc
	Nonpareil-J	11071 d	1.09 cde	65.5 a	26.6 de	3224 de	6442 cd
	Kahl	10720 de	0.96 fg	47.6 e	22.6 fg	2733 fg	5954 de
	Chips	11465 cd	0.97 fg	54.4 d	24.4 ef	2956 ef	5722 ef
	Kochi	5882 f	1.28 b	59.5 bc	16.5 h	2002 h	4696 g
2009	Kester	14706 a	0.84 f	65.6 f	27.1 c	3285 c	11080 a
	Nonpareil-70	13756 ab	1.04 bcd	74.6 ab	31.4 ab	3798 ab	10905 abc
	Nonpareil-J	12803 abc	1.04 bcd	71.6 bcd	29.0 bc	3513 bc	9955 cd
	Kahl	11035 cde	0.87 ef	59.1 g	21.1 de	2559 de	8513 ef
	Chips	9771 ef	0.93 def	58.6 g	20.0 e	2422 e	8144 ef
	Kochi	7252 g	1.17 a	68.9 de	18.7 e	2259 e	6955 h
2010	Nonpareil-70	8823 bcd	1.28 abcd	72.3 ab	24.9 a	3011 a	13916 ab
	Kester	6833 efg	1.10 bcdef	56.1 e	16.7 bc	2020 bc	13100 bc
	Nonpareil-Jones	8315 cde	1.23 abcdef	70.9 ab	22.6 a	2737 a	12691 c
	Chips	9089 abc	1.15 bcdef	65.9 abc	23.0 a	2789 a	10933 d
	Kahl	7587 cde	1.01 f	56.5 de	16.9 b	2048 c	10561 d
	Kochi	3902 h	1.40 a	64.4 bcd	12.1 bc	1466 bc	8421 e

Table 1. (Continued). Performance of Kester relative to Nonpareil and other pollinizers in the McFarland RVT from 2006 to 2014.

Year	Planted 2004 Variety	No. of nuts/tree	Average kernel wt (g)	Shelling percentage	Kernel pounds per Tree	Kernel pounds per Acre	Cumulative kernel yield (lbs/acre)
2011	Nonpareil-70	17744 abc	1.05 bc	70.7 a	41.0 a	4962 a	18878 ab
	Kester	18253 ab	0.91 bcde	64.8 abcd	36.8 a	4460 a	17560 cd
	Nonpareil-Jones	16993 abcd	0.96 bcde	70.0 ab	36.0 a	4360 a	17051 d
	Chips	11901 f	0.94 bcde	60.3 de	24.7 bcd	2985 bcd	13918 e
	Kahl	12420 f	0.89 cde	53.5 f	24.4 bcd	2953 bcd	13514 e
	Kochi	8701 g	1.22 a	63.5 cde	23.3 d	2825 d	11247 f
2012	Nonpareil-70	8530 b	1.2 bc	70.9 bc	22.6 ab	2733 ab	21611 ab
	Kester	7617 bc	1.19 bcd	69.4 bcd	20.1 abc	2432 abc	20270 bc
	Nonpareil-Jones	8855 b	1.18 bcd	67.7 bcd	23.0 ab	2783 ab	19833 c
	Chips	9008 b	0.92 h	75.3 ab	18.2 bc	2201 bc	16416 d
	Kahl	8830 b	1.05 fg	55.0 d	20.4 abc	2465 abc	15979 d
	Kochi	2025 d	1.41 a	26.0 e	6.3 d	763 d	12816 e
2013	Nonpareil-70	18718 b	0.87 b	63.5 a	36.0 a	4354 a	25965 ab
	Nonpareil-Jones	18241 b	0.87 b	63.5 ab	35.1 a	4243 a	24076 b
	Kester	16267 c	0.66 c	56.6 b	23.9 c	2890 c	22958 c
	Chips	12689 d	0.89 b	57.3 b	24.9 bc	3010 bc	19466 d
	Kahl	15587 c	0.85 b	55.3 b	29.1 b	3524 b	19503 d
	Kochi	7911 e	1.09 a	63.7 ab	19.0 d	2300 d	15651 e
2014	Nonpareil-70	15105 b	1.12 bcd	70.5 bc	37.4 ab	4522 ab	30486 ab
	Nonpareil-Jones	16267 c	0.86 e	57.6 d	32.2 b	3901 b	28584 d
	Kester	14378 bc	0.92 cde	69.5 bcd	29.1 bc	3616 bc	27075 e
	Chips	11188 cde	0.98 cde	67.7 bcd	23.9 cd	2886 cd	25432 f
	Kahl	9310 e	1.03 bcde	55.3 e	21.0 d	2543 d	22046 g
	Kochi	5981 f	1.25 b	66.8 cd	16.5 d	1996 d	15651 e

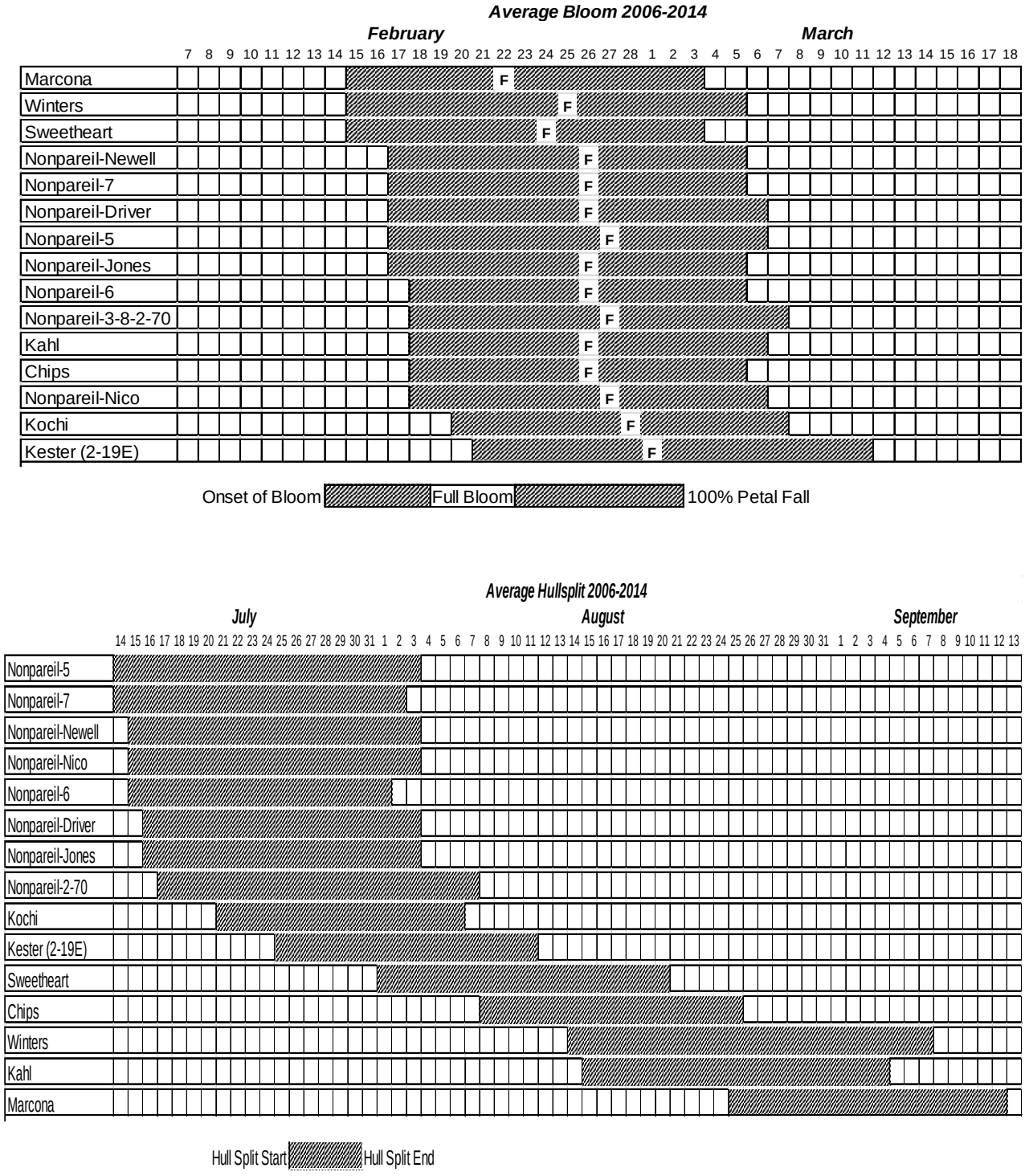

Figure 4. (Top)**.** Averaged 2006 to 2014 bloom times relative to *Nonpareil* sources in the McFarland RVT. (Bottom) Averaged 2006 to 2014 hull split and harvest times relative to *Nonpareil* sources in the McFarland RVT.

Table 2. Disease ratings of *Kester* (designated here as breeding selection 2-19E) relative to *Nonpareil* and other pollinizers in the McFarland RVT during high disease years 2010 (top) and 2013 (center) as well as 2014 (bottom). [Note higher hull rot in 2013 associated with heavy crop set followed by water stress].

	Scab Rating		***Alternaria rating***		***Hull Rot Strikes***
selection 2-19e	0.00 a	Chips	0.00 a	Kahl	8.33 a
Chips	0.00 a	Kahl	0.00 a	Sweetheart	11.00 a
Kahl	0.00 a	Kochi	0.00 a	Marcona	13.33 a
Kochi	0.00 a	Marcona	0.00 a	selection 2-19e	18.83 a
Marcona	0.00 a	Nonpareil 3-8-2-70	0.00 a	Price	23.01 a
Nonpareil 3-8-2-70	0.00 a	Nonpareil-5	0.00 a	Chips	24.00 a
Nonpareil-6	0.00 a	Nonpareil-6	0.00 a	Nonpareil-Nico	30.67 a
Nonpareil-7	0.00 a	Nonpareil-7	0.00 a	Nonpareil 3-8-2-70	61.33 a
Nonpareil-DR	0.00 a	Nonpareil-DR	0.00 a	Nonpareil-J	62.67 a
Nonpareil-J	0.00 a	Nonpareil-J	0.00 a	Nonpareil-5	65.17 a
Nonpareil-Newell	0.00 a	Nonpareil-Newell	0.00 a	Nonpareil-7	72.67 a
Nonpareil-Nico	0.00 a	Nonpareil-Nico	0.00 a	Nonpareil-6	82.83 a
Price	0.00 a	Price	0.00 a	Nonpareil-Newell	83.67 a
Sweetheart	0.00 a	selection 2-19e	0.00 a	Nonpareil-DR	98.17 a
Nonpareil-5	1.00 a	Sweetheart	0.00 a	Kochi	262.00 b
Winters	2.00 b	Winters	0.00 a	Winters	539.67 c

	Scab Rating		***Alternaria rating***		***Hull Rot Strikes***
Chips	0.00 a	Nonpareil-Nico	0.67 a	Kahl	2.33 a
Kahl	0.00 a	Nonpareil-7	0.67 a	Marcona	3.33 a
Kochi	0.00 a	Nonpareil-J	0.83 a b	Chips	5.00 a b
Marcona	0.00 a	Sweetheart	1.00 a b	Nonpareil-DR	10.33 a b
Nonpareil 3-8-2-70	0.00 a	Nonpareil-Newell	1.00 a b c	Nonpareil-Nico	10.67 a b
Nonpareil-5	0.00 a	Nonpareil-5	1.00 a b c	Nonpareil-5	15.00 a b
Nonpareil-6	0.00 a	Nonpareil-6	1.00 a b c	Nonpareil 3-8-2-70	22.00 a b c
Nonpareil-7	0.00 a	Nonpareil 3-8-2-70	1.00 a b c	Nonpareil-J	26.67 a b c
Nonpareil-DR	0.00 a	2-19E	1.17 a b c d	Nonpareil-7	31.00 a b c
Nonpareil-J	0.00 a	Nonpareil-DR	1.17 a b c d	Nonpareil-Newell	34.00 a b c
Nonpareil-Newell	0.00 a	Chips	1.50 b c d	Nonpareil-6	39.67 a b c
Nonpareil-Nico	0.00 a	Marcona	1.67 c d e	Sweetheart	48.67 a b c
Sweetheart	0.00 a	Kochi	1.83 d e	2-19E	94.00 b c
2-19E	0.17 b	Winters	2.33 e	Winters	104.83 c
Winters	3.00 c	Kahl	2.33 e	Kochi	325.83 d

	Scab Rating		***Alternaria rating***		***Hull Rot Strikes***
Kester (2-19E)	0 a	Nonpareil-J	0.0 a	Kahl	0 a
Nonpareil-7	0 a	Nonpareil-5	0.0 a	Marcona	0 a
Nonpareil-Newell	0 a	Nonpareil 3-8-2-70	0.0 a	Sweetheart	1 a
Nonpareil-J	0 a	Nonpareil-7	0.0 a	2-19E	2 a
Nonpareil-5	0 a	Nonpareil-Nico	0.0 a	Nonpareil 3-8-2-70	2 a
Nonpareil 3-8-2-70	0 a	Nonpareil-6	0.0 a	Winters	2 a
Nonpareil-DR	0 a	Nonpareil-Newell	0.2 a b	Chips	3 a
Nonpareil-6	0 a	Kochi	0.3 a b	Nonpareil-Nico	3 a b
Marcona	0 a	2-19E	0.5 b c	Nonpareil-7	4 a b c
Kahl	0 a	Nonpareil-DR	0.5 b c	Nonpareil-6	5 a b c
Sweetheart	0 a	Chips	0.5 b c	Nonpareil-Newell	5 a b c
Nonpareil-Nico	0 a	Marcona	0.8 c d	Nonpareil-5	6 a b c
Chips	0 a	Sweetheart	1.0 d e	Nonpareil-J	11 b c
Kochi	0.17 a	Kahl	1.3 e	Nonpareil-DR	11 c
Winters	2.17 b	Winters	3.0 f	Kochi	25 d

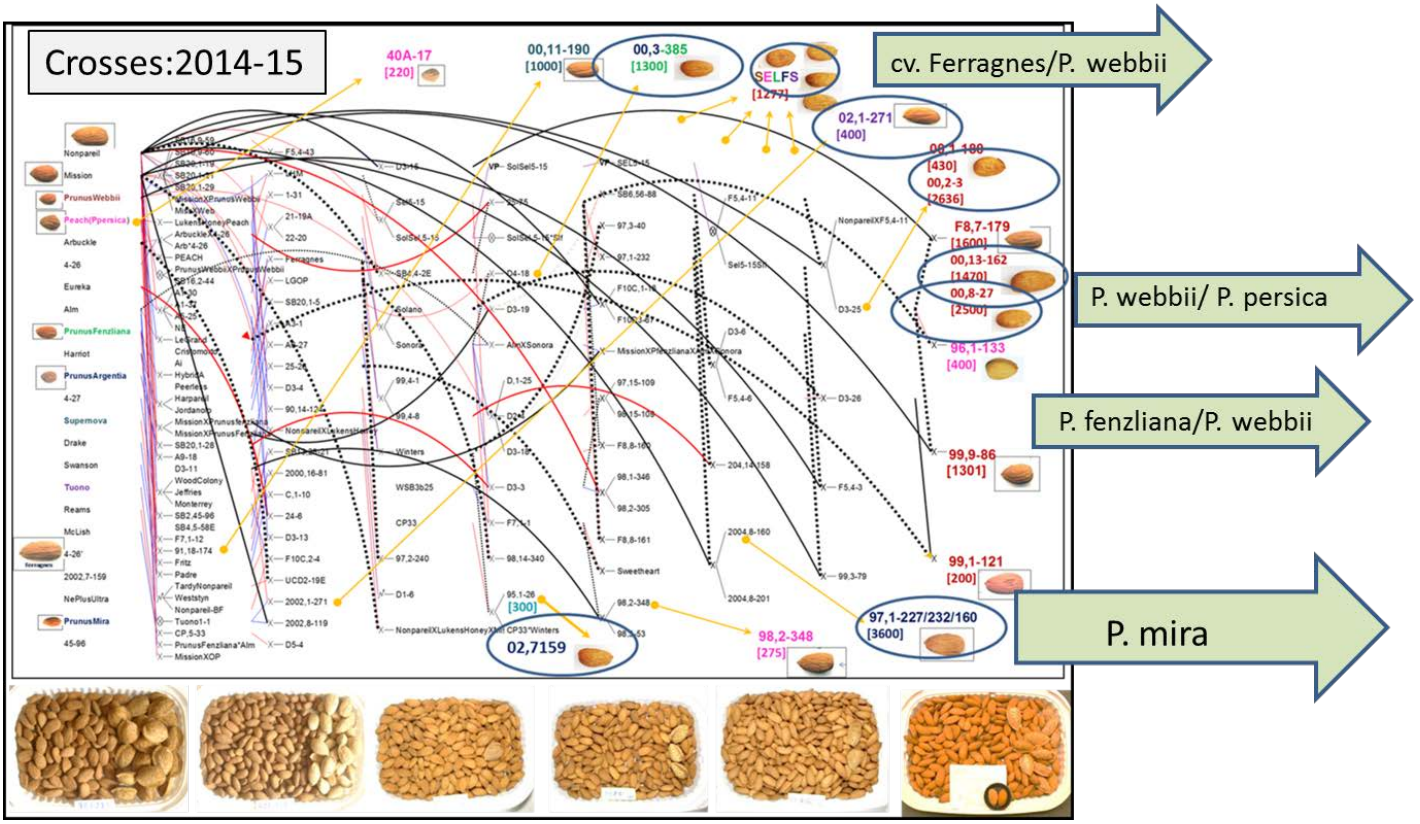

Figure 5. Summary of the UCD breeding germplasm pedigrees from diverse and often wild almond and related species parents (left column) for advanced selections currently being tested in regional variety trials (circled items and bottom row). Lines connect progeny to parents; solid lines identify seed parent while dotted lines identify the pollen parent. Broad green arrows identify UCD lineages targeted for further, focused improvement in 2014-15 breeding crosses, with the initial germplasm source identified within the arrows.

Generate and Evaluate Breeding Progeny

Because traditional almond varieties lack the characteristics needed for the next generation of California production (including self-fruitfulness, improve disease and pest resistance as well as improved resistance to drought/salt stress and other consequences of climate change), new germplasm has been incorporated from European and Asian varieties as well as wild species including *Prunus webbii, P. argentea, P. mira, P. fenzliana. P. scoparia* and cultivated peach, *P. persica*. Through an intensive process of cross-hybridization and recurrent selection, desired traits from this diversity of germplasm sources have now been introgressed and incorporated into California-adapted breeding lines (**Figure 5**, see detailed descriptions in earlier annual reports). The first series of advanced breeding selections developed from this germplasm was planted in 2014 in the new Regional Variety Trials (see summaries in 2013-14 annual report). The next generation of California-adapted introgression breeding lines will target the consolidation of the most promising self-fruitful and resistance traits into productive almond varieties with good commercial qualities. A major challenge of this selection cycle will be anticipating the critical production/resistance needs of almond varieties destined for California planting 10 to 20 years from present. Thus, a short term goal of the breeding program is to concentrate desirable traits from advanced breeding lineages in developing new and improved cultivars. Concurrently, a longer term goal is the maintenance of as broad a genetic and trait diversity as possible to maintain

genetic options for solving future though not yet fully anticipated production needs (resistance to new pests, diseases, nutrient toxicities, etc.). For the more focused, short-term cultivar development, four breeding lineages have been emphasized (broad green arrows in **Figure 5**) as having the greatest potential for cultivar development in the near future. For example, **Figure 6** shows kernel samples from a population of breeding seedlings developed from the cross Nonpareil x A00,8-27 (designated UCD 8-27 in RVT) from the P. webbii/P. persica lineage summarized in **Figure 5**. Each kernel represents an individual seedling progeny tree and while some selection for kernel quality occurred when seed was collected during routine fall, 2014 progeny evaluations, results demonstrate very good opportunities for recovering high kernel qualities, particularly given the range of diverse seed qualities and sizes of the original parental materials (see **Figure 7**).

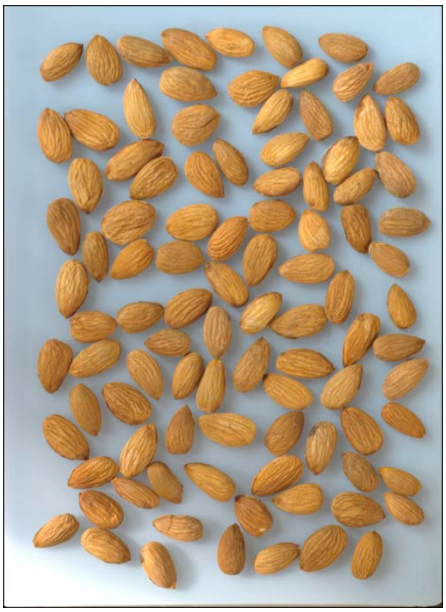

Figure 6. Samples from progeny of cross *Nonpareil* x breeding selection A00,8-27 segregating for self-fruitfulness. [Each kernel represents a separate progeny].

Hybridization is achieved by four basic methods: 1. Caging individual trees or branches to exclude outside insect pollinators and then making controlled hybridizations (or self pollinations to test for self fruitfulness) by hand, 2. Caging an entire tree and using honeybees or bumblebees to deliver selected and supplied pollen to caged tree flowers (often using multiple pollen donors and using molecular markers to identify paternity in subsequent seedling trees), 3. Using isolation blocks of seed parent trees and delivering pollen either by hand or using honeybees/bumblebees, and 4. Using isolated blocks of selected seed parent genotypes planted in solid blocks of Nonpareil/Monterey orchards. Methods 1 and 3 are typically used when more focused crosses are desired, while methods 2 and 4 are utilized when very large numbers of progeny trees are desired, either to make more rapid progress on a focused goal such as kernel size, or to capture a larger genetic and so phenotypic variability in the progeny. The concurrent use of multiple approaches also buffers the breeding program from the occasional crossing failures. In 2014 approximately 1000 seed was obtained using methods 1 and 3, while approximately 5000 seed was set using method 2. Method 2 utilized a large, isolated Nonpareil tree of known low-Noninfectious Bud-Failure potential which had been used for caged crosses for several years. Good seed set was obtained using both honeybee and bumblebee pollinators and multiple pollen donor sources as pollenizers. However, approximately one week before scheduled harvest, most nuts were lost to apparent rodent harvest. (An adjacent field had recently been cleared and harbored a large population of ground squirrels). Despite this loss, sufficient seed was collected through method 4 since many of the desired pollen parents had already been established as seed parents in M4 isolation blocks. Controlled crosses in 2015 had similar goals to those in 2014 (**Figure 5**) and a very early harvest of the caged Nonpareil seed parent (resulting from a very early bloom and warm weather early in the season) has resulted in approximately 4000 seed having now been collected and processed. An additional ~1000 seed is anticipated from controlled crosses to individual caged trees while 6000 to 8000 seed are anticipated from crosses in isolation blocks.

Over 12,000 seed were collected in the 2014 season with over 6000 germinated and grown in UCD greenhouse/screenhouses where they were subjected to a very intense selection for tree architecture and growth vigor with the goal the elimination of up to two-thirds of the progeny prior to field plantings. The intense selection is applied to quickly eliminate inferior genotypes including progeny expressing inbreeding depression which has plagued European almond breeding programs attempting to concentrate genes for self-fruitfulness (pollen-pistil self-compatibility combined with flower structures promoting self pollination).

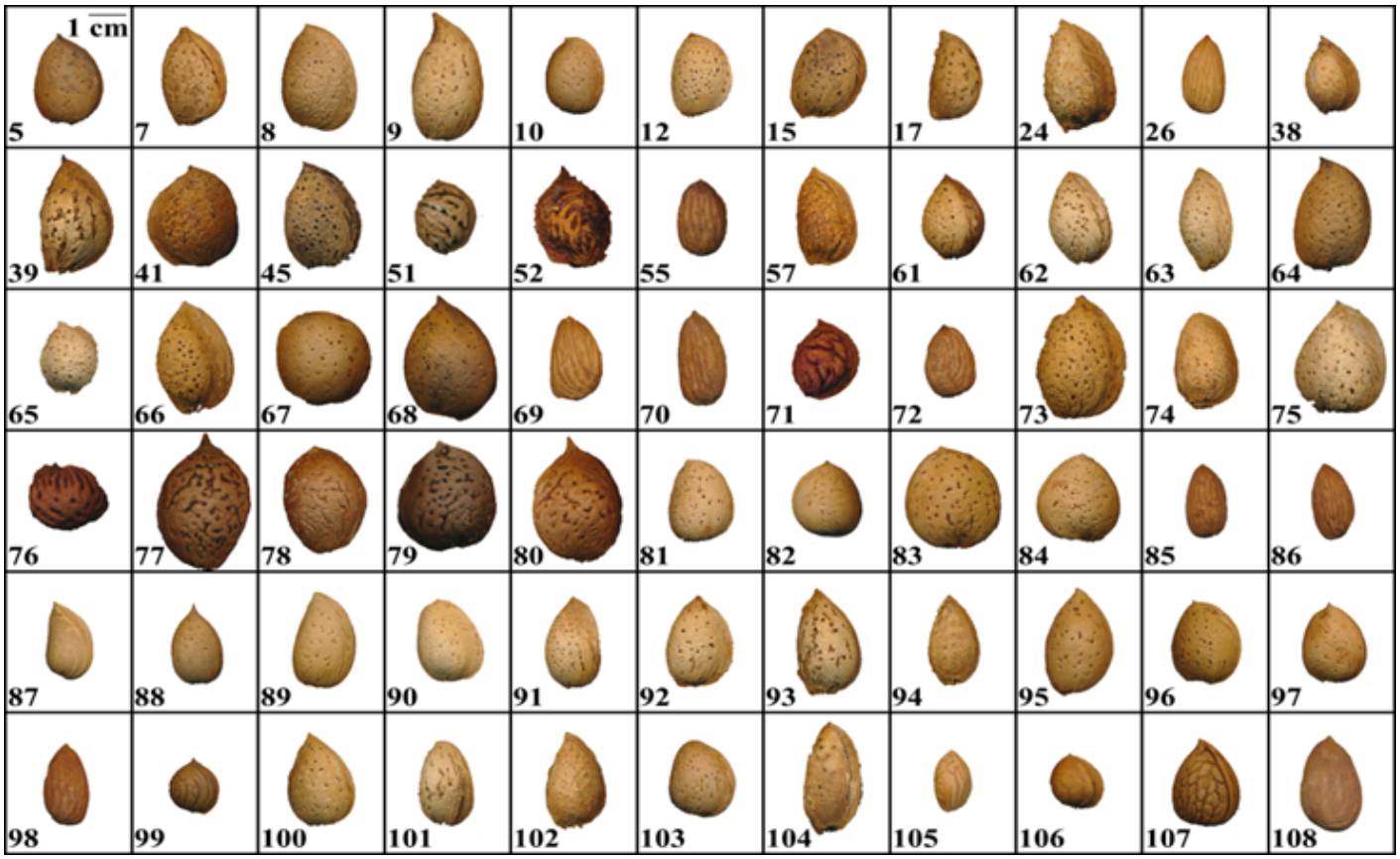

Figure 7. Representative sample showing the diversity of almond types analyzed in the UC-University of Florida protein study. The numbering of the seeds is the same as in **Table 3** and **Figure 8**. All seeds are in-shells except # 26 (Nonpareil), 55, 69, 70, 72, 85, 86, 98, and the large kernel-size selection 108 (UCD3-40 in RVT).

Concurrently, UCD breeding germplasm is being developed and evaluated in order to maintain desired genetic diversity and identify potentially useful as well as deleterious traits. Germplasm evaluation is facilitated by long-term collaborations with other researchers interested in elucidating particular physiological molecular pathways. Key collaborations include the RosBreed SCRI project for molecular marker development in Prunus fruit crops (see earlier annual reports, www.rosbreed.org, and references 4, 8, and 12), the ABC funded USDA/ARS Rootstock Germplasm Project (see current USDA/ARS annual report), a seed protein analysis project with Dr. Sathe at the University of Florida (see reference 14), and extensive collaborations with UCD and UCB, and UCR researchers and farm advisors. Small (10 to 100 tree) grower test plots developed in collaboration with local farm advisors are particularly important in rapidly identifying opportunities

Table 3. UCD breeding germplasm analyzed for seed protein characteristics including potential allergenicity in a collaborative study with University of Florida. The numbering of the individual genotypes is the same as in **Figures 7** and **8**. (Differences within columns are color-coded).

No.	Genotype	Origin	(%) Almond genome	Nut Length (mm)	Kernel Length (mm)	Nut Width (mm)	Kernel Width (mm)	Nut Thickness (mm)	Kernel Thickness (mm)	Nut Mass (g)	Kernel Mass (g)	Soluble protein (g/100 g)	R-ELISA	R-WB	R-DB
99	A7-23	*P. argentea* (bitter seed)	0	19.03	13.38	15.25	9.73	12.05	6.04	1.47	0.37	17.28	0.61	0.64	0.61
107	A7-25	*P. webbii* (bitter seed)	0	28.97	20.39	18.28	11.75	13.66	7.26	2.93	0.82	19.09	0.51	0.75	0.57
102	F10D,2-14	*P. fenzliana* (F2)	0	30.55	22.3	16.48	11.38	11.33	8.43	4.54	1.03	19.21	1.66	0.78	1.1
52	Andross	Peach (*P. persica*) (bitter seed)	0	35.31	17.77	26.12	11.43	19.5	3.89	6.21	0.36	20.65	0.39	0.53	1.01
105	A10-4	*P. bucharica* (bitter seed)	0	19.14	14.33	10.33	6.62	7.35	4.66	0.58	0.21	20.94	0.59	1.01	0.82
87	A7-28	*P. webbii* (bitter seed)	0	25.72	18.43	14.13	9.1	10.2	6.3	1.39	0.49	21.04	0.88	1.11	1.03
101	F10D,2-12	*P. fenzliana* (F2)	0	26.49	20.61	16.11	10.78	11.51	7.04	1.41	0.77	21.38	1.53	1.06	1.44
71	P11-58	*P. mira* (bitter seed)	0	26.55	14.48	17.75	9.86	12.82	4.33	2.48	0.29	23.39	0.53	0.79	0.83
76	A13-1	*P. persica* × *P. davidiana* (bitter seed)	0	21.47	13.77	20.69	11.41	17.83	6.1	3.83	0.46	23.41	0.45	0.5	0.9
51	40A-17	Peach (*P. persica*) (bitter seed)	0	24.25	13.35	16.83	7.18	12.45	3.35	1.81	0.11	23.74	0.51	0.52	1.02
106	A2-11	*P. tangutica* (bitter seed)	0	16.54	13.36	15.23	10.28	12.4	8.28	1.34	0.49	25.44	0.7	0.94	0.87
88	F5,4-42	*P. webbii* (F2)	0	26.82	18.54	14.98	9.46	10.83	6.7	1.96	0.55	25.8	0.64	1.1	1.06
5	**F5,4-10**	*P. webbii* × (Nonpareil × *P. persica*) BC1	38	27.5	19.69	18.32	11.94	12.78	7.22	2.69	0.78	22.12	0.53	1.02	0.96
77	Hansen2168	Almond × *P. persica*	50	44.06	27.95	28.46	15.71	18.29	7.34	9.07	1.44	12.35	1.57	0.81	1.31
97	F10D,3-24	*P. webbii* (BC1)	50	25.71	19.33	19.52	13.23	13.29	6.13	2.66	0.71	13.39	1.27	0.95	1.16
79	Nickels	Almond × *P. persica*	50	36.88	23.87	28.7	16.37	20.85	8.75	9.18	1.53	13.79	0.75	0.09	0.85
104	F10D,3-50	*P. fenzliana* (BC1)	50	36.2	27.32	19.3	13.93	13.31	8.75	2.37	1.59	15.37	2.18	0.73	0.91
96	F10D,3-13	*P. webbii* (BC1)	50	25.39	19.4	19.08	12.02	13.66	8.03	1.85	0.83	17.07	0.47	0.57	0.87
100	F10D,3-3	*P. argentea* (BC1)	50	29.57	23.42	18.62	12.41	13.8	7.01	1.88	0.96	17.47	0.26	0.4	0.65
93	F10D,3-2	*P. webbii* (BC1)	50	30.57	19.71	17.83	11.09	13.64	6.99	1.53	0.77	17.84	0.66	0.51	1.09
94	F10D,2-5	*P. webbii* (BC1)	50	28.66	20.83	14.57	9.81	11.31	8.07	1.23	0.76	17.99	0.47	0.75	0.86
89	F10D,3-15	*P. webbii* (F2BC1)	50	33.32	24.03	20.99	12.86	14.64	7.18	4.1	0.96	18.58	0.33	0.91	0.82
41	F10C,12-28	(Nonpareil × *P. persica*) F2	50	35.09	20.24	23.93	13.04	17.99	9.02	4.96	1.08	19.32	1.76	0.71	1.19
92	F10D,1-2	*P. webbii* (BC1)	50	29.97	20.76	19.8	12.21	14.21	7.15	1.59	0.84	20.4	0.68	1.11	1.14
91	F10D,1-4	*P. webbii* (BC1)	50	30.79	23.09	18.07	11.93	13.31	7.57	1.94	0.95	20.5	1.32	0.62	1.1
90	F10D,1-22	*P. webbii* (F2BC1)	50	28.91	21.59	21.35	12.65	15.24	7.72	2.45	0.97	21.05	1.78	1.01	1.11
78	Hansen536	Almond × *P. persica*	50	34.51	23.82	24.61	13.93	18.9	7.46	7.44	1.12	21.06	0.66	1	0.77
95	F10D,3-26	*P. webbii* (BC1)	50	33.55	24.05	20.27	11.4	14.4	7.45	3.23	0.93	21.17	1.06	1.02	0.89
45	F10C,20-51	(Nonpareil × *P. persica*) F2 (bitter seed)	50	35.12	25.14	21.25	12.63	14.98	7.31	2.43	1.1	23.87	0.56	0.7	0.69
57	F5,16-60	(Mission × *P. argentea*) F2	50	32.85	23.77	17.06	11.1	11.9	7.34	1.56	0.87	24.08	0.44	0.57	0.99
84	F10D,3-23	Padre × F5,4-4	69	27.45	20.37	19.82	11.85	13.38	7.71	2.32	0.84	14.48	1.49	0.76	1.11
12	F5,20-42	Padre × F5,4-10	69	26.76	21.42	17.85	12.07	14.03	8.18	1.87	1	16.72	0.65	0.99	0.66
83	F10D,1-26	Nonpareil × F5,4-4	69	30.84	23.05	24.82	14.16	15.84	6.87	3.88	1.11	17.64	1.61	1.27	0.99
17	F8N,7-4	F5,4-10 × Sonora	69	31.96	22.74	16.12	10.66	10.66	6.21	1.17	0.76	19.52	0.65	1.14	0.81
39	8010-22	Nonpareil × F5,4-10	69	37.57	24.6	19.31	12.5	14.1	7.07	1.9	1.05	21.06	2.09	1.43	0.89
55	SB13,25-75	Nonpareil × F5,4-10	69	NA	23.08	NA	12.54	NA	7.76	NA	1.17	22.18	1.78	0.94	1.49
82	F10D,2-18	Nonpareil × F5,4-4 (see No. 4)	69	24.86	19.04	17.53	10.8	13.13	8.47	1.95	0.8	22.4	0.76	0.65	1.2
15	F8N,6-68	F5,4-10 × Solano	69	30.72	21.57	19.93	12.47	14.38	7.19	1.89	0.96	23.47	0.88	1.02	0.91
81	F10D,3-7	Almond × *P. webbii* × *P. persica* (BC2)	84	26.25	20.45	16.6	10.62	12.64	6.74	1.41	0.69	15.35	0.42	0.55	0.77
72	97,1-232	SB13,25-75 × Winters (see No. 55)	85	NA	23.62	NA	13.42	NA	8.16	NA	1.29	20.61	2.06	0.99	0.9
9	F5,13-54	(Mission × *P. fenzliana*) BC1 × Sonora	88	37.19	23.69	19.52	11.92	16.68	8.31	2.94	1.05	16.28	0.7	0.54	0.68
10	F5,10-9	(Mission × *P. fenzliana*) BC1 × Sonora	88	27.28	21.12	18.82	12.24	14.15	7.04	3.08	0.82	18.11	0.61	1.08	0.99
103	F10D,2-3	(Mission × *P. fenzliana*) BC1 × Sonora	88	27.63	21.82	20.09	13.17	16.3	8.92	3.24	1.13	20.71	1.56	0.89	1.15
7	F5,6-13	(Mission × *P. fenzliana*) BC1 × Sonora	88	32.03	22.06	17.25	10.83	10.51	6.71	1.66	0.84	25.6	0.95	0.83	0.84
8	F5,6-1	(Mission × *P. fenzliana*) BC1 × Sonora	88	33.78	23.01	23.68	14.64	16.75	7.38	5.08	1.33	25.88	0.92	1.13	0.94
108	97,3-40	Almond × *P. webbii* × *P. persica* (BC3)	92	NA	33.26	NA	15.14	NA	8.7	NA	2.08	25.31	0.9	0.9	0.87
75	2004,9-1	Nonpareil × 97,1-232	93	34.28	24.96	23.78	13.46	18.07	7.54	3.15	1.24	14.54	1.89	1.1	0.86
74	2004,8-201	Nonpareil × 97,1-232	93	32.14	24.05	21.45	12.97	13.97	8.13	2.06	1.26	15.81	1.67	1.09	1.22
73	2004,8-160	Nonpareil × 97,1-232 (see No. 72)	93	38.45	28.58	22.52	14.18	15.41	8.64	2.96	1.77	19.84	2	1.15	0.85
38	SB13,54-39E	(Nonpareil × *P. persica*) BC3	94	26.19	16.93	15.83	10.23	12.33	8.18	1.05	0.7	21.51	1.96	0.72	1.16
98	97,2-240	*P. webbii* (BC4)	94	NA	23.76	NA	12.61	NA	9.45	NA	1.28	22.22	0.4	0.61	1
80	2005,20-192	(*P. persica*) BC4	94	37.09	20.55	26.46	14.58	19.27	7.37	7.31	0.99	23.91	0.63	0.88	1
85	2000,2-3	Almond × *P. webbii* × *P. persica* (BC4)	96	NA	23.91	NA	11.62	NA	8.97	NA	1.17	19.89	1.93	0.96	0.75
86	2000,8-27	Almond × *P. webbii* × *P. persica* (BC4)	96	NA	24.26	NA	12.13	NA	8.62	NA	1.2	23.92	0.55	0.87	0.9
68	Tuono	Almond variety	100	38.43	26.35	27.67	16.27	18.3	8.22	5.45	1.58	17.14	0.32	0.96	0.8
69	2004,18-20	Almond variety	100	NA	26.34	NA	13.12	NA	8.7	NA	1.54	18.72	0.68	0.85	0.99
61	Mission	Almond variety	100	27.89	20.76	19.79	12.36	15.77	8.87	2.55	1.04	19.17	0.46	0.84	0.93
64	Ferragnes	Almond variety	100	36.35	26.8	23.06	14.18	17.04	8.29	4.09	1.48	19.37	1.56	1.02	1.21
70	95,1-26	Almond variety	100	NA	29.66	NA	14.25	NA	9.47	NA	1.98	20.94	1.1	0.66	0.74
24	Sonora	Almond variety	100	37.02	27.7	18.89	13.08	12.69	7.8	2.25	1.52	22.07	0.74	1.08	1.13
67	Marcona	Almond variety	100	29.38	21.96	25.83	17.26	19.62	8.75	5.55	1.55	22.22	0.88	1.02	1
66	**Winters**	Almond variety	100	36.41	26.33	19.25	11.87	14.08	8.13	2.09	1.21	22.37	1.05	0.73	1.3
26	**Nonpareil**	Almond variety	100	NAc	24.74	NA	13.49	NA	7.86	NA	1.31	23.07	1.02	1	1
65	Sweetheart	Almond variety	100	22.47	19.1	18.98	12.51	14.33	8.84	1.54	0.98	25.52	1.73	1.12	1.16
63	Kahl	Almond variety	100	34.27	25.95	17.03	12.11	14.99	8.04	2.2	1.2	26.29	1.22	1.12	0.9
62	Chips	Almond variety	100	28.66	21.51	19.45	12.68	14.71	8.18	2.02	1.06	26.46	1.68	0.91	1.17

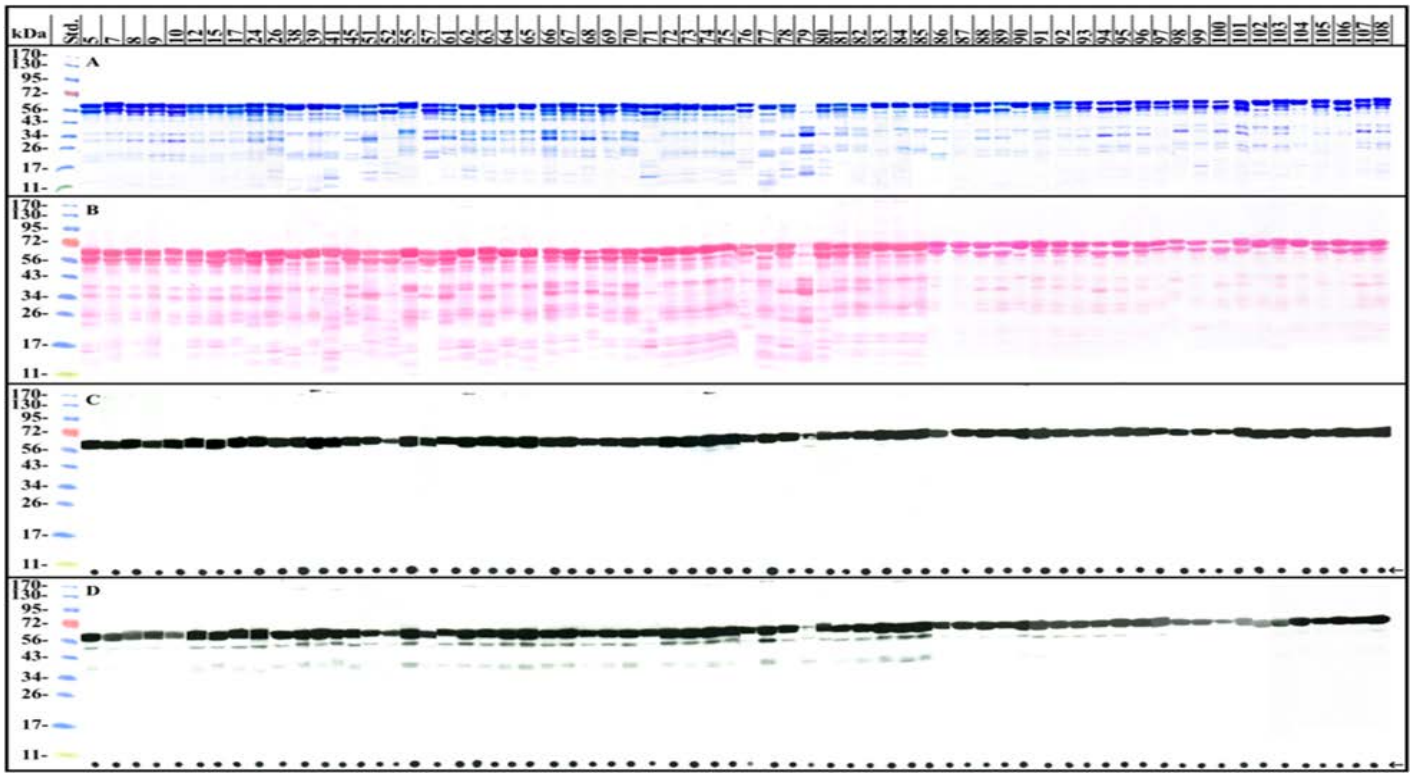

Figure 8. Diverse soluble protein characteristics of UCD almond breeding germplasm. (A) Analysis by SDS-PAGE electrophoresis); (B) proteins transferred onto the Nitrocellulose paper after SDS-PAGE and stained with Ponceau S. Western blots for proteins probed with murine anti-amandin- mAb 4C10 (C) and mAb 4F10 (D). Dot-blots for the proteins probed with 4C10 and 4F10 are shown by arrows at the bottom of the corresponding Western blots (C) and (D), respectively. Std.: molecular weight standards. The sample number indicated on the top is the same as in **Figure 7** and **Table 3**. Note the decreased band intensity and width and the corresponding decrease in dot size and intensity, judged subjectively, in certain samples.

and deficiencies associated with the broader UCD germplasm. For example, decision to advance specific UCD selections to the current round of regional variety trials were based on previous small-scale grower plantings representing a more extensive germplasm which allowed identification of both advanced selections as well as unique germplasm showing promise for improved tolerance to disease and drought stress. Grower plots, including regional trials at the Nickels Soils Lab and more recently Chico State Farm have also facilitated the maintenance of a broad genetic diversity desirable for developing novel genetic options to future problems (and so have partially compensated for the loss of some field facilities at UCD). An example of the range of nut diversity being maintained in this way is shown in **Figure 7** and **Table 3** while differences in relative kernel allergenicity are plotted in **Figure 8**. (All results show a range of allergenicity values associated with diverse germplasm sources, all are within levels, and to current cultivars and all are well below levels for more reactive nuts such as peanuts in Brazil nuts). [See reference 14].

Identify effective predictors of improved cropping potential.

Traditionally, cropping potential referred to the maximum potential yield given optimal access to nutrients, sunlight, good pollinators, and orchard land and irrigation water. The increasing costs of these components is changing the equation for optimizing cropping potential towards achieving the best returns while considering all the input costs. Crop quality thus comes into play because of improved market value. While considerable progress is being made in elucidating the genetic basis of important traits including specific stress and disease resistances (see references 2, 3, 4, 7, 8, and 12) the application of these markers towards actual crop improvement remains constrained by our lack of good understanding of what the actual field determinants are for such complex characteristics as annual and cumulative yield and kernel quality. The UCD breeding program is pursuing improved understanding of crucial field determinants through collaborations with researchers, Farm Advisors and growers. **Table 3** shows recently published (see reference 14) results from an ongoing study of almond kernel protein quality with Dr. Sathe at University of Florida. While their specific goal was to understand the specific proteins associated with food allergies specific to nut crops, our goal was to characterize the range of seed storage protein variability present within our diverse germplasm (since storage protein represents the bulk of the kernel mass), as well as monitoring the level of potential allergens to prevent their introduction/augmentation during the breeding process. Genotypes analyzed include wild species donors, standard almond cultivars as well as genotypes representing increasing levels of introgression of wild germplasm into a cultivated almond background. Data are sorted on the 1st column which shows the proportion of the genotype analyzed that is derived from standard California almond background. Values in all subsequent columns are color-coded (red = low, green = high values) to highlight the extensive variability present in the wild germplasm as well the increased variability for important kernel characteristics transferred to advanced UCD breeding lines, (including several now in regional variety trials). Results have highlighted opportunities for improving kernel physical and biochemical characteristics. For example, while relative allergen risk (last 3 columns compared against Nonpareil as a standard; i.e. Nonpareil equals 1) tends to be generally correlated with increasing levels of soluble protein, opportunities are identified such as selection number 108 (breeding designation 97, 3-40, designated UCD 3-40 in the new RVT) which have increased protein levels with decreased allergen risk yet with improved kernel size and shape (see #108 in **Figure 7**). Relative levels for specific putative allergens are also plotted out in **Figure 8** for these selections. While variation exists, the most important finding is that while higher allergen risk is present in some of the wild donors utilized, the increased risk has not been transferred to advanced breeding lines (generally those with 90% and greater cultivated almond background (Column 1 in **Table 3**). A more detailed, and ongoing analysis of this data suggests that allergen risk is heritable but the degree of transfer varies by specific lineage with cultivated peach initially appearing to be the most promising source of improved kernel quality. Results also agree with field-based breeding experience. The variety Sweetheart was released as a California-adapted, paper-shell almond with high kernel quality, including exceptionally high levels of kernel oil, specifically the desirable phytonutrient oleic acid (see Reference 1). The source of this high kernel quality has been determined to be cultivated peach which was initially utilized in the breeding of the Sweetheart variety as a source for self-fruitfulness. (Sweetheart is only partially, self-fruitful; the levels are not high enough to be commercially dependable).

The critical components determining almond tree yield are being pursued through a more holistic orchard analysis, primarily using light-bar data from the Lampinen research group which utilizes the ratio of tree canopy light capture to subsequent tree kernel yield (yield per PAR) as a standard measure of yield efficiency. As shown in long-term analysis (detailed in previous annual reports), the Kester variety has consistently demonstrated yield efficiencies comparable to the Nonpareil standard despite having a tree size approximately 20% smaller while the similarly smaller UCD variety 'Winters' shows a higher average efficiency (**Figure 9**). The role of tree architecture in maximizing light interception while facilitating a more efficient dispersal of fruit development sites throughout the canopy (through different combinations of shoot/spur bearing habit dynamics) are concurrently being analyzed in collaborative studies with tree models been developed by the DeJong lab, while shoot bud fate mapping (whether axillary buds at different positions will produce lateral shoots, spurs, flowers or blank nodes) are being pursued in collaboration with both the DeJong and Lampinen research groups. While such approaches have historically been utilized in pursuit of maximum yield potential, their elucidation is as important and perhaps more important in the pursuit of optimal cropping efficiency. In parallel with these more analytical, model-based studies, we have been assessing new crop efficiency options by examining cropping performance of a diverse cross-section of our breeding germplasm in different California production areas. Improved performance of specific selections identify both promising possible future cultivars for those specific environments as well as help to identify critical determinants of productivity under different environments (including possible unorthodox approaches towards optimizing crop efficiency).

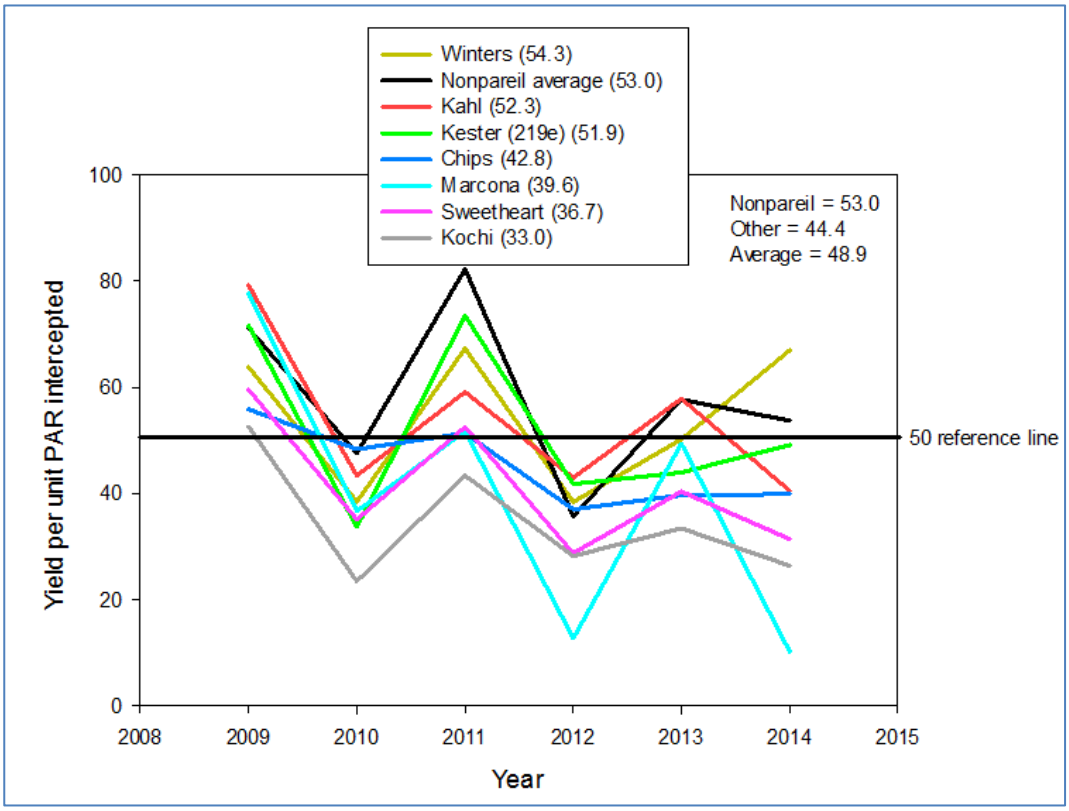

Figure 9. Yield per unit intercepted PAR over 6 consecutive years for standard varieties and advanced UCD selections (kernel pounds per 1% light intercepted). Number following variety name in legend indicates the five year average value. Average for all varieties and years was 49.3. A value of 50 is what we have found to be near optimal for highest orchards efficiency.

Almond is unique among most other fruit and nut crops in that it is highly adapted to adverse, desert-like environments as is demonstrated in its ability to set a reasonable crop under dryland conditions. Part of this unique capacity lies in almonds ability to remain photosynthetically active at higher temperatures than other fruit and nut crops as well as its ability to partially shut down or going into a type of summer dormancy when conditions become too severe. Ongoing analysis with Matthew Gilbert, (Plant Sciences, UCD) of critical leaf temperatures variation in advanced UCD as well as USDA selections demonstrates that despite their advanced introgression stage to good commercial kernel and tree quality, (i.e., the genotypes are highly selected and so have lost much of their initial variation), most of the UCD selections maintain considerable variability for this important trait including the including critical leaf temperatures above 40° C (see Gilbert annual report for details).

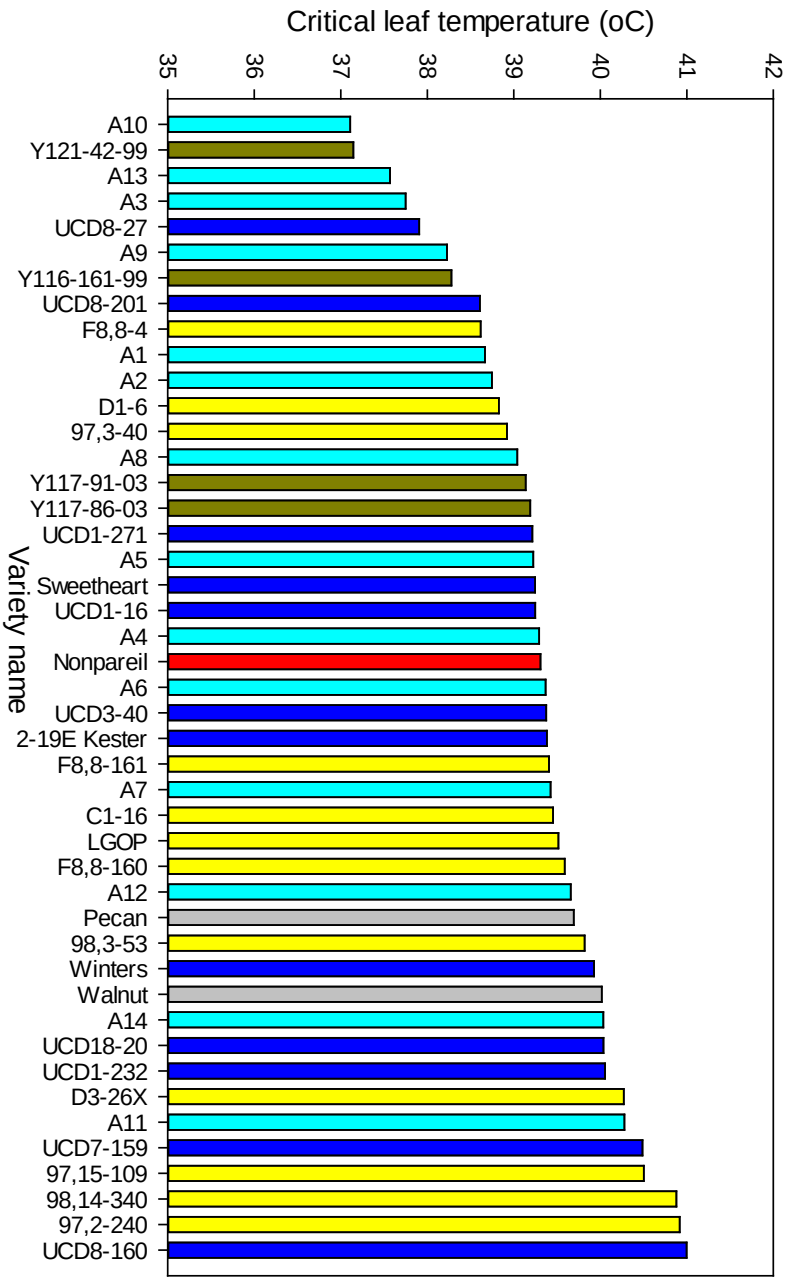

Figure 9. Differences in critical leaf temperatures for USDA ('A' and 'Y' prefix) and UCD (all others) selections currently in regional variety trials. UCD selections show a range in ratings including all 5 of the high-end scores, demonstrating the value of utilizing diverse germplasm in the cultivar breeding program.

Again, the ongoing breeding challenge is the concurrent pursuit of a focused selection for genotypes containing the optimal combination of productivity and resistances (disease/insect/ environmental stress, etc.) while at the same time maintaining sufficient diversity in the breeding material to effectively address future production challenges which remain difficult to predict due to rapidly changing market and production environments. A key component of this approach is our continued collaboration with University, USDA, industry and grower expertise, where regional testing through large scale, replicated RVT assessment as well as smaller regional grower plantings remain crucial for tethering breeding objectives with real production and marketing world needs.

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