# Almond Variety Development

**Project No.:** **09-HORT1-Gradziel/Crisosto**

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## Objectives:

Develop (a) improved pollinizers for Nonpareil, and ultimately, (b) varieties that possess self-fertility and improved market value and resistance to disease, insects and environmental stress. Specific objectives for 2009 - 2010 include:

- Utilize expanded grower trials to evaluate regional performance of advanced breeding lines to identify the most promising genes/selections for resistance and market quality for inclusion in new Regional Variety Trials.
- Improve selection efficiency for required traits (productivity, resistance to disease/pest/environmental stress, marketability, sustainability). Prioritize required traits in partnership with growers, handlers and processors.
- Accelerate the variety development cycle through expanded controlled hybridizations followed by efficient screening of progeny trees for self-compatibility, tree productivity, kernel quality and resistance to key pests, diseases and environmental stresses, including water use efficiency.

## Interpretive Summary:

The California almond industry is entering a period of change driven by increasing market demands, loss of pollinators, reductions in natural resources including good-quality land and water, and changing climate.

While almond represents a diverse and highly adaptable species, (as demonstrated by the proliferation of wild almonds trees along many Central Valley roadsides and creeks), commercial production is dependent almost entirely on the variety *Nonpareil* and its pollenizers, most of which have *Nonpareil* and *Mission* as direct parents. Because of this dependence on a very narrow germplasm base, the UC Davis (UCD) almond breeding program has targeted the introduction of new and diverse germplasm and the

subsequent breeding of this diverse and often wild germplasm to be well adapted to Central Valley conditions while retaining the traits of interest, particularly self-compatibility, disease/pest resistance and tolerance to environmental stresses.

Because it takes at least 5 years to grow a seedling tree from seed to bearing tree, the commercial transfer of new germplasm is tedious, requiring decades for the recovery of commercially adapted advanced breeding lines. In addition, unlike the European and Central Asian almond breeding programs, which primarily utilize the old self-compatible Italian variety *Tuono* as their source of self-compatibility, the UC breeding program has incorporated new germplasm from a wide array of sources including cultivated and wild peach and almond species. Advanced breeding lines are approaching commercial quality and currently over 40 breeding selections are in Sacramento and San Joaquin grower trials to assess regional productivity, levels of self-compatibility and disease/pest resistance and environmental stress tolerance.

While the ultimate goal is a series of self-fruitful and productive *Nonpareil*-type varieties with differing harvest dates, many current advanced lines also express a diverse range of kernel quality traits and tree architectures, providing greater grower options for tailoring varieties to specific cultural and market needs. Working with processor cooperators, we have determined that over half of these selections still possess levels of kernel flavor (typically a slight amaretto taste) or seed coat color (which is associated with higher antioxidant activity and disease resistance) that would preclude their mixing with standard Nonpareil and California marketing groups. Many of these are early resistance breeding lines which are currently being superseded by more advanced UCD breeding selections.

Higher flavor and phytonutrient level, however, have also been perceived by some growers and processors as having the potential to expand current, traditional markets and several selections are advancing to large-scale field and market testing, with germplasm made available to private breeders. An example is the recent UCD released *Sweetheart* variety as a premium quality, heart-shaped Marcona-type almond, which possesses partial self-compatibility, very high levels of the heart-healthy phytonutrient oleic-acid, and improved resistance to hull-rot, navel orangeworm and aflatoxin contamination.

Consequently, maximizing breeding gains depends upon identifying and prioritizing essential traits, the efficient recombination of these often novel (and so untested) genetic solutions with established genes for local productivity and marketability, and the generation of the large numbers of progeny from controlled crosses to ensure recovery of the rare individuals possessing the best genetic combinations.

Simultaneously, we need to maintain as much genetic diversity and so genetic options as possible. For example, recent reports from European breeding programs indicate that their dependence on a single genetic source (*Tuono*) for self-compatibility has ultimately led to lower cultivar productivity because of genetic inbreeding depression.

However, maintaining this extensive UCD germplasm has required extensive and costly field plots, which is becoming increasingly difficult because of ongoing University cuts. We are consequently in the process of large reductions of field plots and so breeding germplasm. To make this transition with minimal loss in future breeding potential we are analyzing an prioritizing both our breeding material and breeding objectives using both advanced computer modeling and molecular analysis. We are also in the process of accelerating the use of molecular markers in the breeding program to take advantage of its potential efficiencies.

Tree productivity or yield remains the most difficult breeding objective to model. Working with Bruce Lampinen [Project 10-HORT13-Lampinen], we have shown that light interception by the tree canopy is the ultimate determinant of yield potential for cultivars grown under high-input California conditions. While final yield is clearly related to the number of flowers produced, in high yielding environments other factors become crucial to fully achieving the full yield potential. Spur-bearing cultivars predominate in very high yielding cultivar/environment sites. Spur-bearing allows a more uniform and so efficient distribution of developing fruit throughout the photosynthetically active portion of the tree canopy. In addition, a higher probability of nut set is evident in spur-bearing versus shoot-bearing flowers due, in part, to the higher flower densities typical of shoots. Cumulative yields, however, are maximized in cultivars which, although primarily spur-bearing, can express strong shoot bearing habit during the initial years of tree growth, as well as regenerative shoot growth in older trees which have lost bearing potential either through branch loss or loss of entire adjacent trees. Large trees with open branch architectures have been shown to have a yield advantage, particularly in young orchards. Because of inevitable shading-induced yield loss on adjacent cultivars, a large tree’s size was found to be a disadvantage for pollenizer cultivars if they ultimately reduce the yield of the adjacent high-value main cultivar.

Despite cutbacks in University research and field support, the UCD almond variety improvement program continues to generate and evaluate large numbers of breeding progeny. In 2009 - 2010, over 10,000 new progeny trees were generated from over 35,000 crosses among 18 different crossing combinations and over 25,000 bearing trees were evaluated for horticultural and market quality. The consistently high breeding numbers are being made possible through greater efficiencies in greenhouse and field evaluations, the greater use of molecular markers to assess crossing potential, and the greater use of field mechanization to minimize field costs.

## Materials and Methods:

The final objective of any variety development program is to develop varieties with clear improvements over the cultivars they are targeted to replace while showing no significant deficiencies in quality and productivity. Tree crops such as almond present special breeding challenges in their long seed-to-seed generation time and their large size which reduces the magnitude of the progeny populations which can be readily evaluated. In addition, it frequently takes decades of field evaluations to determine the true potential/deficiencies of the new variety in the various Central Valley growing sites and climates. The extensive efforts required have discouraged aggressive private almond breeding efforts, shifting breeding responsibilities to public programs. The rapidly changing cultural, environmental, and marketing conditions for California almond production, has also brought about the need for the development of new genetic options to address production and marketing challenges, requiring additional efforts in the identification and recovery of new germplasm for eventual use by both public and private variety improvement programs. Previous annual reports have focused on the subject of new germplasm and improved breeding techniques (2007 and 2008) as well as the specific breeding methods utilized at UCD (2009). This report will attempt a more general overview of the UCD almond breeding strategy and will focus on four areas crucial to its success: I) the characterization of current germplasm; II) discovery of

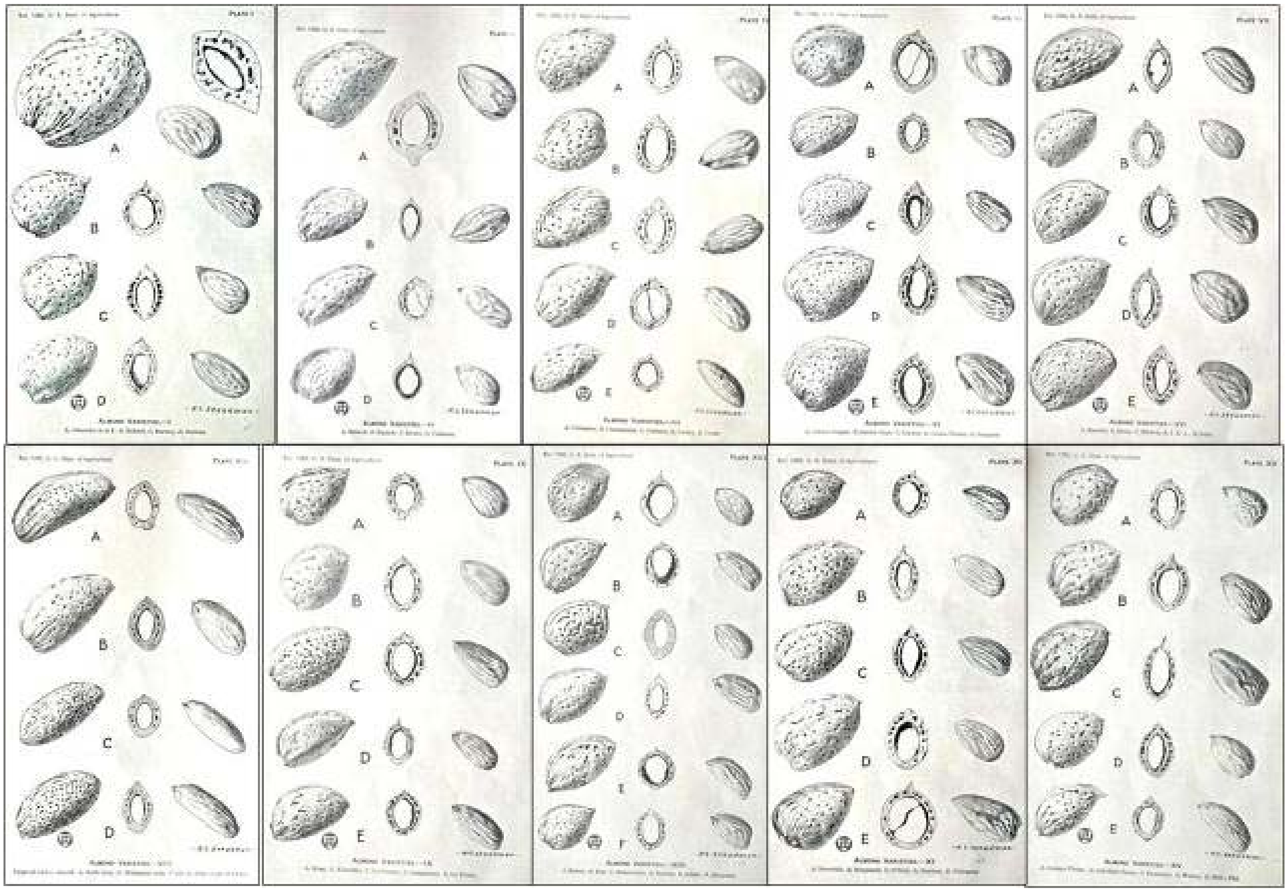


**Figure 1.** Representative varieties described as growing in California in the early 1900s by Milo Wood. 1924. USDA Bulletin No. 1282.

promising new germplasm and successful gene transfer into California-adapted breeding lines; III) the prioritization of targeted traits and IV) the initial characterization of advanced breeding lines containing introduced genes under Central Valley growing conditions.

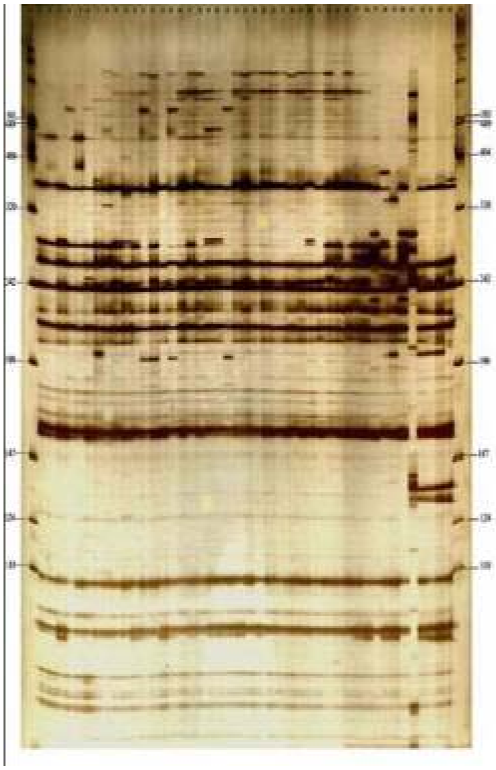


**Figure 2**. Gel used in genomic studies showing distinct banding patterns of distinct DNA sequences.

## Results and Discussion:

### I) **Germplasm characterization**.

Both genetic and literature surveys conclude that the early almond industry in California was founded on a wide diversity of germplasm from Europe, North Africa, and Asia. Over 100 different named varieties were described by Milo Wood as growing in California in the early 1900s (examples shown in **Figure 1**). However, as both the market and production practices became more focused, the germplasm dramatically narrowed. Previous work by our program had indicated that most currently planted California cultivars are probably Nonpareil, Mission, or progeny of crosses between Nonpareil and Mission. [Exceptions include the varieties Sonora and Padre developed by Dale Kester's breeding program at UCD which incorporated new germplasm into traditional California germplasm. See also **Figure 13**.] Our initial analyses was based largely on cross-incompatibility genotypes (S-alleles), and early molecular markers, and left open the possibility that genes from some of the other early California varieties such as Peerless were passed down and incorporated in current varieties. Recently, more accurate DNA markers have been developed by Bud Dangl [Project 09-HORT14-Gradziel/Dangl] (where differences in DNA content result in different sized fragments of DNA which can then be characterized by distinct banding patterns on specialized gels, **Figures 2 and 3**), which has shown that this early genetic diversity has been essentially lost, with only Nonpareil and Mission as

| | A | a | B | b | C | c | D | d | E | e | F | f | G | g | H | h | I | i |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La Prima | 182 | 184 | 130 | 148 | 130 | 142 | **231** | **231** | 99 | 114 | 212 | 227 | 236 | 238 | 129 | 155 | 148 | 158 |
| Arbuckle | 182 | 186 | 122 | 140 | 142 | 142 | 199 | 203 | 110 | 122 | 229 | 231 | 224 | 238 | 147 | 179 | 138 | 148 |
| Lewelling | 182 | 193 | 148 | 150 | 130 | 150 | 203 | 233 | 114 | 114 | 212 | 227 | 236 | 242 | 155 | 155 | 148 | 158 |
| IXL | 182 | 194 | 130 | 136 | 142 | 146 | 211 | 231 | 99 | 110 | 225 | 259 | 224 | 232 | 129 | 155 | 144 | 148 |
| Tardy Nonpareil | 182 | 194 | 130 | 148 | 142 | 146 | 211 | 233 | 99 | 110 | 212 | 259 | 224 | 236 | 155 | 155 | 148 | 158 |
| WestSteyn | 182 | 194 | 130 | 148 | **142** | **146** | 211 | 233 | 99 | 110 | 212 | 259 | 224 | 236 | 155 | 155 | **148** | **158** |
| Jeffries | 182 | 194 | 130 | 148 | **142** | **142** | 211 | 233 | 99 | 110 | 212 | 259 | 224 | 236 | 155 | 155 | **158** | **158** |
| Jordanolo | 194 | 204 | 130 | **184** | 132 | 146 | 211 | 215 | 110 | 116 | 212 | 229 | 224 | 242 | 155 | 161 | 146 | 148 |
| Davey | 194 | 208 | 130 | 148 | 142 | 146 | 211 | 223 | 110 | 110 | 221 | **259** | 224 | 224 | 129 | 155 | 146 | 158 |
| SansFaute | 194 | 216 | 130 | 146 | 130 | 142 | 203 | 211 | 99 | 114 | 225 | 227 | 224 | 234 | 129 | 129 | 148 | 148 |
| Bidwell | 196 | 196 | 150 | 160 | 130 | 150 | 199 | 199 | 110 | 114 | 245 | 247 | 232 | 242 | 129 | 155 | 144 | 148 |
| Langeudoc | 196 | 216 | 122 | 146 | 130 | 136 | 199 | 203 | 108 | 114 | 227 | 227 | 234 | 236 | 129 | 147 | 136 | 148 |
| **Nonpareil** | 182 | 194 | 130 | 148 | 142 | 146 | 211 | 233 | 99 | 110 | 212 | 259 | 224 | 236 | 155 | 155 | 148 | 158 |
| **MISSION** | 196 | 216 | 122 | 146 | 130 | 136 | 199 | 203 | 108 | 114 | 227 | 227 | 234 | 236 | 129 | 147 | 136 | 148 |
| THOMPSON | 194 | 216 | 122 | 130 | 130 | 142 | 203 | 211 | 99 | 114 | 212 | 227 | 224 | 236 | 147 | 155 | 136 | 148 |

**Figure 3.** Sample of molecular markers developed by Dangl which both serve to ID varieties as well as identify possible parents contributing a specific marker complement.

parents for most currently planted commercial California almonds. The basis for this genetic loss appears to be a consequence of the widespread use of almond seedlings as rootstocks in early California production. Our research has shown that Mission seed would have been preferred to Nonpareil seed in rootstock plantings because it gives higher germination rates and is less susceptible than Nonpareil seedlings to various canker diseases. Commercially, Mission showed poorer kernel quality and lower yields than Nonpareil, but was extensively planted because at that time it was one of the few varieties which covered the late Nonpareil bloom. Conversely, most of the pollination of Mission trees would be by Nonpareil, resulting in most seed used for rootstocks having a Mission by Nonpareil parentage which in turn, served as the foundation material for subsequent new varieties. This is because almost all almond cultivars in California (probably including Thompson, Sauret #2, Mono, Wood Colony, Durango, Merced, Rosetta, Price Cluster, Aldrich, Sano, Ripon, Carmel, Sauret # 1, Livingston, Monterey, Plateau, Avalon, Folsom, Blue Gum, and Butte) originated as grower selections. For example, Carmel was discovered in a commercial Nonpareil orchard in the 1960s and so was originally thought to be a mutation of Nonpareil. Molecular analysis, however, supports both Mission and Nonpareil as parents. Because the orchard was on almond rootstock, it appears that Carmel originated as an almond seedling rootstock in which the bud had failed to take. While the resulting tree would usually be of inferior quality and so quickly recognized and rogued out, trees showing adequate quality would be retained and with time occasionally recognized if they possessed superior quality and propagated, as with Carmel. Using today’s more accurate molecular markers, Carmel

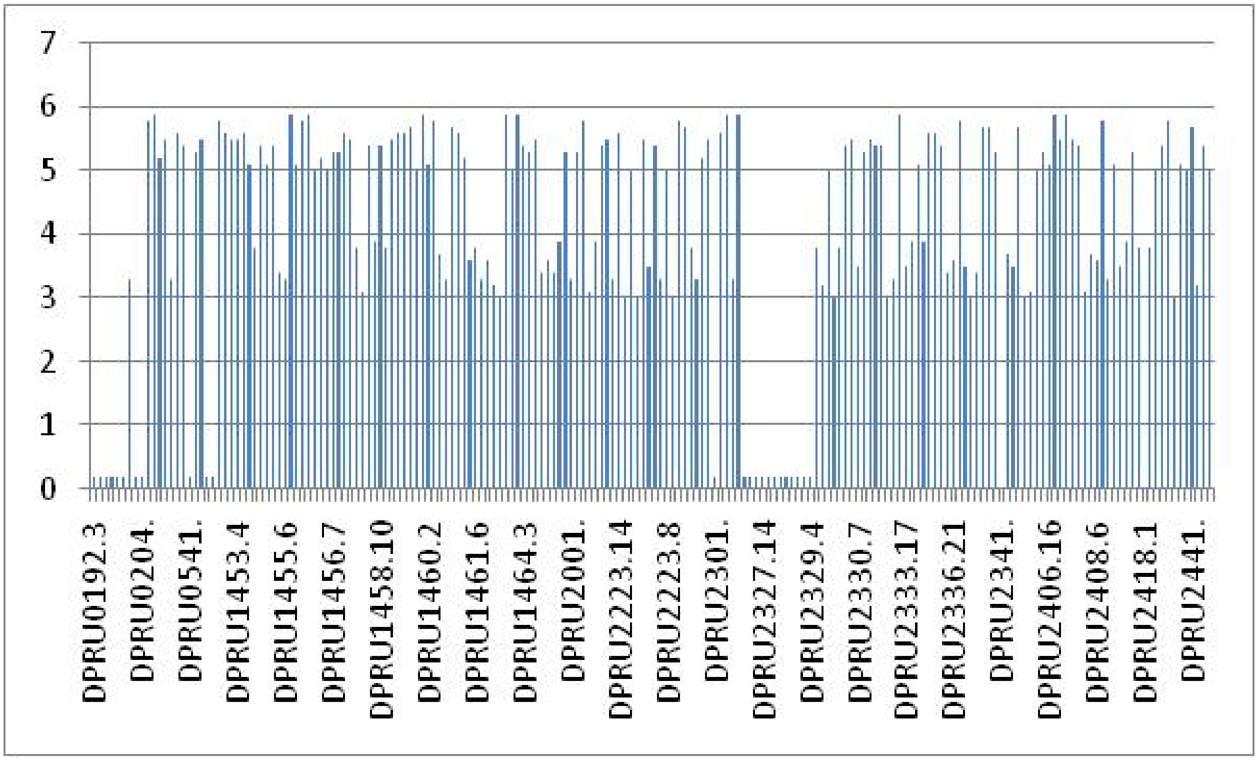


**Figure 4.** Results from our USDA funded hull-rot resistance survey (0-resistant; 6 is very susceptible)

(as with Thompson in **Figure 3**) can readily be seen to be the result of the recombination of genes from both Nonpareil and Mission. Our analysis of current and historic almond varieties using the improved molecular markers developed by Dangl [Project 09-HORT14-Gradziel/Dangl], while confirming predominance of the Mission by Nonpareil parentage (to the exclusion of other historic lineages), also turned up some surprises. Until now, the variety Jeffries was also considered to be a bud-sport or a mutation of Nonpareil as it appears identical to Nonpareil in both tree and nut characteristics and has the same ‘S8’ cross-incompatibility allele (while appearing to have a nonfunctional Nonpareil ‘S7’ cross/self-incompatibility allele). The apparent non-function of the S7 allele allows Jeffries to be pollinated by Nonpareil (the original Jeffries was reported to be discovered as a heavily cropped branch in an otherwise fruitless solid-Nonpareil planting). Analysis using current molecular markers, however, clearly shows that it possesses alleles from a parent other than Nonpareil (**Figure 3**) and so has a seedling origin. A commercial implication of this finding is that in larger plantings the Jeffries tree and kernel may eventually deviate from the accepted Nonpareil market type and so lose market value. This finding also confirms the leakiness of the S-allele-based cross/self-incompatibility mechanism in almond, since it shows that S8 pollen can occasionally be effective in pollinating an S8 pistil. [By forced-selfing of Mission, we were similarly able to recover S1S1 and S5S5 genotypes in the progeny for use in test-crosses to rapidly determine specific cross-incompatibility genotypes].

The findings of a narrow germplasm base for most current California almond varieties confirms the limited opportunities of finding new genetic options for meeting new production/marketing requirements. As an example, a summary of the results from our 2009 hull-rot resistance screening study of almond germplasm (including standard

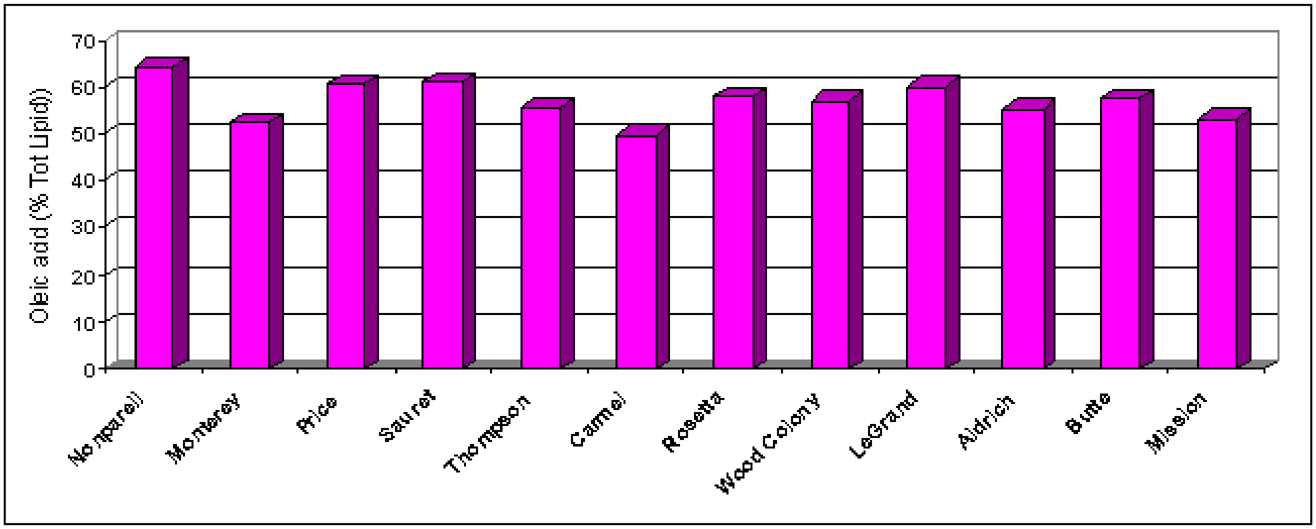


**Figure 5.** Average oleic acid content of Nonpareil, Mission and cultivars resulting from a Nonpareil x Mission cross. (Ann. Rpt. 2008).

varieties, heirloom varieties and UCD breeding selections) is shown in **Figure 4**. While lower levels of disease susceptibility were identified in certain California varieties such as Nonpareil, high levels of resistance were only found in some UCD interspecific derived breeding lines and some European cultivars. Consequently, to improve hull rot resistance in future varieties, outside germplasm would need to be utilized with. This limitation is also demonstrated in **Figure 5**, where content of the phytonutrient oleic acid is shown for the parents Nonpareil and Mission as well as several varieties which have been shown by molecular markers to be their probable progeny. As is typical for traits controlled by multiple genes, the progeny show levels intermediate to those of the parents. To achieve phytonutrient levels above this range, outside germplasm will again need to be identified and incorporated into California adapted breeding lines. The recently released Sweetheart variety has the highest oleic acid contents of any variety we have measured at approximately 73% and its development serves as an example of the UCD approach to the acquisition of new germplasm.

## II) **New Germplasm**.

The original seedling was derived from a cross between breeding selections UCD25-26 and SB3,54-39E and was initially evaluated as seedling SB13,36-52 (**Figure 6**). It's lineage includes the heavily planted California cultivar 'Nonpareil' and the early flowering but lower market-quality cultivars 'Harriot' ($S_6S_{14}$), as well as 'Eureka' ($S_8S_{13}$), the late flowering 'Mission' ($S_1S_5$) cultivar, as well as the 'Lukens Honey' peach (*Prunus persica* L.) as a source of pollen-pistil self-compatibility and disease and pest resistance. While multi-year evaluations concluded that SB13,36-52 expressed only moderate levels of self-compatibility, it's exceptionally high oleic acid content and associated roasting quality, and distinctive heart-shaped kernel (**Table 1**) suggested its potential as a California-adapted alternative to the commercially important high roasting quality Spanish cultivar 'Marcona'.

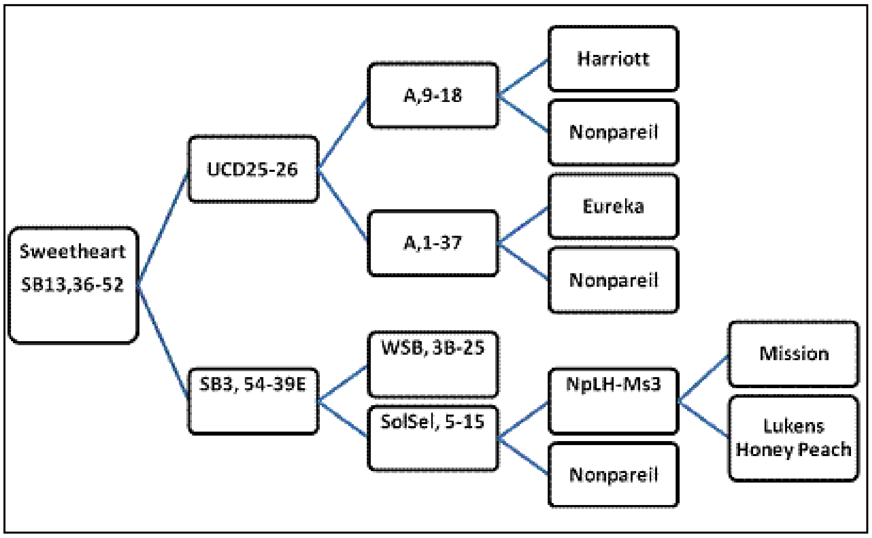


**Figure 6.** Pedigree of 'Sweetheart' almond.

Based on these promising tree and kernel qualities, seedling SB13,36-52 was selected for regional testing as an early flowering pollenizer for 'Nonpareil'. Almond flower fecundity is higher in the early bloom, resulting in early pollenizers having greater economic importance. Most early flowering pollenizers, however, show inconsistent bloom overlap with 'Nonpareil' and a consequent lower productivity for both cultivars. Flowering time in almond is determined by the accumulation of sufficient chilling units to overcome flower bud dormancy, followed by the accumulation of sufficient heat units for bud development to flowering. Requirements for both chilling and heat units differ among individual cultivars resulting in variable year-to-year bloom overlap. Currently, the only method to accurately evaluate bloom overlap is long-term field evaluations. Seedling SB13,36-52, along with other breeding selections and cultivar standards including the Spanish variety Marcona, was evaluated from 1999 to 2010 in replicated blocks planted in 1993 in Colusa and Solano County and in 2004 to 2010 in Kern County. Data was collected yearly on bloom and harvest period, pollen cross-compatibility, nut yield and quality, and disease and insect damage. A number of smaller grower plantings at additional sites were also utilized to two verify regional findings. Fatty acid analysis was from multi-year and multi-site replications. Over the ten years of regional evaluation, selection SB13,36-52 demonstrated only moderate levels of pollen cross-compatibility but full cross-compatibility with Nonpareil and consistent bloom overlap with the early 'Nonpareil' bloom. These properties combined with its high phytonutrient content and high market quality resulted in the decision to release selection SB13,36-52 as the patented cultivar 'Sweetheart.

**Figure 7.** Physical appearance of shell nuts and kernels of 'Sweetheart' compared to 'Marcona' almond.

The 'Sweetheart' tree is upright and vigorous (**Figure 8**). Production occurs primarily on spurs located on older wood. This bearing habit results in consistent, year-to-year productivity. The tree has an open architecture that allows greater light penetration and air circulation to the canopy interior. Flowers are numerous and produce abundant pollen. Flower petals are large and white with slightly scalloped margins, with only a slight reddening at the petal base as bloom progresses (**Figure 8**, inset). The S-allele genotype for 'Sweetheart' is $S_1S_{14}$ as compared to 'Nonpareil' ($S_7S_8$) making 'Sweetheart' one of the few California cultivars which is fully cross-compatible with 'Nonpareil' (both pollen types $S_1$and $S_{14}$ are compatible as opposed to most current varieties which have a Nonpareil pollen type {as a result of the Nonpareil parentage) as well as a non-Nonpareil {usually Mission} cross-compatible type). Sweetheart is also one of the few California cultivars showing intermediate levels (10-20%) of self-compatibility. Self-compatibility in almond is variable with most commercial cultivars setting less than 10% of flowers being self-pollinated and so considered self-incompatible. Self-compatible cultivars need to achieve greater than 20% set following self-pollination to be considered commercially useful. For a few cultivars, primarily 'Sweetheart' and 'Winters', the selfing percentage is between 10% and 20%, which while too low to be considered self-compatible, does confer greater crop stability were honeybee cross-pollination is limiting. (If the $S_1S_{14}$ S-genotype is verified in 2011 studies to be identical for both 'Winters' and 'Sweetheart', it would support our current hypothesis that the moderate levels of self-compatibility result primarily from the presence of the leaky $S_{14}$ allele rather than a more subtle influence of a larger number of modifier genes as previously proposed. This finding would have important implications in its demonstration that traditional almond self-incompatibility alleles can show atypical expressions in certain genetic combinations. This quality, if verified, could have positive applications as it suggest that the combination of self-compatible alleles ($S_f$) with more traditional but 'leaky' alleles like $S_{14}$ may result in more uniformly high year-to-year levels of self-compatibility. It also highlights the risks of over-dependence on one to a few self-compatibility alleles (as with the S'160' allele discussed in the next section). [A similar example where European almond breeding programs use of the Tuono self-compatibility source as their primary source of self-compatibility was described in the 2009 annual report, where advanced breeding-lines showed good levels of self-compatibility but lower yield potential, presumably due to inbreeding or similar negative remnants from the Tuono parent.]

**Figure 8**. Physical appearance of 'Sweetheart' tree showing upright growth habit and characteristic shoot and flowers (inset).

Kernel size and quality of 'Sweetheart' are similar to 'Marcona' (**Table 1**) with similar high levels of the phytonutrient oleic acid which contributes to the high roasting quality and longer storage times before nuts begin to become rancid. Because retail prices for 'Marcona' have been more than twice those of even the premium 'Nonpareil' prices, experimental plantings of this important Spanish variety have been planted in the Central Valley, through with most being unsuccessful because of poor cultivar survival in major production regions. Part of Marcona's failure is due to the initial propagation material being infected with Prunus Necrotic Ringspot virus, to which Marcona is susceptible. [We have now identified virus-free source material which is currently undergoing final testing prior to inclusion in FPS foundation plantings; as summarized in 2008 Annual Report].

In performance, 'Sweetheart' consistently showed good overlap with early 'Nonpareil' bloom in all years and sites evaluated, including the Sacramento Valley where the more variable winter and spring temperatures frequently result in erratic bloom patterns (**Table 1**). The combination of open tree architecture, high flower-density, good bloom overlap with 'Nonpareil', and partial self compatibility has resulted in consistently good productivity being comparable to healthy 'Marcona'' though lower than 'Nonpareil' (**Table 1**). In regional grower trials 'Sweetheart' has shown only moderate to low susceptibility to hull rot (*Rhizopus* spp.) and alternaria leaf spot (*Alternaria spp*.). Hull and kernel resistance to post-harvest fungal diseases is also maintained into storage, conferring greater resistance to postharvest pests including navel orangeworm (*Amyelois transitella* Walker) and Indian meal moth (*Plodia interpunctella* Hubner), since infected hull tissue provide a better growth environment for the more vulnerable 1st instar larvae. Kernel mass, while statistically similar to 'Nonpareil' and 'Marcona', tends to be smaller under high production. Kernel dimensions are similar to 'Marcona' with 'Sweetheart' showing a more uniform chordate shape (**Figure 7**) but with a much reduced shell mass. The shelling percentage (ratio of kernel to kernel-plus-shell) of approximately 0.65, while lower than 'Nonpareil' (**Table 1**) is twice that of 'Marcona' with its thick and highly lignified shell (**Figure 7**). The incidence of other undesirable nut types, particularly double-kernels and kernels having multiple embryos was low, similar to 'Nonpareil' and 'Marcona'. Harvest of 'Sweetheart' is typically 3 weeks after 'Nonpareil' and so does not interfere with this and other early to mid-season cultivars, yet is approximately 2 weeks earlier than 'Marcona'.

**Table 1**. Kernel trait means for 'Sweetheart' relative to 'Marcona' and 'Nonpareil'. Measurements made from 2006 to 2009 at Sacramento and San Joaquin Valley Evaluation Trials[z].

| | Nonpareil | Sweetheart | Marcona |
|---|---|---|---|
| Bloom start (Julian date) | 47 a | 45 a | 46 a |
| Full bloom date | 58 a | 56 a | 55 a |
| Bloom end date | 67 a | 70 a | 66 a |
| Hull split date | 197 a | 217 b | 234 c |
| Kernel length (mm) | 24.8 b | 20.4 a | 19.8 a |
| Kernel width (mm) | 12.2 a | 14.4 b | 14.9 b |
| Kernel thickness (mm) | 8.3 a | 8.9 a | 8.6 a |
| Kernel mass (g) | 1.05 a | 0.98 a | 1.07 a |
| Double kernels (%) | 3.0 a | 2.6 a | 3.0 a |
| Multiple embryos (%) | 3.5 b | 3.0 b | 0.5 a |
| Creased kernel (%) | 8.5 b | 5.5 ab | 3.2 a |
| Lipid (%) | 38.8 a | 43.4 b | 42.6 b |
| Oleic acid (%) | 66.8 a | 73.0 b | 72.8 b |
| Hull rot (%) | 100 c | 23.1 a | 82.4 b |
| NOW (%) | 79.5 c | 14.1 b | 0 a |
| Shell seal (%) | 44.5 a | 88.5 b | 100 c |
| Shelling (%) | 72.2 c | 64.5 b | 32.2 a |
| Yield (kg/ha) | 2696 b | 2023 a | 2101 a |

[z] Mean separation performed within each row by Duncan's multiple range test, P=0.05

Sweetheart should be considered a niche-market cultivar because of its unique kernel shape and high oleic acid content/high roasting quality, and as a consequence is expected to have only limited plantings. The atypical (and normally commercially undesirable) kernel shape as well as desirable traits such as high kernel oil quality was commonly observed in early interspecific breeding lines first evaluated in the early 1990s. [Because it would normally take approximately 5 years to identify the most promising individuals within a breeding population (a seedling tree only start to fruit in the fourth year), and then an additional 10 years (at a minimum) for replicated regional testing, recently released cultivars would have their origins in the early 1990s or previous]. This can be visualized in **Figure 9**, which shows a promising UCD breeding lineage. Although having better kernel qualities, Sweetheart would be comparable to breeding selection F5,4-11 in **Figure 9** in its retention of both a normally undesirable peach-type kernel shape as well a very desirable trait (self-compatibility in the case of F5,4-11 ). As shown in **Figure 9**, while a desirable Nonpareil-type kernel shape can be recovered fairly readily in breeding lineage through proper choice of parent, it is much

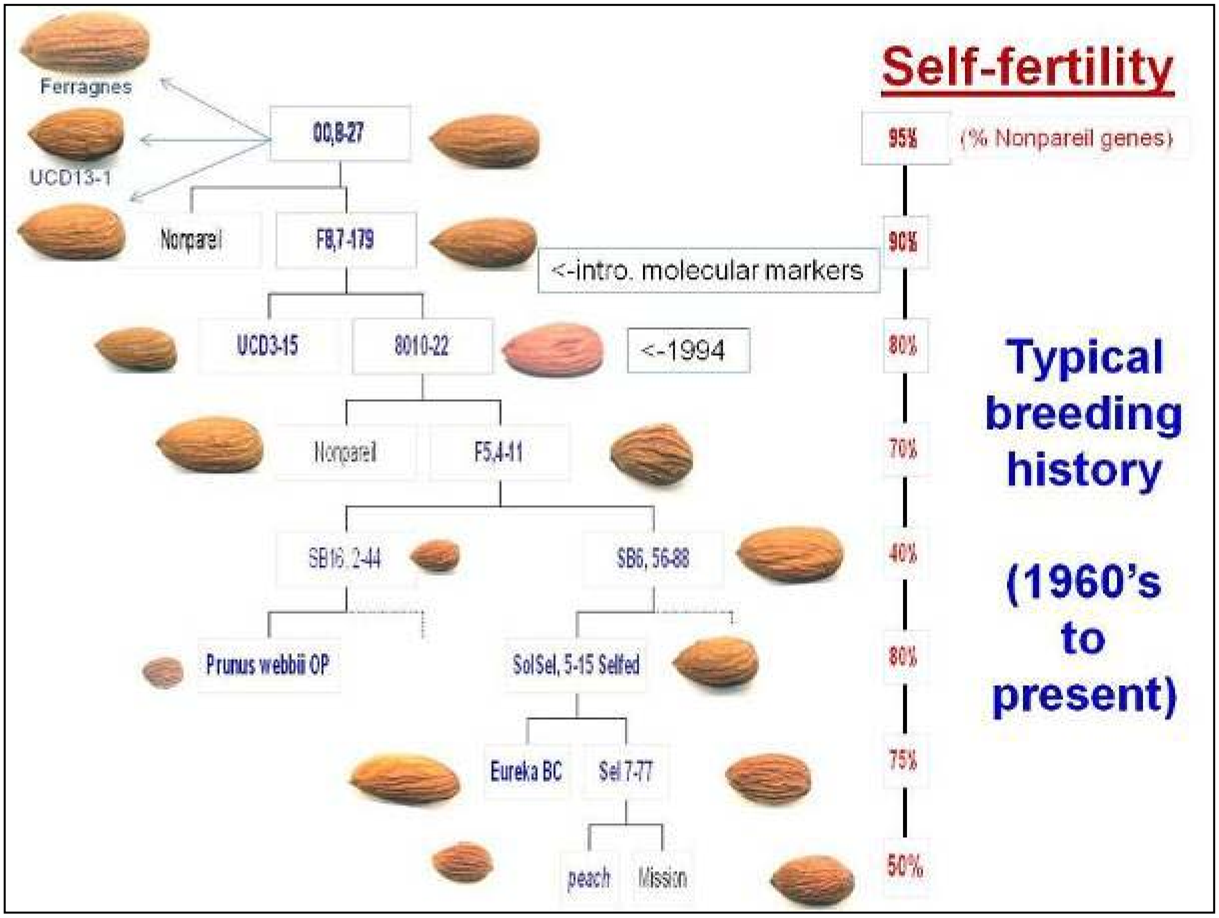


**Figure 9**. Typical UCD almond breeding lineage showing development of the 00,8-27 self-compatible breeding parent.

more difficult to recover large kernel size since progeny kernel sizes tend to be intermediate in size to their parents.

III) **Trait priorities and selection scheme.**

As described in earlier annual reports, breeding efforts have targeted high levels of self-compatibility combined with larger kernel size and Nonpareil-type kernel shape and quality.  Within these more focused breeding schemes, efforts were also made to maintain the higher levels of insect and disease resistance and kernel nutritional quality originating in the different interspecific introgression lines (see Appendix A.).  Because darker seed coat colors have been associated with improved nutritional (antioxidant) levels as well as certain disease/insect resistance, no strong selection pressure against darker seed coat colors were applied during this initial period.  As a result, the advanced UCD almond selections now in regional testing for self-compatibility and resistance levels show improved kernel size and shape with a wide range and seed coat colors (**Figure 10** and Appendix C).  These selections continue to represent a diverse germplasm, including genes from *Prunus persica (*peach*), Prunus webbii, Prunus mira, Prunus fenzliana* and the self-compatible European variety Tuono,
which have been transferred to a California almond background (introgressed) with repeated, sequential selections for the desired traits.  Most advanced selections are now approaching or have achieved typical Nonpareil-type dimensions (for comparison, selection 00,8-27 of **Figure 9** is located in the bottom left corner of **Figure 10**).

**Figure 10.** Comparison of nut size, shape and color for a representative sample of UCD almond selections now in regional disease/yield testing (image can be enlarged for improved resolution.

Because kernel size and shape is determined by a number of genes, most progeny from crosses between two selected parents will be intermediate in size and shape to those parents. Consequently, the ideal parent for future crosses would possess a Nonpareil-type shape but in a larger size than Nonpareil in order to allow the largest possible number of progeny to achieve Nonpareil-size or better. For example, advanced selection 2004,8-160, which contains genes from *Prunus mira*, Nonpareil and Winters almond (see 2009 annual report) combines Nonpareil-type shape, large kernel size and high levels of self-compatibility and high productivity (**Figure 11**, Appendix C). This selection also possesses a darker seed coat or pellicle which is less desirable in today's market. To characterize the range of commercial seed-coat colors, the 'R' value of the standard RGB color space was calculated for a range of Mission and Nonpareil seed from Regional Variety Trials in the Sacramento and San Joaquin valleys. Results show a generally broad range from R-values of approximately 25 to 54 for commercial kernel color within these two cultivars (**Figure 12**). While R-values for most advanced UCD selections currently in regional trials reside within these values, the majority were towards the darker Mission-type, with some individuals such as 97,3-40 being distinctly darker than Mission (**Figure 12**). In addition, some advanced selections such as 2004, 8-107 had kernel seed coat colors even lighter than Nonpareil. To achieve Nonpareil-type color in the next generation of breeding progeny, crosses have been made between parents showing the highest levels of self-compatibility and kernel size/shape (such as 2004,8-160) with parents showing good commercial quality with lighter seed coat colors (such as Nonpareil, Sonora, and 2004,8-107). A crucial determinant of breeding progress towards lighter kernel color will be the ease of inheriting the lighter seed-coat color. To test the heritability (proportion of progeny inheriting the desired trait) of seed-coat color, over 100 progeny were evaluated from the cross Nonpareil (light) by F8,7-179 (dark; see **Figure 9**). Results are presented visually in **Figure 13** where each seed shown is a representative sample from an individual progeny tree. In this study, a large proportion of progeny inherited the lighter seed-coat color. Progeny also inherited high proportions of desirable kernel size and shape, though the individual traits appear to be inherited independently.

**Figure 11.** Shell and kernel characteristics of self-compatible selection 2004,8-160.

To develop a more precise understanding of the inheritance of seed-coat color, and eventually develop useful molecular markers similar to those currently being utilized to identify cross-and self-incompatibility genotypes, we are pursuing a genomic analysis of this trait as part of the RosBreed Consortium Project. This multimillion dollar, national/international project (ABC is an industry partner) attempts to identify useful molecular markers to important quality traits for fruit crops within the Rosaceae (primarily peaches, apples, cherries and strawberries, see www.). Although almond was not included in this project because it is not a fruit crop, the extensive use of almond and wild almond relatives in the UCD peach breeding program have allowed us to include important almond breeding parents including Nonpareil, Nonpareil BF, Sonora, Tardy Nonpareil, UCD25-75, Ferragnes, Jordanolo, 2004,18-20, 2004,8-160, 95,1-26, F10D,3-25, F10D,4-18, F8,7-179, Nemaguard, Nickels, and Winters. Breeding lineages for the UCD almond variety development program as well as peach lineages derived from almond and almond species crosses are currently being mapped out. Detailed lineages are needed so that both genetic compositions (as characterized by molecular markers positioned throughout the genome) and trait appearance or phenotype (levels of resistance, phytonutrient content, seed-coat color, etc.) as determined by laboratory and field analysis can be determined for selected individuals throughout the lineage. High-level computer software will then be utilized to identify close correlations of specific molecular markers with specific traits of interest so that those markers can be used to identify those particular traits in the future. Molecular markers assisted trait selection has advantages in that selection is much less ambiguous than the environmentally variable field observations, and initial selection/rogueing-out can be made before fruiting, even at the seedling stage. Tracing the presence of specific molecular marker and it's highly correlated plant trait (kernel color, etc.) across the breeding lineage allows a higher level of selection accuracy without the need for large progeny population sizes. Much larger lineages will be evaluated for the UCD peach breeding populations including a large number of interspecific lineages containing almond and related species. More accurate molecular markers for kernel color are anticipated from the peach studies, though because of the close genetic relationship between peach and almond, the same markers should be applicable to almond breeding.

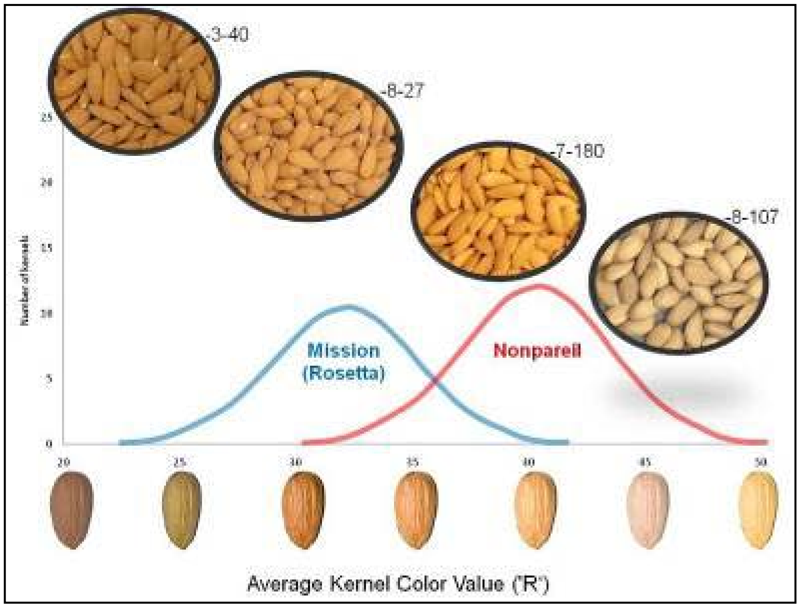


**Figure 12.** Graphical summary of 'R' values for a range of Mission and Nonpareil seed from Regional Variety Trials in the Sacramento and San Joaquin valleys.

## Specific traits associated with tree yield.

The ability to use molecular marker assisted selection has its greatest advantage for those traits which are very difficult to measure in the field because of a strong environmental affect and/or control of the trait by multiple genes with medium to small individual contribution. Final tree productivity is among the most important considerations a grower makes in choosing almond cultivars for planting, yet is one of the most difficult ones to genetically characterize. Yield potential has traditionally been considered a consequence of the total number of flowers produced, the proportion of their subsequent successful fruit set and the final kernel size. Concurrent improvements in our ability to differentiate genetic determinants of tree yield using both traditional and marker assisted selection techniques highlight the need for a fuller understanding of the ultimate determinant of yield potential in both established and new cultivars. As an initial step towards this goal, an extensive database of almond production and horticultural characteristics has been developed to identify basic trends and relationships.

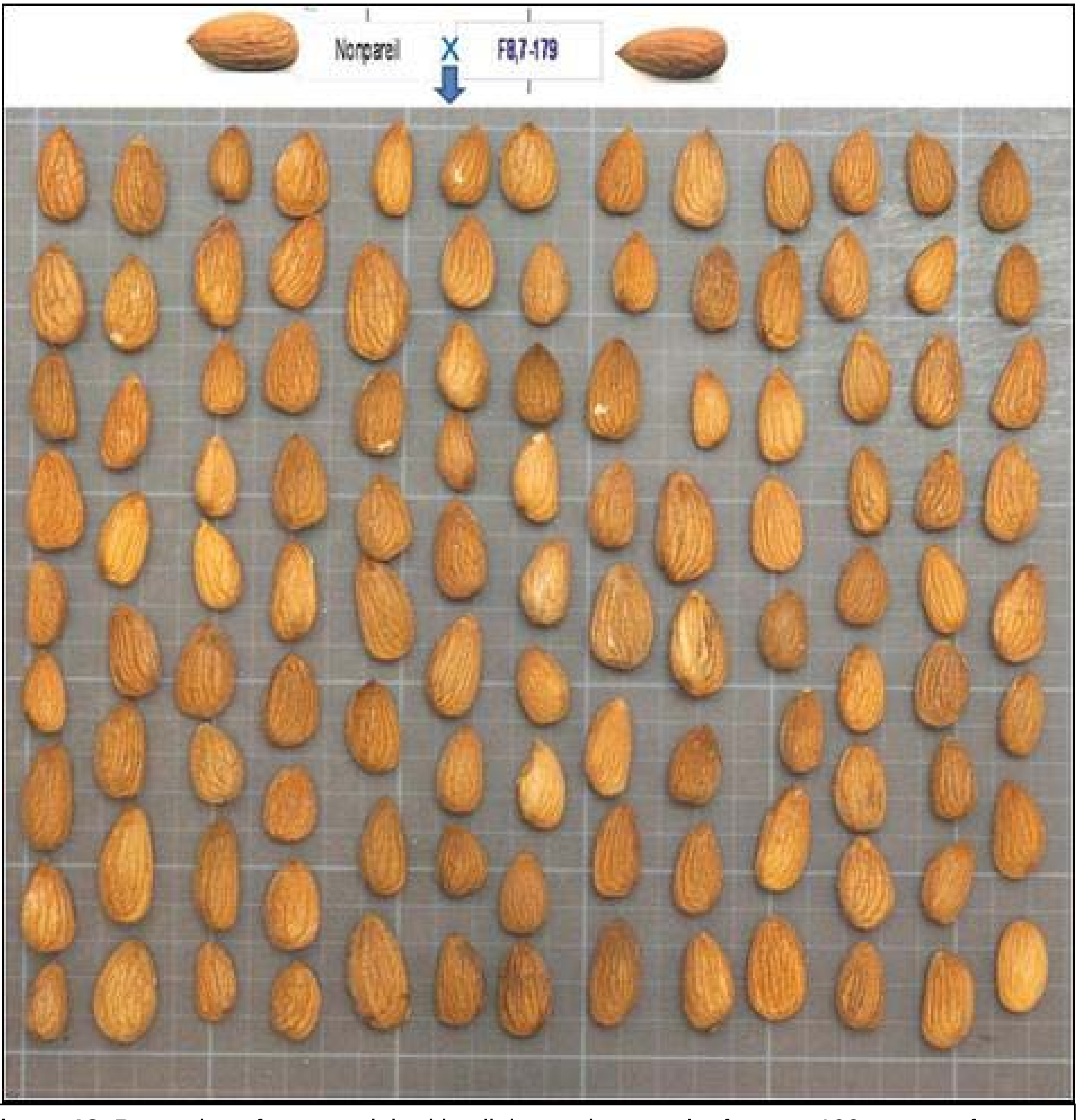


**Figure 13.** Proportion of progeny inheriting light seed-coat color for over 100 progeny from the cross Nonpareil (light) by F8,7-179 (each kernel represents 1 progeny tree).

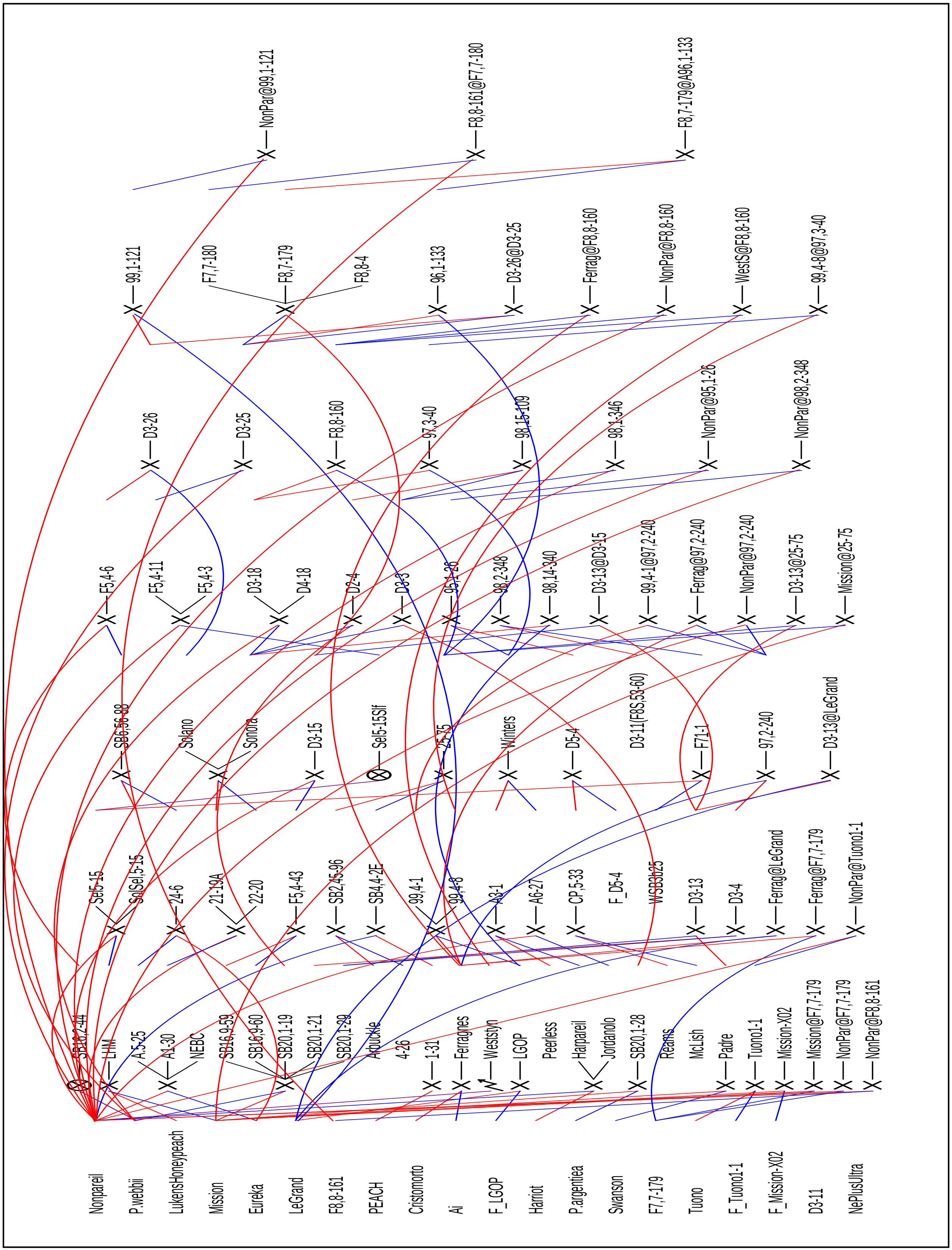


**Figure 14.** Flow chart of almond breeding lineages of the 1990's which served as germplasm foundation for more recent cross-hybridizations (red-seed parent; blue pollen parent. Image can be enlarged to increase resolution).

### Regional Variety Trial Productivity Trends

Production data was pooled from 10 regional almond evaluation sites throughout the Central Valley of California, extending from latitudes of approximately 35° to 40° and so representing a range of growth environments (**Figure 15**). A total of 40 cultivars, representing all California varieties with commercial plantings exceeding 200 ha were evaluated. Regional trials were initiated in 1981 with the most recent trials planted in 1993. Production and horticultural data was collected from each cultivar for at least the first 15 years of growth. All cultivars were planted on peach rootstock; with *Lovell* peach being the primary rootstock for northern Sacramento Valley sites and *Nemaguard* peach rootstocks being used in the often more sandy, southern San Joaquin Valley soils. Averaged data from 20 to 40 trees per cultivar per site were analyzed in this study. Data was analyzed for a range of horticultural traits including flower and kernel number, density and distribution, tree architecture (including Bruce Lampinen's analysis of midday light interception) [Project 10-HORT13-Lampinen], flower fecundity (seed set following standardized pollinations with compatible pollen), pollen viability (germination percentage at dehiscence), differences in flower production of pollen and nectar among cultivars, kernel size, annual cultivar yield at each test site, and cumulative cultivar yield for each site over the duration of the evaluation period.

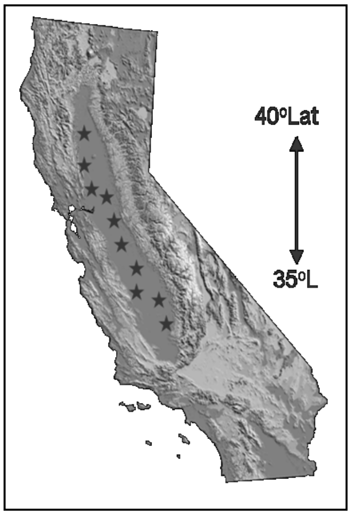


**Figure 15.** Regional sites where replicated testing occurred in almond yield trials.

### Flower quality

No strong relationship was found between yield potential and flower density or fecundity (including pollen and nectar quality and quantity) indicating sufficient levels preexisted in the commercially established cultivars evaluated. Important preliminary relationships were identified between yield potential and the number of nuts per tree, kernel size, tree canopy light interception, and bearing habit.

### Number of nuts per tree

A strong correlation was found between cultivar yield and total nuts per tree for a given year (**Figure 16**). The correlation was particularly strong for cultivar/sites yielding under 1 metric ton per hectare though becoming more diffuse with increasing productivity. However at the highest productivities of between 4 and 5 metric tons per hectare, a wide range between 20,000

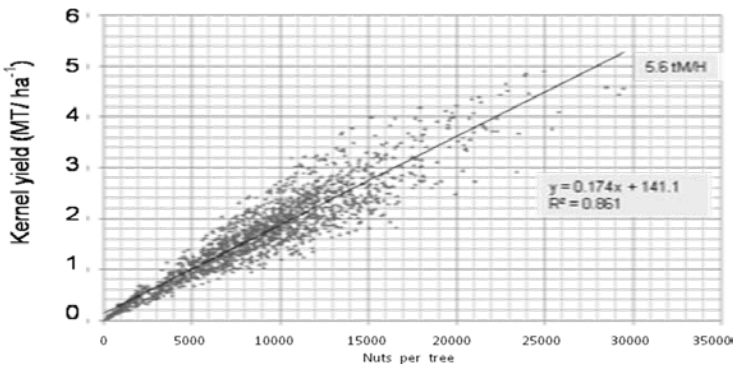


**Figure 16.** Relationship between average number of nuts per tree and end of season cultivar yield of kernel meats for all cultivars, sites and years sampled.

and 30,000 nuts per tree were observed indicating the importance of both kernel size and final tree size to final productivity. Larger tree sizes tended to be particularly more productive in young orchards before the orchards matured and became fully closed (i.e. no open spaces existed between adjacent trees within and between rows resulting in near complete shading of the orchard floor). While larger trees maintain a higher final yield potential even in mature orchards because of their larger canopy, they are commercially undesirable if the cultivar is a lower market-value pollenizer to adjacent high market-value cultivars since the larger trees would result in more shading of the high-value cultivars resulting in their reduced yields and so lower final orchard profitability.

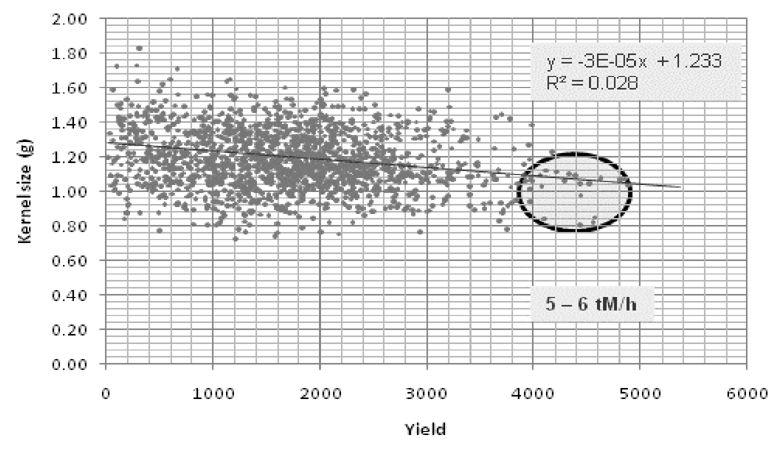


**Figure 17.** Relationship between average kernel size and end of season cultivar yield of kernel meats for all cultivars, sites and years sampled.

## Kernel size

Kernel size ranged from approximately 0.7 g to over 1.8 g for cultivars evaluated (**Figure 17**). Almond kernel sizes smaller than 0.7 g are commonly observed in breeding populations but are considered too small for commercial use in California. Very large sized kernels often bring increased market prices but appear associated with lower final tree yields. Most commercial cultivars had kernel sizes between 0.8 and 1.6 g. At the very high yields of 5-6 metric tons per hectare, cultivars showed kernel sizes of approximately 1 g, indicating a possible optimum size for maximizing tree productivity.

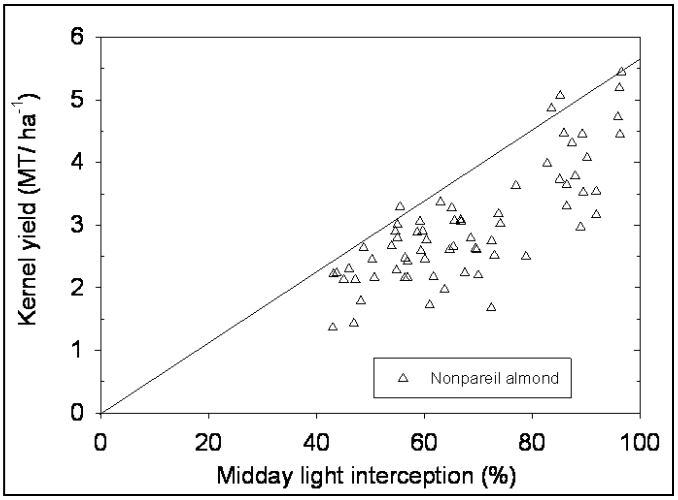


**Figure 18.** Relationship between midday light interception and end of season yields for the 10 year old cv. 'Nonpareil' trees in regional trials planted after 1993. [B. Lampinen data]

## Tree canopy light interception

Effective canopy light interception was strongly associated with final tree productivity (**Figure 18**). (Midday light interception measurements were recorded only for regional trial cultivars planted since 1993). While the fundamental importance of captured solar radiation has been demonstrated for a range of crop plants, the almond work has emphasized the importance of both tree architecture and fruit bearing habit in determining cultivar efficiency for light interception and energy conversion to final kernel yield. Preliminary results are consistent with a highly localized source-sink (leaf-to-fruit) transport of carbohydrates similar to the more fully characterized sink-limited relationships originally developed for peach. The peach work has demonstrated that the limited carbohydrate transport from photosynthesizing leaves to developing fruits (within approximately 30 cm) requires a uniform and saturated fruit distribution throughout the photosynthetically active canopy in order to maximize tree yield. While the larger canopy area of larger trees will provide a yield advantage even in mature orchards, the proper distribution of fruit bearing units is also crucial to maximize yield potential and can be particularly important for maximizing yields in smaller pollenizer cultivars such as 'Carmel' and 'Winters' while minimizing shading and so yield loss on an adjacent high-market value cultivars such as 'Nonpareil'. In addition to tree architecture, the nature of the fruit bearing unit (shoot versus spur) appears to be a crucial component of final yield potential within individual production years and for cumulative cultivar/site production.

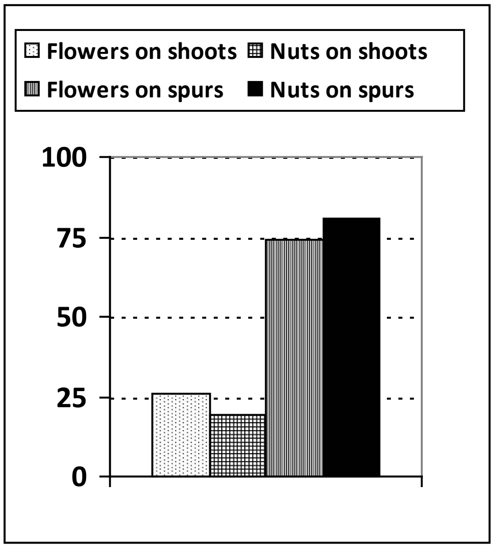


**Figure 19**. Proportion (%) of shoot-flowers to spur-flowers on 10 year old cv. 'Nonpareil' trees with the proportion of final fruit sets.

## Bearing habit

In mature, bearing trees, spur production accounted for the majority of effective fruit bearing units contributing to yield (**Figure 19**) as spurs are more efficient than shoots in balancing fruit renewal with carbohydrate costly vegetative growth. In addition, in highly productive cultivars such as 'Nonpareil', spurs tend to show a higher fruit-set efficiency than shoots (**Figure 19**) presumably because of a greater availability of spur-stored carbohydrates in the more flower-limited spurs compared with the much higher flower density shoots. Interestingly, this work has also indicated that spurs with high initial flower counts (3-4) have higher

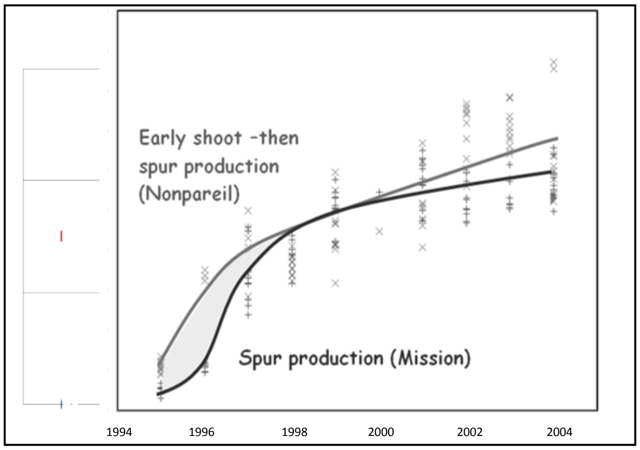


**Figure 20**. Comparison of averaged cumulative yields for shoot- plus spur-bearing cv. 'Nonpareil' and predominantly spur-bearing cv. 'Mission' for evaluation sites planted in 1993.

**Figure 21**. Interspecific peach x Prunus argentea hybrid P01-7-180 showing normal growth and crop load 1 month after summer irrigation shut-off. (Note decline of peach controls at left).

fruit-set efficiencies than spurs with only 1 to 2 flowers. The initial number of flowers developing per spur is probably an indication of the total carbohydrate reserves available to that spur at the time of flowering (and prior to leaf development) with greater carbohydrate reserves facilitating higher final fruit sets. When cumulative yield is evaluated, cultivars such as 'Mission' which produced predominantly spur-born fruit appear to be at a disadvantage when compared to cultivars such as 'Nonpareil 'which primarily produced on spurs but maintain the capacity for shoot production (**Figure 20**). Because spurs take several additional years to come into full production compared to shoots, cultivars with early shoot production show an early yield advantage which can be sufficient to influence the final 15 two 20 year cumulative yield rankings. The ability of shoots to rapidly establish fruiting-wood is also an advantage in older trees as it allowed a more rapid recovery from yield loss from scaffold/branch loss from disease or breakage (**Figure 20**).

### Rootstock traits.

While the primary goal of the UCD breeding program is cultivar development, the generation of large numbers of interspecific hybrids and subsequent interspecies backcrosses has made available new germplasm with promising potential as rootstocks. Interspecies almond x peach hybrids such as the UCD released Hansen and Nickels rootstocks can increase cultivar yields by promoting greater vigor in the scion tree as well as conferring greater resistance to diseases and environmental stresses. More complex interspecies rootstocks, including crosses to other species within the group, have also been shown to increase overall tree vigor as well as contribute environmental stress/disease resistance beyond the previously utilized almond by peach hybrids. Several interspecies hybrids including crosses between almond and the wild almond species *Prunus webbii, Prunus argentea, Prunus scoparia, Prunus kuramica,* as well as interspecies hybrids between peach and the related species *Prunus argentea, Prunus scoparia, Prunus webbii, and Prunus tangutica*, are currently in regional testing a cooperative project with Fowler Nurseries.

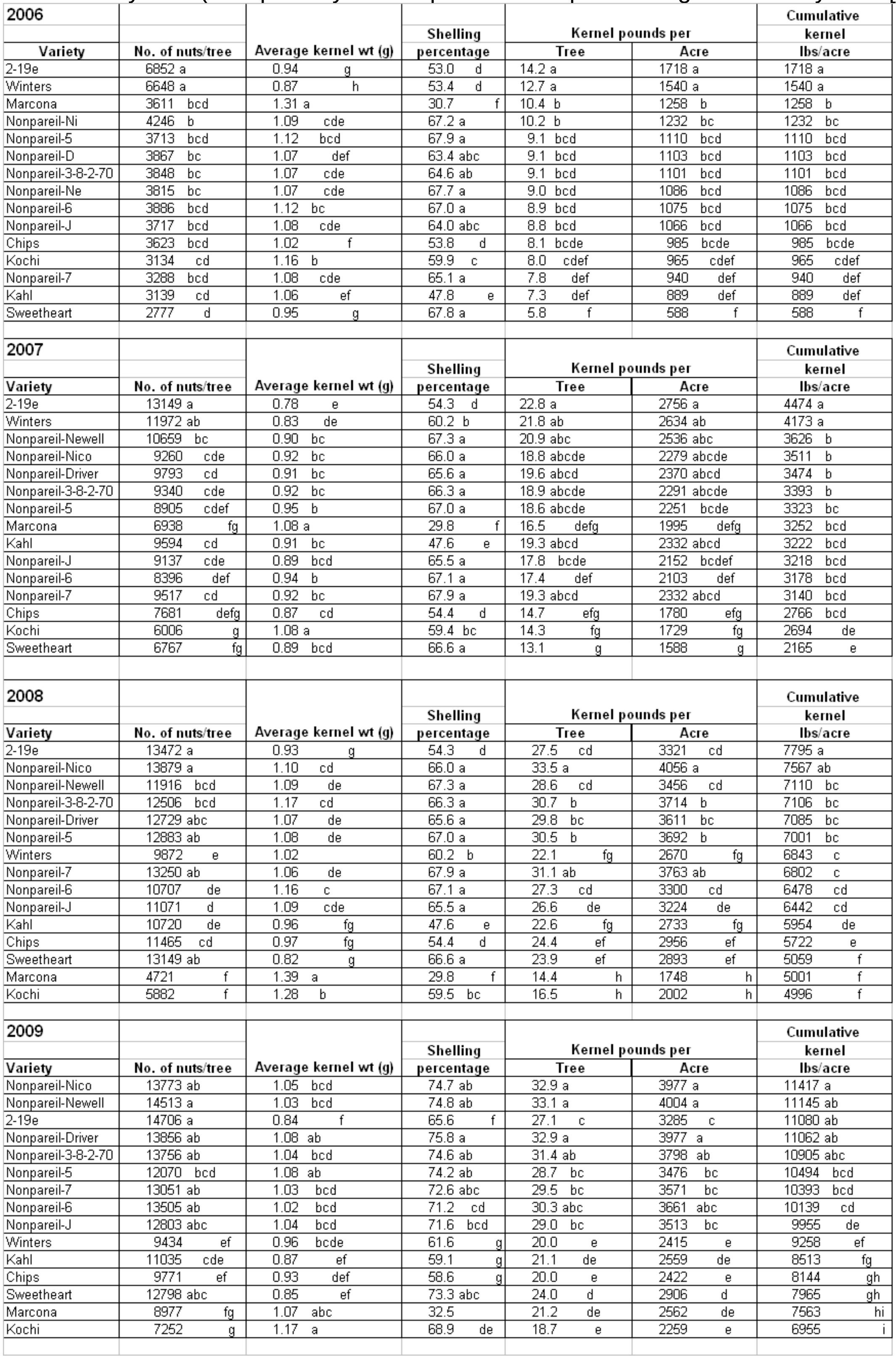
**Figure 22**. Nonpareil almond on nemaguard (left) and Interspecific peach x Prunus scoparia hybrid P00-3-205 (right) showing rootstock effect on scion architecture and yield potential. (Photo courtesy of Chuck Fleck, Fowler Nurseries).

Desirable rootstock traits would include improved tree size and architecture, greater rootstock and scion vigor and improved disease resistance and improved water use efficiency (drought resistance). In initial testing, improved drought tolerance has identified in peach x *Prunus argentea* hybrids (**Figure 21**) as well as modified tree architectures in peach x *Prunus scoparia* hybrids (**Figure 22**). UCD interspecies hybrid/backcross populations are also being made available to the USDA/ARS Rootstock Marker Assisted Selection program located at Davis California [Project 10-HORT16-Aradhya/Ledbetter]. Because interspecific rootstocks often show a pronounced growth vigor resulting from the interaction of the two intact genomes rather than the individual effect of individual genes, it may be more difficult to dissect out individual traits (and their individual genetic control) for many horticultural traits. For example, while specific plant resistance responses to diseases such as hypersensitivity or the generation of phytoalectin-like plant protection compounds can sometimes be traced to one to a few controlling genes, the dissection of these individual genes within hybrid rootstocks may be difficult since the hybrid vigor itself would act to overrun/compensate for actual disease damage and so mask other resistance factors. Similar conditions might also be expected to exist when selecting for improved drought tolerance in hybrid material. Thus the USDA/ARS project results are essential to provide a preliminary foundation in understanding mechanisms of resistance, etc. for future work in this area. [Almond by peach hybrids showing segregation for Noninfectious Bud Failure are also being included in the study, both to evaluate the molecular basis of the resultant hybrid vigor (as described above) and also to gauge the value of molecular markers for identifying the genetic regions active in Noninfectious Bud Failure expression. This information may eventually lead to molecular marker-based prediction tests for Noninfectious Bud Failure if the condition is controlled by one to a few specific genes, or (more likely based on previous experience) facilitate the identification of the region of DNA where the normal genetic expression of winter dormancy,(Bud-Failure is, in essence, a failure to go into normal winter dormancy) is suppressed by epigenetic or non--genetic mechanisms (i.e. the controlling gene DNA coding remains unchanged but it's expression is suppressed by outside mechanisms such as methylation, etc.).

| Selection | Bloom vs. Nonp. | Kernel (g) | Shell-out (%) | Doubles (%) | Origin | Length (mm) | Width (mm) | Thick (mm) | Self-set (%) |
|---|---|---|---|---|---|---|---|---|---|
| UCD2-19E | 5 | 0.95 | 0.62 | 1 | California almond | 21 | 11.4 | 8.1 | 4 |
| Sweetheart | 0 | 0.95 | 0.51 | 0 | Peach (P. persica) | 19.6 | 13.2 | 8.7 | 14 |
| LG-05 | 8 | 1.08 | 0.62 | 8 | Peach | 21.8 | 11.9 | 9.4 | 60 |
| F8,8-4 | 1 | 1.36 | 0.60 | 9 | Prunus webbii | 25.7 | 12.9 | 9 | 76 |
| F8,8-161 | 5 | 1.16 | 0.50 | 14 | Prunus fenzliana | 25.3 | 12 | 8.3 | 80 |
| F8,8-160 | 5 | 1.29 | 0.62 | 0 | Prunus mira | 27.1 | 11.9 | 8.3 | 86 |
| F8,7-180 | 2 | 1.27 | 0.60 | 0 | Prunus webbii | 29.3 | 12.8 | 7.5 | 8 |
| F8,7-179 | 2 | 1.08 | 0.62 | 3 | Peach | 27 | 12.2 | 8.5 | 76 |
| F7,1-1 | 0 | 0.68 | 0.71 | 0 | Peach | 17.4 | 10.2 | 8.2 | 96 |
| F10C,2-4 | 2 | 1.18 | 0.44 | 15 | California almond | 25.7 | 13.2 | 7.8 | 4 |
| F10C,1-16 | 4 | 1.16 | 0.68 | 3 | California almond | 26.2 | 11.4 | 8.5 | 7 |
| D3-26 | 5 | 1.22 | 0.63 | 1 | Prunus webbii | 25.3 | 12.9 | 8.5 | 10 |
| D,1-6 | 2 | 1.45 | 0.73 | 18 | California almond | 26.1 | 13.5 | 8.2 | 8 |
| D,1-25 | 5 | 0.74 | 0.40 | 1 | Prunus mira | 24.4 | 11.6 | 6.9 | 80 |
| C,1-10 | 3 | 1.22 | 0.69 | 2 | California almond | 27.1 | 14.3 | 7.5 | 5 |
| 99,9-86 | 0 | 1.33 | 0.51 | 0 | Prunus webbii | 25.6 | 13.8 | 8.9 | 80 |
| 99,4-8 | 6 | 1.51 | 0.27 | 0 | Peach | 26.2 | 16.8 | 8.5 | 4 |
| 99,3-79 | 4 | 1.30 | 0.42 | 12 | Prunus webbii | 21.3 | 13.3 | 10.5 | 7 |
| 98,3-53 | -1 | 1.72 | 0.75 | 0 | Peach | 29.6 | 15 | 8.7 | 66 |
| 98,2-305 | 5 | 1.06 | 0.52 | 0 | Prunus argentea | 24.9 | 13.3 | 7.5 | 4 |
| 97,3-40 | -5 | 1.77 | 0.45 | 1 | Prunus fenzliana | 32.3 | 14.5 | 9.3 | 7 |
| 97,2-240 | 3 | 1.19 | 0.65 | 3 | Prunus webbii | 22.6 | 13.1 | 9.4 | 3 |
| 97,15-109 | 3 | 1.22 | 0.66 | 3 | Prunus argentea | 27.2 | 13 | 8 | 64 |
| 95,1-26 | 1 | 1.80 | 0.56 | 2 | European almond | 29.1 | 14.2 | 9.6 | 56 |
| 2000,2-3 | 1 | 1.17 | 0.57 | 3 | Peach | 24.4 | 12 | 9.1 | 90 |
| 2000,16-81 | 3 | 0.93 | 0.52 | 4 | Irradiated almond | 21.5 | 11.7 | 9.8 | 82 |
| 2000,8-27 | 3 | 1.07 | 0.51 | 10 | Prunus webbii | 24.1 | 11.7 | 8.4 | 88 |
| 204,14-158 | 0 | 1.48 | 0.39 | 0 | Prunus fenzliana | 25.9 | 14.2 | 8.8 | 52 |
| 2002, 7-159 | 4 | 1.14 | .64 | 3 | Tuono almond | 26.7 | 11.5 | 8.8 | 67 |
| 2004,8-160 | 3 | 1.85 | 0.65 | 0 | Prunus mira | 30.4 | 15.4 | 8.5 | 96 |

**Appendix A.** Selected breeding lines used as parents for self-compatibility and kernel quality. (Bloom – days before (-) or after (+) Nonpareil; Origin refers to the germplasm source of the major trait of interest (i.e. self-compatibility, disease resistance, etc.); Self-set refers to average self-set (bagged) compared to adjacent set on unbagged, insect pollinated branch).

**Appendix B.** Yield, number of nuts, average kernel weight, shelling percentage and kernel pound per acre yield for the 2006 through 2009 seasons. Data for each year is sorted by cumulative yield. (Compiled by B. Lampinen lab as part of Regional Variety Trial [RVT] study).



| 2006 | | | Shelling | Kernel pounds per | | Cumulative kernel |
|---|---|---|---|---|---|---|
| Variety | No. of nuts/tree | Average kernel wt (g) | percentage | Tree | Acre | lbs/acre |
| 2-19e | 6852 a | 0.94 g | 53.0 d | 14.2 a | 1718 a | 1718 a |
| Winters | 6648 a | 0.87 h | 53.4 d | 12.7 a | 1540 a | 1540 a |
| Marcona | 3611 bcd | 1.31 a | 30.7 f | 10.4 b | 1258 b | 1258 b |
| Nonpareil-Ni | 4246 b | 1.09 cde | 67.2 a | 10.2 b | 1232 bc | 1232 bc |
| Nonpareil-5 | 3713 bcd | 1.12 bcd | 67.9 a | 9.1 bcd | 1110 bcd | 1110 bcd |
| Nonpareil-D | 3867 bc | 1.07 def | 63.4 abc | 9.1 bcd | 1103 bcd | 1103 bcd |
| Nonpareil-3-8-2-70 | 3848 bc | 1.07 cde | 64.6 ab | 9.1 bcd | 1101 bcd | 1101 bcd |
| Nonpareil-Ne | 3815 bc | 1.07 cde | 67.7 a | 9.0 bcd | 1086 bcd | 1086 bcd |
| Nonpareil-6 | 3886 bcd | 1.12 bc | 67.0 a | 8.9 bcd | 1075 bcd | 1075 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 cdef | 965 cdef | 965 cdef |
| Nonpareil-7 | 3288 bcd | 1.08 cde | 65.1 a | 7.8 def | 940 def | 940 def |
| Kahl | 3139 cd | 1.06 ef | 47.8 e | 7.3 def | 889 def | 889 def |
| Sweetheart | 2777 d | 0.95 g | 67.8 a | 5.8 f | 588 f | 588 f |

| 2007 | | | Shelling | Kernel pounds per | | Cumulative kernel |
|---|---|---|---|---|---|---|
| Variety | No. of nuts/tree | Average kernel wt (g) | percentage | Tree | Acre | lbs/acre |
| 2-19e | 13149 a | 0.78 e | 54.3 d | 22.8 a | 2756 a | 4474 a |
| Winters | 11972 ab | 0.83 de | 60.2 b | 21.8 ab | 2634 ab | 4173 a |
| Nonpareil-Newell | 10659 bc | 0.90 bc | 67.3 a | 20.9 abc | 2536 abc | 3626 b |
| Nonpareil-Nico | 9260 cde | 0.92 bc | 66.0 a | 18.8 abcde | 2279 abcde | 3511 b |
| Nonpareil-Driver | 9793 cd | 0.91 bc | 65.6 a | 19.6 abcd | 2370 abcd | 3474 b |
| Nonpareil-3-8-2-70 | 9340 cde | 0.92 bc | 66.3 a | 18.9 abcde | 2291 abcde | 3393 b |
| Nonpareil-5 | 8905 cdef | 0.95 b | 67.0 a | 18.6 abcde | 2251 bcde | 3323 bc |
| Marcona | 6938 fg | 1.08 a | 29.8 f | 16.5 defg | 1995 defg | 3252 bcd |
| 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 bcdef | 3218 bcd |
| Nonpareil-6 | 8396 def | 0.94 b | 67.1 a | 17.4 def | 2103 def | 3178 bcd |
| Nonpareil-7 | 9517 cd | 0.92 bc | 67.9 a | 19.3 abcd | 2332 abcd | 3140 bcd |
| Chips | 7681 defg | 0.87 cd | 54.4 d | 14.7 efg | 1780 efg | 2766 bcd |
| Kochi | 6006 g | 1.08 a | 59.4 bc | 14.3 fg | 1729 fg | 2694 de |
| Sweetheart | 6767 fg | 0.89 bcd | 66.6 a | 13.1 g | 1588 g | 2165 e |

| 2008 | | | Shelling | Kernel pounds per | | Cumulative kernel |
|---|---|---|---|---|---|---|
| Variety | No. of nuts/tree | Average kernel wt (g) | percentage | Tree | Acre | lbs/acre |
| 2-19e | 13472 a | 0.93 g | 54.3 d | 27.5 cd | 3321 cd | 7795 a |
| Nonpareil-Nico | 13879 a | 1.10 cd | 66.0 a | 33.5 a | 4056 a | 7567 ab |
| Nonpareil-Newell | 11916 bcd | 1.09 de | 67.3 a | 28.6 cd | 3456 cd | 7110 bc |
| Nonpareil-3-8-2-70 | 12506 bcd | 1.17 cd | 66.3 a | 30.7 b | 3714 b | 7106 bc |
| Nonpareil-Driver | 12729 abc | 1.07 de | 65.6 a | 29.8 bc | 3611 bc | 7085 bc |
| Nonpareil-5 | 12883 ab | 1.08 de | 67.0 a | 30.5 b | 3692 b | 7001 bc |
| Winters | 9872 e | 1.02 | 60.2 b | 22.1 fg | 2670 fg | 6843 c |
| Nonpareil-7 | 13250 ab | 1.06 de | 67.9 a | 31.1 ab | 3763 ab | 6802 c |
| Nonpareil-6 | 10707 de | 1.16 c | 67.1 a | 27.3 cd | 3300 cd | 6478 cd |
| 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 e |
| Sweetheart | 13149 ab | 0.82 g | 66.6 a | 23.9 ef | 2893 ef | 5059 f |
| Marcona | 4721 f | 1.39 a | 29.8 f | 14.4 h | 1748 h | 5001 f |
| Kochi | 5882 f | 1.28 b | 59.5 bc | 16.5 h | 2002 h | 4996 f |

| 2009 | | | Shelling | Kernel pounds per | | Cumulative kernel |
|---|---|---|---|---|---|---|
| Variety | No. of nuts/tree | Average kernel wt (g) | percentage | Tree | Acre | lbs/acre |
| Nonpareil-Nico | 13773 ab | 1.05 bcd | 74.7 ab | 32.9 a | 3977 a | 11417 a |
| Nonpareil-Newell | 14513 a | 1.03 bcd | 74.8 ab | 33.1 a | 4004 a | 11145 ab |
| 2-19e | 14706 a | 0.84 f | 65.6 f | 27.1 c | 3285 c | 11080 ab |
| Nonpareil-Driver | 13856 ab | 1.08 ab | 75.8 a | 32.9 a | 3977 a | 11062 ab |
| Nonpareil-3-8-2-70 | 13756 ab | 1.04 bcd | 74.6 ab | 31.4 ab | 3798 ab | 10905 abc |
| Nonpareil-5 | 12070 bcd | 1.08 ab | 74.2 ab | 28.7 bc | 3476 bc | 10494 bcd |
| Nonpareil-7 | 13051 ab | 1.03 bcd | 72.6 abc | 29.5 bc | 3571 bc | 10393 bcd |
| Nonpareil-6 | 13505 ab | 1.02 bcd | 71.2 cd | 30.3 abc | 3661 abc | 10139 cd |
| Nonpareil-J | 12803 abc | 1.04 bcd | 71.6 bcd | 29.0 bc | 3513 bc | 9955 de |
| Winters | 9434 ef | 0.96 bcde | 61.6 g | 20.0 e | 2415 e | 9258 ef |
| Kahl | 11035 cde | 0.87 ef | 59.1 g | 21.1 de | 2559 de | 8513 fg |
| Chips | 9771 ef | 0.93 def | 58.6 g | 20.0 e | 2422 e | 8144 gh |
| Sweetheart | 12798 abc | 0.85 ef | 73.3 abc | 24.0 d | 2906 d | 7965 gh |
| Marcona | 8977 fg | 1.07 abc | 32.5 | 21.2 de | 2562 de | 7563 hi |
| Kochi | 7252 g | 1.17 a | 68.9 de | 18.7 e | 2259 e | 6955 i |

**Appendix C. Advanced UCD Self-compatible Almond Selections in Regional Grower Evaluations**. Breeding selections represent a very wide genetic variability due to their interspecific origins. In addition to self-compatibility, novel genetic options for disease and insect resistance have been incorporated in this material. By establishing evaluation plots for these selections in different areas of the Sacramento and San Joaquin valleys, we hope to more thoroughly evaluate the value for further resistance breeding, as well as their potential as possible cultivar releases.

UCD2-19E. Lineage: Tardy Nonpareil X Arbuckle. This selection was one of the highest producing varieties at the Kern RVT plot with an accumulated (1996-2005) yield of 26,112 pounds per acre following an exceptionally high crop of 4890 pounds per acre in 2003 plots. UCD2-19E can show a strong alternate bearing habit where years of high crop yield are followed by low crops. It is believed that on years of very high crop, insufficient nutrients are available to the overloaded fruiting spurs to initiate the number of flowers needed to maintain the crop, and in some cases to maintain the very viability of the spur into the next season. In the current Kern County RVT, we have been successful in maximizing year-to-year production by closely monitoring current season crop yield and providing increases in both irrigation water and fertilizer nutrients as needed. Under these conditions, UCD2-19E has been the highest producer in 2006, 2007, and 2008 and amongst the highest in 2009 (see Appendix B.). In addition to its very high crop, 2-19E shows good kernel quality, a late bloom ~7d after Nonpareil, and resistance to flower blight. Low hull rot and Alternaria blight disease levels have also been observed in all plots to 2009.

LG-O5. Lineage: LeGrand-Open-Pollinated. Kernels have good quality and a Padre-type shape, though are somewhat larger. Shells are soft, moderate in thickness with good seals. Kernels show moderate levels of doubles (~8%) and creasing. The tree is more compact, like Carmel, with upright scaffolds but allowing good productivity because of a shorter internode distance between leaves and spurs. Most production in the mature trees is on spurs which are well distributed throughout the canopy. The level of self-compatibility appears consistent unlike the LeGrand parent. Trees have shown good productivity both at the Winters and southern San Joaquin evaluation plots. Bud-failure has been observed in progeny of LG-05 indicating an increased BF-potential of the parent but no symptoms have been observed on 15th leaf parent trees; some yield loss from flower blight in Kern County in 2009. Bloom starts ~8 d after Nonpareil.

C,1-10. Lineage: Wood Colony x Fritz. The result of a cross between two traditional, commercial varieties, this selection combines a Nonpareil-type kernel and paper shell with a later flowering and later maturing tree. In regional trials, tree productivity has so far been unexceptional. This selection also seems more susceptible to foliar diseases than other advanced selections moderate hull rot and internal dead wood. Its similarity to Nonpareil, however, would make this a very useful variety if it performs well in regional trials. Moderate levels of kernel crease (~12%) and an overly spreading tree architecture may also be problematic with the selection.

C,1-16. Lineage: F10D,3-67 = Nonpareil X D3-19 {(Mission X P.fenzliana) X Solano}. This selection is derived from a cross to P. fenzliana with the goal of transferring improved disease resistance and cropping architecture. Tree is productive in both Sacramento and San Joaquin Valley test plots and consistently yields uniform and good-quality Price-like kernels. Some blind wood observed in 2008-09 due possibly to hull rot. Shells are paper and relatively well sealed. Tree is upright to spreading with some interior crowding resulting from crossed branches. Bloom starts ~3 d after Nonpareil.

C,2-4. Nonpareil-BF X Monterey. [Tested as selection F10D, 5-39 in some locations]. This selection resulted from a cross between a high bud-failure Nonpareil selection and a variety Monterey (to evaluate latent bud failure potential in the variety Monterey). Kernels show good-quality, and being intermediate to Carmel and Sonora in shape and size. Shells are paper in texture and moderately well sealed. High doubles. Upright, heavily branched trees with low flower blight and hull rot. Experience has shown that crosses to high bud-failure sources have in approximately 50% probability of inheriting the predisposition to noninfectious bud-failure though no symptoms have been observed in the 15th year-old parent tree. Bloom starts ~2 d after Nonpareil.

D,1-25. Lineage: (Mission X P.webbii) X Sonora. Kernels being relatively long, wide and flat and thus well suited for the sugar coating or panning market. In addition, kernels possess a unique and desirable amaretto flavor. The combination of kernel shape and kernel flavor quality have made it of interest to specialty markets processors. There is some evidence bark splitting/cracking and in some cases bark deterioration (a occasional consequence from wide crosses). The selection is being released for regional testing for growers and processors interested in this particular niche market. It is not self-compatible and has not been noted as having promising disease resistance. It produces a more spreading tree approx. 30% smaller than Nonpareil with some possible branch crowding in the interior. The tree blooms approximately 6 d after Nonpareil and harvests approx. 18 d after Nonpareil. Average kernel length/width/thickness is 2.3/1.2/0.8 cm. Ave. kernel weight is 0.9 g; kernel/kernel + shell crack-out is 0.44. Shells are attractive and well-sealed.

D,1-6. Lineage: 90,14-124= (Jeffries X Nonpareil). D,1-6 was selected for its very good Nonpareil-type kernel and thin paper shell conferring a high crack out with an improved barrier to insect pests. Shell seal is good at 96%. Trees appear only moderately productive in regional trials though with no evidence of reduced vigor or increased susceptibility to disease as is often associated with selfed or inbred genotypes. Double kernels have been observed at high (18%) proportions. Tree is upright to spreading with only moderate crop levels. (Sample

Nonpareil (left) and Carmel (right) kernels shown inside grey circle).

**D3-25.** Lineage: Nonpareil X F5,4-11 {P.webbii *(SEL5-15Selfed)). This relatively early breeding selection combines genes from P. mira (a wild peach), P. webbii (a wild almond) and P. dulcis (cultivated almond). The selection combines Nonpareil-type kernel quality with semi-upright tree architecture and good levels of self-compatibility. Both tree productivity and bearing wood renewal have declined with age and older trees tend to become more bushy & weepy. This selection is also associated with greater susceptibility to flower blight, hull rot and possibly Bud-failure (BF). Crops in regional trials have been moderate. Shell seal is poor at ~8% sealed. Moderate hull rot damage observed in 2009 in Kern County plots.

**D3-26.** Lineage: F5,4-6 {P.webbii X P.webbii} X Solano. [Labeled as F10D, 3 -216 in some plots]. Tree is large with upright-spreading branches and moderately productive. Nuts are ovate, similar to Peerless, and like Peerless have a semihard shell resulting in good resistance to insect damage but moderate crack out ratios. Some evidence for alternate bearing has been observed in the parent trees, but trees in regional trials continued to show moderately good growth and productivity. In addition to alternate bearing, the selection is being watched for consistency of bearing wood regeneration and susceptibility to peach twig borer damage and Noninfectious Bud-failure.

**F8,7-179.** Lineage: D3-15 (Nonpareil X F5,4-43 {P.webbii X P.webbii}{SEL5-15Selfed})) X D3-25 [(Nonpareil X F5,4-11{P.webbii X P.webbii}{SEL5-15Selfed})]. Combining multiple and distinct sources of self-compatibility (from both peach and P. webbii), this selection has shown consistently good levels of self compatibility even in seasons were spring storms have suppressed flower development. Improved levels of both foliar (including Alternaria leaf spot) and blossom diseases have also been observed though susceptibility to hull rot has also been observed. Kernels show good quality and are of uniform size and shape with some doubles though with a darker seed coat color. The shells are paper, though only 50% sealed. Early productivity in regional trials has been moderate to high. Regional trials are being watched closely for disease susceptibility and bearing wood renewal. Bloom starts ~3 d after Nonpareil.

**F7,1-1.** Lineage: (Sel5-15 {Nonpareil X Lukens Honey peach X Mission} X WSB3b25). Breeding selection Sel5-15, has proven to be one of our most effective sources for both self-compatibility and improved disease resistance derived from peach and more exotic almond germplasm. The Butte-type kernel is a small in size, and uniform in its appearance with freedom from defects. It has a paper shell with 74% seal. . Tree has an upright to upright -spreading architecture which can be similar to, but 10% larger than Nonpareil. Bloom occurs 6 to 8 d after Nonpareil. Flower densities and levels of self compatibility are high, resulting in a high yield in Fresno County test plots in 2009. Harvest occurs approximately 28 days after Nonpareil. Average kernel length/width/thickness is 1.8/1.1/0.8 cm. Ave. kernel weight is 0.8 g; kernel/kernel + shell crack out is 0.68 F7,1-1 has been one of the most resistant selections in Jim Adaskaveg's UCD almond disease evaluation block [Project 09-PATH4-Adaskaveg] with demonstrated resistance to bacterial blast and Monilinia flower blight.

**F8,8-160.** Lineage: D4-18 [(Mission X {P.fenzliana X Alm}) X Sonora] x 25-75. This and F8,8-161 have incorporated genes from the wild almond species *P. fenzliana* into a cultivated almond background. F8,8-160 was selected for its consistent level of self-compatibility and its good-quality kernel. Seed coat color is like Mission or darker. Shells are paper, and poorly (70%) sealed. Trees have shown good productivity both at the Winters and southern San Joaquin evaluation plots. Kernels are uniformly elliptical and relatively thick resulting in good kernel weights and so improved yield potential. In regional test plantings, trees are upright-spreading to bushy with moderate to good crop distribution primarily on spur bearing wood resulting in a tree size similar to Plateau or Carmel. Bloom occurs approximately 6 d after Nonpareil and can be profuse. Harvest occurs approximately 5 weeks after Nonpareil. Average kernel length/width/thickness is 2.2/1.2/0.9 cm. Ave. kernel weight is 1.0 g; kernel/kernel + shell crack out is 0.57.

**F8,8-161.** Lineage: as F8,8-160. F8,8-161 was selected for its consistent level of self-compatibility and its good-quality kernel. Shells are comparable to, to slightly thicker than Carmel, having good (98%) seals. Trees have shown good productivity both at the Winters and southern San Joaquin evaluation plots. Doubled nuts (two nuts developing on a unique T-shape spur) are often observed and may contribute to the higher yield potential this selection. Pollen is fully cross compatible with Nonpareil and most major commercial almond varieties. Tree is upright and similar in size and vigor to Fritz. Bloom occurs approximately 7 d after Nonpareil and is profuse. Harvest occurs approximately 26 d after Nonpareil. Average kernel length/width/thickness is 2.3/1.2/0.8 cm. Ave. kernel weight is 1.2 g; kernel/kernel + shell crack out is 0.63. Doubles (~14%) may be a problem and Monilinia flower blight and Alternaria leaf spot has been observed in San Joaquin valley plantings.

**F8,7-180.** Lineage: as with F8,7-179. Although a sister line to F8,7-179, the selection is self-incompatible, having inherited none of the self-compatibility factors from the parents. Kernels are of good quality being larger than Nonpareil. Shells are thin, paper consistency and only moderately well sealed. Trees show problems in bearing wood renewal leading; eventually to lower yields this selection has shown only moderate productivity at Winters, and southern San Joaquin test sites. . Trees flower just after Nonpareil and pollen is fully cross compatible with Nonpareil and Carmel. Low hull-rot in field trials but moderate to high flower blight observed in 2008-09.

**F8,8-4.** Lineage: D3-15 (Nonpareil X F5,4-43{P.webbii X P.webbii}{SEL5-15Selfed})) X D3-25(Nonpareil X F5,4-11{P.webbii X P.webbii}{SEL5-15Selfed}). This complex interspecies cross, combines genes from P. mira (a wild peach), P. webbii (a wild almond) and P. dulcis (cultivated almond). Kernels are of good quality, ovate in shape, and with good thickness resulting in good individual kernel mass. Shells have a medium thickness and are generally well sealed but can show moderate (~60%) seal with heavy crops. Doubled-nuts have been observed in this selection but at relatively low numbers. Nuts are borne primarily on spurs but also on current shoot terminals, particularly in younger trees. Kernel quality problems, particularly double kernels, need to be watched with this selection. The tree is upright and approx. 10-20% smaller than Nonpareil with a good, open architecture. Flowering occurs 2 d after Nonpareil. Flowering has been profuse (high flower density) making it a good pollinizer for the later Nonpareil bloom. Harvest occurs approx. 30 d after Nonpareil. Average kernel length/width/thickness is 2.1/1.2/1.0 cm. Ave. kernel weight is 1.1 g; kernel/kernel + shell crack out is 0.55. Kernels have good size, shape and texture

**97,1-227.** Lineage: 25-75 [{Arbuckle X 4-26} X {SB4, 4-2E}] X Winters. The seed parent 25-75 is highly self-fertile (derived from the peach species Prunus mira) and productive. The Winters parent contributes a more open, upright-spreading tree structure as well as an improved kernel size and quality. Kernels are large and uniform with a desirable Nonpareil-type elliptical shape. Shells have a medium thickness and are well sealed with good resistance to NOW and ant damage. Self-compatibility in this selection is rated as good, meaning that 50% or more of viable flowers will set seed when selfed under artificial (mesh bag limbs, limited controlled pollinations, etc.) conditions. The tree is upright to spreading and has shown good production in 2009 in Fresno County test plots. Blooms approx. 5 d after Nonpareil and harvest approx. 21 d after Nonpareil. Average kernel length/width/thickness is 2.6/1.5/0.8 cm. Ave. kernel weight is 1.5 g; kernel/kernel + shell crack out is 0.42. Shells are easily cracked yet have good seals.

**97,1-232.** Lineage: 25-75 [{Arbuckle X 4-26} X {SB4, 4-2E}] X Winters. A sister line to 97, 1-227, resulting in good levels of self-compatibility and tree productivity. Nuts are large and ovate, being similar to Monterey. Kernel shells are thinner than 97,1-227 resulting in greater crack-out but greater susceptibility to insect damage. The tree has been more productive and more spreading than 97,1-227 particularly in Fresno County test plots which showed very high yields in 2009. A relatively high tree loss following transplanting was observed in one Fresno County test plot though this may have been due to nursery tree damage. Flower self-compatibility is rated as good, being slightly better than its sister line when compared over several years. Potential deficiencies include a possible predisposition to shriveled kernels and kernel gumming and a tree architecture that may develop to be overly spreading. The tree is approx. 20% smaller Nonpareil. The tree blooms approximately 5 d after Nonpareil and harvests approx. 21 d after Nonpareil. Average kernel length/width/thickness is 2.3/1.4/0.8 cm. Ave. kernel weight is 1.2 g; kernel/kernel + shell crack out is 0.40.

97,2-240. Lineage: D3-4 {(Mission X P.webbii) X (Mission X P.webbii)} X Ferragnes. The seed parent is a backcross from the cross between Mission and P. webbii, a wild bushy almond species with small but well sealed nuts. The French variety *Ferragnes* was used as the pollen parent to increase kernel size and quality and contribute a more upright architecture to the tree. Kernels are Carmel-type in size and appearance with few doubles. [For reference, a Nonpareil kernel (left) and Carmel kernel (right) are placed within a black disk within the sample tray]. The kernel shell has been reduced to a very thin but very durable inner shell resulting in crack outs exceeding 70%, combined with very high shell seals and so low vulnerability to insect damage and aflatoxin contamination. Trees are medium in height and productive, though the spreading architecture results in a more bushy tree shape and a higher incidence of early limb splitting and possible tree loss if early orchard trees are not managed properly. Hull rot with shoot die-back is also common in southern sites. The possible excessive spreading nature of this tree remains its most serious potential deficiency. Flowers are self-incompatible but are cross-compatible with all major California cultivars. (Sample Nonpareil (left) and Carmel (right) kernels shown inside grey circle).

97,3-40. Lineage: D4-18 [(Mission X {P.fenzliana X Alm})] X Winters. The seed parent is a backcross of Mission and the wild almond species *P. fenzliana. P. fenzliana* was selected to bring in early flowering, good shell seal, a more upright tree productivity, and disease resistance. Winters was selected as the pollen parent to contribute better kernel quality and to maximize tree productivity through its tendency to produce consistently productive lateral branching. This selection exhibits very large Sonora-type kernels in a Peerless-type well-sealed shell. Twin kernels (2 embryos within the same seed-coat) have been observed but do not appear to be a problem. Flowering time is very early, occurring with Sonora or before. Despite its early flowering, the selection has been very productive in the southern San Joaquin test site with resistance to both hull-rot in Alternaria blight. Flowers are self-incompatible but compatible with all commercial California almonds because of its unique S-allele genotype. The large, high-quality kernel combined with its attractive, durable shell make this selection a possible replacement for Peerless. Potential deficiencies include its very early flowering and darker seed coat color.

97,4-333. Lineage: Nonpareil X F7,1-1 [(Sel5-15={Nonpareil X Lukens Honey X Mission} X WSB3b25) X 25-26. The seed parent is Nonpareil crossed with the very productive, self-compatible and disease resistant selection F7,1-1. The self-compatibility from the pollen parent is derived from peach but was not transferred to this selection, which is self-incompatible. The kernel possesses good quality and is Carmel-like in appearance but typically not as thick. Nuts have a paper shell which is only moderately sealed. Tree productivity appears mediocre with moderate foliage and excessive internal shoot die-back to its greater susceptibility to hull-rot. Medium yields and the relative flatness of the kernels remain potential deficiencies of concern. (Sample Nonpareil (left) and Carmel (right) kernels shown inside grey circle).

**98,11-77.** Lineage: Nonpareil (F5,3-12) X 90,13-59 (Jeffries X Nonpareil). This selection was chosen for its high-quality Nonpareil-type kernels combined with a good sealed shell and disease resistance. The semi-hard shell confers greater insect resistance but results in lower crack out ratios. Potential concerns with this selection include possible deterioration in tree architecture due to its large, bushy shape and tangled internal branch architecture resulting in reduced yields as trees age. (Sample Nonpareil (left) and Carmel (right) kernels shown inside grey circle).

**98,14-340.** Lineage: Sonora X LeGrand-OP. LeGrand-OP is a selection from crossing the partially self-compatible variety LeGrand with Sonora. Flower self-compatibility is rated as good. Kernels are medium large and somewhat resemble the Sonora parent though slightly shorter. Shriveled and creased kernels were apparent in initial harvests but these were from essentially dry land farmed trees with better kernel quality observed in irrigated orchards. Kernel eating quality is very good. Trees are upright-spreading and only moderately productive as trees tend to be more compact with dense, somewhat willowy dense-foliage though low disease. Good resistance to Alternaria blight and flower blight.

**98,15-109.** Lineage: D2-4 SB20,1-19 (Missions X P.webbii) X Sonora) X D3-3 SB20,1-28 (Missions X P. argentea) X Sonora. The result of a complex interspecies cross involving cultivated almond (P. dulcis), and the wild almond species P. webbii and P. argentea, this selection combines good levels of self-compatibility, and a more spreading tree architecture. Erratic (cross-over) branching have been observed, however, with some, mainly internal, branch die-back, possibly from flower blight. Kernels are medium quality, with slightly beaked kernels and shells. Some kernel creasing and doubling were apparent in Winters, California seedling blocks, though this could have been the consequence of the near dry land farming methods used for this and related selections. Kernel quality remains a concern in ongoing evaluations as is the possibility that the tree habit may be overly spreading.

**98,2-305.** Lineage: Nonpareil X F7,3-11/D3-3 (SB13,28-21 X P.webbii hybrid). The result of a cross between Nonpareil and F7, 3-11, a self-compatible and aflatoxin resistant selection. Tree is large, upright and appears to be only moderately productive. Both shell and kernel are of medium quality as they are somewhat flat and elongated. Kernels consistently express the distinct and desirable amaretto flavor which combined with their elongated and relatively flat structure may make this a useful variety for panning or sugar coating. Potential deficiencies being examined in regional testing include inconsistency of amaretto flavor, kernel shape, only moderate productivity and susceptibility to hull rot.

**98,3-53.** Lineage: D3-11 (=F8S,53-60) X F7,1-1 [(Sel5-15{Nonpareil X Lukens Honey X Mission} X WSB3b25)]. The seed parent, D3-11, was selected for its very good kernel quality, potential disease resistance and tree productivity. Tree architecture, however, was excessively spreading, and in particular, the terminals and laterals bearing the crop were too weepy or feathery for consistent mechanical harvest. The pollen parent, F7, 1-1, was selected for its high disease resistance, high productivity, and good spur production. Hull rot is common however in this selection. Kernels tend to be small and Ruby-like though with occasional blank nuts. The resultant selection has combined the better attributes of both parents with good-quality Sonora-type kernels within an upright and productive tree. Trees tend to be large in size and so more prone to wind blow over. Very thin shells confer high crack out ratios but the poor seal (8%) result in increased vulnerability to insect damage.

**99,1-121.** Lineage: D3-26 (F5,4-6{{P.webbii X P.webbii} X {SolSel, 5-15 X 24-6}}) X LeGrand. A cross between D3-26 with its good tree, kernel and shelf characteristics (described previously) and the variety LeGrand to incorporate improved bearing habit and self-compatibility. The tree is upright and has been very productive in Fresno County test plots. Flowers show good levels of self compatibility and kernels show consistent high-quality. Kernels and shells are somewhat similar to Monterey in appearance with a slight but distinct beaking. The tree is very upright, and approx. 20% smaller than Nonpareil. Bloom occurs approximately 6 d after Nonpareil, while harvest occurs approx. 28d after Nonpareil. Kernels show good-quality but double-kernels may be a problem. Average kernel length/width/thickness is 2.4/1.4/0.9 cm. Ave. kernel weight is 1.3g; kernel/kernel + shell crack out is 0.30. The shell is similar to the variety Mission, having a very good shell-seal and so low worm damage. Bud-failure has been observed in 2008-09 on siblings of this cross and so a higher potential for it eventually showing bud-failure need to be considered.

**99,4-8.** Lineage: Ferragnes X LeGrand-OP (LGOP). (Sometimes listed in regional trials as 99,4-2). Combining the upright tree architecture and large kernel size of Ferragnes with the productivity and self-compatibility of LGOP, this selection has proven only partially self-compatible (i.e. between 25 to 50% of all viable flowers artificially selfed pollinated will set seed). Kernels are of good quality, being somewhat similar to Solano. Shells are hard, with a very good seal and insect resistance but moderate crack out ratios. The tree is upright-spreading and productive. The shell is durable, attractive, and bleachable. Because of its good disease resistance, high productivity, and high-quality kernel and shell, the selection is being considered as replacement for the Peerless variety. Blooms approx. 6d after Nonpareil.

1999,3-189. Lineage: D5-24 (SB20,1-5 (Mission x Hybrid-A[fenz]) x Sonora)* UCD25-75.
Tree is vigorous and upright spreading. Bloom occurs approximately 3 days after Nonpareil with harvest approximately 1 week after Nonpareil. Flowers are fully self-compatible and productive. Kernels are well sealed but can show high doubles (22%). Production has been moderate to high at all locations with moderate susceptibility to hull rot.

1999,3-79. Lineage: Mission * D,3-6 (F5,4-10 {SB16, 2-44[Prwebbii*Prwebbii]*SB6, 56-88[SolSel, 5-15*Slf]) *Solano). Tree is upright-spreading and moderately productive. Bloom occurs approximately 4 days after Nonpareil. Flowers are self-incompatible. Kernels are uniform with moderate to good quality and moderate to good shell seal. Produced some double kernels (~12%). Shell is thick and well-sealed with only 42% Kernel/nut crack-out.

1999,4-97. Lineage: CP,5-33 * D3-25.
Tree is upright and only moderately productive. Nuts are uniform and of good quality. Bloom occurs with Nonpareil and harvest is approximately 2 weeks after Nonpareil. Flowers are fully self-compatible with production primarily on spurs. Shells are thin but with moderate to good seal. Appears to have resistance to brown rot flower blight.

1999,9-86. Lineage: Mission * D3-25 [(Nonpareil X F5,4-11{P.webbii X P.webbii}[{SEL5-15Selfed})]. Tree is upright-spreading and productive but with some tendency to alternate bear. Bloom occurs approximately with Nonpareil with harvest approximately 3 weeks after Nonpareil. Kernels are of very high quality and uniform with a slightly darker pellicle color. Flowers are self-compatible.

2000,11-190. Lineage: F1-1 * 91,18-174 (Supernova op). Tree is upright to upright-spreading and productive. Bloom occurs approximately 5 days before Nonpareil with harvest occurring approximately with Nonpareil. Flowers are fully self-compatible. Kernels are uniform with moderate to good quality and moderate to good shell seal. May produce some double kernels and some scab was evident in 2008-09.

**2000,13-162.** Lineage: F7,1-1 * F7,7-179. Tree is more compact, similar to Carmel, but somewhat more spreading. Blooms approximately 10 days after Nonpareil and harvest approximately 1 week after Nonpareil. Flowers are fully self-compatible. Kernels are elongated, being somewhat similar to Sonora and of good eating quality. Some double kernels are produced with some shot -hole evident in 2008-09.

**2000,16-81.** F7,1-12 * 91,18-174 (Supernova op). Trees are upright and productive producing well sealed kernels. Kernel size is moderately large occasionally showing shriveling. Bloom is approximately with Nonpareil and harvest is approximately 2 weeks after Nonpareil. Flowers are fully self-compatible and appear more resistant to flower blight. Some shot-hole was observed in 2008-09.

**2000,3-385.** Lineage: D3-18 * UCD25-75. Tree is a upright-spreading, and more compact in size like Carmel. It is very productive though prone to alternate bearing if under fertilized. Bloom is approximately 6d after Nonpareil. Flowers are fully self-compatible and self-fruitful. Production is on high density spurs which can produce very high crops but a tendency to alternate bear. Kernels are Sonora-like in shape the somewhat smaller. Nuts are well sealed and of high quality.

**2002,1-271.** Lineage: D3-11 * Touno1-1. Tree is upright-spreading with a more open architecture. Flowers are fully self-compatible. Kernels are large and have a tendency to crease. Bloom occurs approximately 5 days after Nonpareil with harvest occurring approximately 2 weeks after Nonpareil. Flowers appear more resistant to flower blight. Nuts are well sealed with high crack out ratios.

**2002,8-119.** Lineage: Mission * Tuono1-1.
Tree is upright to upright-spreading. Bloom occurs approximately 1 week after Nonpareil with harvest approximately with Nonpareil. Flowers are fully self-compatible. Kernels are large and broad a similar to Sweetheart and Marcona with well sealed shells but moderate crack out ratios. Some kernel creasing has been observed at levels similar to Marcona. Leaves appear more resistant to leaf-blight in 2008.

**2000,2-3.** Lineage: D3-15 (Nonpareil X F5,4-43{P.webbii X P.webbii}{SEL5-15Selfed})) X D3-25 [(Nonpareil X F5,4-11{P.webbii X P.webbii}[{SEL5-15Selfed})]. A relatively recent selection, 2000,2-3 represents an advancement of the previously described D3-25 selection by incorporating improved tree structure disease resistance and productivity. Self-compatibility and a Nonpareil-type kernel were derived from the D3-25 parent. The D3-15 parent contributed a more upright-spreading tree structure, a more uniform, spur based productivity, and a more durable and well-sealed shell. Tree structure is upright to upright-spreading with a very high productivity resulting from a uniform and high nut distribution. The original tree also shows evidence of improved foliar disease resistance. The tree is semi-upright with radial branching. Anticipated size will be 10% narrower than Nonpareil but similar height. Expected bloom is approximately 6 d after Nonpareil with harvest approx. 21d after Nonpareil. Kernel quality is good. High yielder in 2009 Fresno County test plots. Average kernel length/width/thickness is 2.4/1.2/0.9 cm. Ave. kernel weight is 1.2 g; kernel/kernel + shell crack out is 0.55. Shell-seal is moderate with approximately 70% of the nuts showing complete seals. This selection resulted from a complex series of crosses involving *Prunus persica* (peach) and *Prunus webbii* in its lineage. Bud Failure like symptoms observed in 2008-09 in 10 year old seedling tree.

**2000,8-27.** Lineage: Nonpareil X F8,7-179. As with selection 2000,2-3, (above), this selection represents the next breeding generation derived from selection F8,7-179 (described below). The backcross to Nonpareil has resulted in an improved Nonpareil-type kernel quality and improved shell seal. High levels of self-compatibility have also been recovered as have good tree architecture and uniform crop distribution, primarily on spur bearing wood. The tree also exhibits improved levels of foliar disease resistance when compared to both parents. Kernel uniformity is very high with low levels of doubled or damaged kernels. The tree is upright-spreading and approx. 20% smaller than Nonpareil. The bearing-habit is similar in terms of the ratio of spur to shoot flower buds. The selection blooms approximately 4 d after Nonpareil and harvest approx. 18 d after Nonpareil. High yielder in 2009 Fresno County test plots. Average kernel length/width/thickness is 2.2/1.2/0.9 cm. Ave. kernel weight is 1.2 g; kernel/kernel + shell crack out is 0.64. The paper shells give good crack out but have poor seals (60%) though the worm infestation has not been a problem to date. Kernels show good-quality though double kernels (~10%) may be a problem.

**2004,14-158.** Lineage: 99,4-8 (Ferragnes * LGOP) * 97, 3-40 (P. webbii * Winters). Tree his upright-spreading to spreading. Bloom occurs approximately 2 days before Nonpareil. Harvest is approximately 3 weeks after Nonpareil. Flowers are self-compatible but not consistently so. Kernels are large and of uniform, with good quality and with moderately thin but well sealed shells. Branches are very productive leading to some breakage of seedling trees.

**UC95,1-26.** Lineage: USDA Selection CP33 * Winters. Tree is upright-spreading and productive with large, attractive nuts. Shell-seal is good as is the shell integrity. Tree shows good levels of self-compatibility in some years, but is more erratic in others. Flowering time is late, approx 10 d after Nonpareil. No disease problems observed to 2008-09.

**2004,8-160.** Lineage: NP * 97,1-232[25-75 [Arb * 4-26]*[SB4, 4-2E] * Winters /97,3-40[D4-18 (Mis * [P.fenzliana *Alm])** Winters]. Tree is upright-spreading to spreading. Production of large attractive nuts on high density spurs resulting in consistently high production. Good shell seal and kernel quality though some kernel creasing is common due to the larger size. Seed coat size is darker with a somewhat dusty appearance. Tree is highly self-compatible and appears self-fruitful (self-pollinating). Flowers approx. 5 d after Nonpareil. Early crossing studies on to Nonpareil, however, have shown lower than expected Nonpareil seed sets, requiring further studies in 2011.

**2004,8-201.** Lineage: NP * 97,1-232[25-75 [Arb * 4-26]*[SB4, 4-2E] * Winters /97,3-40[D4-18 (Mis * [P.fenzliana *Alm])** Winters]. [Sister line to 2004,8-160]. Tree is upright and productive. Bloom time is approx. 9 d after Nonpareil. Nuts are of good quality and well-sealed. Kernels are medium to large and somewhat flat. Branches show high density of spur production and show no disease despite the consistently high crops. No kernel defects observed to 2008 and 2009. Because of concerns with 2004,8-160-to-Nonpareil pollen compatibility, 2004,8-201-Nonpareil cross compatibility needs to be checked in 2011.

## Recent Publications:

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