Almond Board of California

Annual Report- 2004-05

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ALMOND BOARD

Project Title: **Almond Variety Development**

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Objectives:

Develop (1) improved pollinizers for *Nonpareil*, and ultimately, (2) replacement varieties that possess self-fertility and improved disease and insect resistance. Specific 2004-05 objectives include:

1. Expand field trials of new UCD advanced selections. Continue to monitor performance of *Winters*, UCD selection '2-19E', new as well as established low-BF *Carmel* sources, and the *Nickels* hybrid rootstock presently in regional trials.
2. Develop rapid selection techniques for self-compatibility, disease resistance, and NOW resistance.
3. Generate the next generation of almonds from controlled crosses and screen progeny trees for kernel quality, tree productivity and resistance to key pests and diseases.

Results

Current breeding objectives include a series of almond varieties having production quality and yield consistency comparable to Nonpareil but with self-compatibility to improve insect pollination efficiency and reduce orchard management needs. Ideally, nuts should also have good shell-seal to restrict worm, ant, fungal (Aspergillus) and bacterial (Salmonella) entry, while retaining high crack-out percentages. Varieties should be free from Non-infectious Bud-Failure and have improved disease and pest resistance. While genetic solutions have been available to these problems in related almond varieties and species, we have only recently been successful in transferring these traits to breeding lines adapted to California environments and processor requirements. This work has greatly increased the genetic options available to the breeding program for solving current and future industry needs. Initial breeding priorities include the recovery of promising genes for self-compatibility as well as resistance to navel orangeworm and diseases caused by Coletotricum spp. (anthracnose), Aspergillus (aflatoxin) and Alternaria. Concurrent with this germplasm development, rapid evaluation assays to improve breeding efficiency are being developed for self-compatibility (with Dr. Dandekar), anthracnose (with Dr. Adeskaveg), aflatoxin (with USDA scientists) and noninfectious Bud-failure (with California nursery industry). Breeding crosses in 2004 reflect the transition of the breeding program from gene identification and incorporation to the final development of the commercial almond varieties containing introduced genes combined with high horticultural quality. This focusing has allowed a greater number of crosses using fewer parents than have been utilized in the past.

Over 14,000 crosses were made in 2004 among 27 different crossing combinations (parents). Over 6800 seed have been recovered from these crosses with field planting occurring in Spring, 2005. A total of over 30,000 seedling trees from controlled crosses are now being grown in breeding plots in Davis and Winters California. In addition to self-compatibility and disease/pest resistance, promising traits have been identified for tree architecture, bearing habit, productivity, and shell crack-out efficiency and adaptability to Central Valley conditions.

Promising selections have been propagated and planted to grower plots in the Sacramento and San Joaquin valleys to assess the commercial productivity under standard orchard conditions. Tree and nut data from these plantings, as well as earlier plantings in the Regional Variety Trials and grower plots are being collected as part of long-term efforts to identify superior breeding selections for release as California varieties.

Field testing of advanced selections using standard as well as rapid assessment techniques.

Table 1. Related almond species contributing traits to cultivated almond.

Range of tree characteristics of backcrosses to interspecific selections.

Source	Tree Size*	Bloom Time	Promising traits
P. argentia	S-M	Early	Resist.; Architect.
P. bucharica	L	Late	Late flowering, Early maturity
P. fenzliana	M-L	Mid	Drought resist., Late flowering
P. scoparia	S-M	Mid	Drought resist., Insect resist.,
P. webbii	S-L	Mid	Insect resist.; Bearing habit
P. dulcis	M-L	Early	Dis./Insect Resist.; Architect.;
Ppersica	M	Late	Resist.; Architect.

(* S -small, M - medium, L-large).

The majority of present California almond varieties are progeny of crosses between Nonpareil and Mission. Consequently, it has been impossible to incorporate new genetic options to current and upcoming California production problems because this parental germplasm, while well adapted to Central Valley environments, has in effect been 'mined out' and does not contain new genes for self-compatibility, improved productivity and pest/disease resistance required to increase California almond production efficiency. Self-compatibility along with other useful traits (Table 1) identified in related almond germplasm has now been transferred to California breeding lines. Advanced breeding lines combining new traits with characteristics required for California commercial production are being developed (as detailed in the 2003 annual report). Since only a single deficiency (such as disease susceptibility, undesirable tree structure, higher than average winter chilling requirement, or presence of bud-failure or other masked genetic dysfunction) can eliminate an otherwise productive variety or rootstock, the only true test of commercial value is extensive field testing in California production areas. The recent development of large numbers of breeding selections has led to the need for greater regional field evaluations to identify the rare individuals combining all required traits. Towards this goal, 2 large-scale grower trials, a rootstock trial and a cultivar trial, were planted in 2004. [Breeding selection lineages as well as a updated evaluation results and field planting maps are available upon request.]

Hybrid rootstock trials.

The rootstock trial is testing 14 breeding lines derived from hybridizations between almond and related species (as listed in Table 1). Hybrid rootstocks have proven valuable for tree crops as they often increase tree vigor (and so ability to buffer against disease loss), and provide a rapid recombination method for combining the best traits from both parents. Peach x almond hybrids are now commonly used in California almond orchards, while rootstocks originating from more complex species hybrids have also recently shown considerable merit. The species currently being tested (Table 1) for hybrid rootstocks show a much wider range of disease and environmental resistances when compared to peach (Prunus persica). To our knowledge, this is the first California test of these species hybrids for rootstock potential. It is a replicated trial using standard cultivars and orchard management practices and is located to the Paramount orchards in Kern County. Initial analysis will assess rootstock-cultivar compatibility, resistance to soil pathogens, affects on tree architecture, and yield precocity. As with all rootstock candidates, however longer-term evaluations will be necessary to determine the full potential/vulnerabilities of these new candidates. Special appreciation is extended to the Paramount Farming Corp. and Fowler Nursery, since these plantings would not have occurred without their participation.

Figure 1. Advanced selection D3-67 combining high yield potential with acceptable nut characteristics. [Nonpareil and Carmel kernels in black disk for comparison]

Variety selection trials.

Replicated field trials of 22 promising advanced variety selections were established at the Nickels Soils Laboratory in Arbuckle, California, and at the Billing's Ranch in Kern County. Tested selections included a range of tree and nut morphologies including candidates showing particular promise for disease/pest resistance and/or self-compatibility. The purpose of these trials is to identify any deficiencies in these advanced selections and, (of special importance at this stage of the breeding program), to evaluate performance similarities/differences of almonds selected at Davis when planted in Sacramento Valley and San

Figure 2. Advanced selection A97,3-40 presently in grower tests as a replacement for the Peerless variety.

Joaquin Valley commercial sites. The most promising of the selections have previously been as described in the 2003 annual report and so will not be repeated here. The primary breeding objective is the development of improved pollinizers for Nonpareil combining good tree and kernel quality, self-compatibility and/or disease/pest resistance. Several advanced selections show a Nonpareil kernel type which is desirable because of its wide market utility. Selections falling within the California and similar marketing groups have also been selected (as in Figure 1) due to the high productivity and/or disease pest resistance.

Figure 3. The Spanish variety Marcona showing a high quality heart-shaped kernel and thick shell.

Efforts are also being directed towards development of replacements for the Peerless and Marcona varieties which have unique but important marketing niches in the California industry. A promising candidate for the replacement of Peerless is breeding line A97,3-40. The selection combines a very high-quality and large kernel with an attractive, bleachable shell and an early flowering, productive tree (Figure 2). The Peerless alternatives are just beginning regional testing. The Marcona alternative, UCD36-52 is in the finals test stages prior to release to the industry.

UCD36-52 as a Spanish Marcona type almond combining high quality and NOW resistance.

Efforts to develop a California-adapted Marcona-type variety have intensified because of the increasing plantings of the Marcona variety in California [due to the high quality of its heart-shaped kernel (Figure 3) and the associated higher market price]. Despite its high market price, Marcona does not appear to be well adapted to California conditions owing to a generally greater disease susceptibility, vulnerabilities to noninfectious Bud-failure, and poor kernel/shell crack-out proportions of

Figure 4. Advanced selection UCD 36-52 combining good Marcona characteristics with pest resistance, high crack-out, good Nonpareil bloom overlap and partial self-compatibility.

approximately 30%. In its principal areas of production in Spain, the Marcona flowers approximately 1 week before Nonpareil and so would not be suitable for cross pollination. UCD selection 36-52 combines the desired heart-shaped kernel of Marcona with its high kernel quality (resulting in part from a higher oleic acid content which confers both an agreeable buttery flavor and improved resistance to kernel rancidity). In addition, selection UCD 36-52 has a moderately well sealed paper shell (Figure 4) with crack-out proportions of approximately 60%. Because it flowers approximately 3-6 days after Nonpareil it would be a suitable pollinizers for the late Nonpareil bloom and since it possesses moderate levels of self-compatibility, it will allow some self seed set if cross-pollination does not occur. Selection UCD 36-52 also demonstrates good levels of resistance to navel orangeworm and Indian meal moth (Figure 5) which results in greater yield recovery and, equally important, reduced incidence of aflatoxin contamination which is highly correlated with insect damage to the kernel. [The selection has been a favorite of Almond Board evaluators since its superior flavor, heart shape and high proportion of monounsaturated fatty acids make it the poster-child (poster-nut?) for almonds' excellent eating qualities and health benefits].

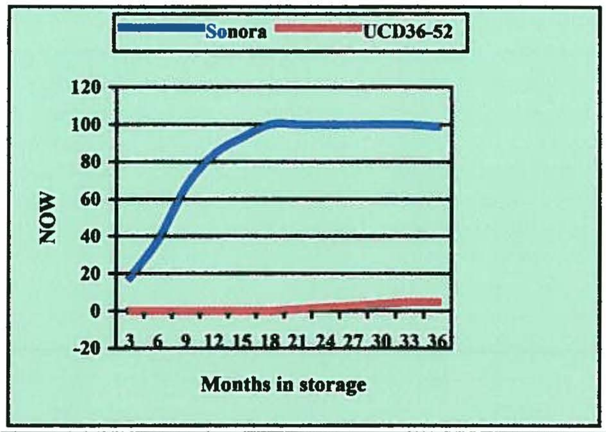


Figure 5. Low infestation of UCD 36-52 following unumigated storage for 36 months with a variety Sonora is a susceptible standard.

Navel orangeworm resistance in UCD 36-52 results in part from a good shell seal but also appears to involve various biochemical components of the kernel. The multiple resistance mechanisms provide a more stable, broad-level resistance but is difficult to transfer to new varieties because of the complexity of the genetics involved. Yield, which is the single most important determinant of variety success, will vary by site in almond production areas of the Sacramento and San Joaquin valleys. A small-

Figure 6. Origins of the Web-trait for insect resistance showing the Prunus webbii source (lower left), the Mission variety (upper left) and the F-1 hybrid (left center). Advanced breeding selection A97, 2-240 combining the Web trait with California adaptivity.

scale (12 trees in a solid 4x4 block), 12-year old test plot at Arbuckle, California has shown UCD 36-52 to be similar to slightly lower in production when compared with nearby Nonpareil trees. Additional grower blocks have been planted in the Sacramento and San Joaquin valleys which are now coming into production. Because of the very high market value of this Marcona-type nut and the consequent high interest by growers familiar with this marketing niche, we have decided to initiate the paperwork for variety patenting and release for UCD 36-52. While final yield potential particularly in the San Joaquin Valley remains unsubstantiated, the general good productivity of this tree combined with its very high market retail price (from $10-$15 a pound) has led to our decision to release this item at this time as a grower alternative to the Spanish variety Marcona which our evaluations indicate is less adapted to California conditions.

Rapid selection for NOW resistance.
A second promising breeding strategy for resistance to insect (including ant) damage (and subsequent higher aflatoxin contaminations) is the 'web'-trait from breeding line A97,2-240. The 'web'-trait , which originated from the wild almond species, Prunus webbii is highly heritable and results in a very thin (high crack-out) but highly sealed shell (Fig. 6). The web characteristic represents a good candidate for rapid assays since it confers a high level of insect resistance, the resistance can be rapidly and accurately evaluated through the simple examination of shell structure, and it is highly heritable (readily transferred to progeny). In addition, unlike thick shelled European-typed almonds which have improved insect resistance but lower crack-out proportions, the web trait is not negatively associated with any production characteristic. While less technical than some of the molecular and biochemical assays used in the breeding program, this rapid selection strategy has the highly desirable characteristics of being very effective, relatively straightforward, lacking ambiguities, and inexpensive.

Monitoring and selection of of low Bud-failure propagation sources for Carmel.
Along the with the advanced breeding selection plantings at the Billing's orchard in Kern County, six experimental Carmel almond clonal sources were also planted. These new test plantings will supplement previous clonal source evaluation plantings in Fresno and Kern County (Table 2). The goal of all plantings is to identify propagation sources for the Carmel almond variety which show low levels of noninfectious bud-failure in nursery propagated trees. A second goal is to test the UCD strategy of progeny testing for identifying promising low bud-failure sources and to test the recent UCD BF model which predicts higher incidence of bud-failure in years following high daytime temperatures during the previous early summer period. Noninfectious bud-failure (BF) is a genetic disorder of almond . The disorder is identified in individual orchard trees of certain cultivars by failure of vegetative buds to grow in the spring (bud-failure), die-back of terminal shoots (dieback), vigorous and erratic growth from surviving buds (witches-broom) and characteristic bark deformations (roughbark). The major California varieties Nonpareil and Mission are susceptible and resistant,

respectively, to this affliction. BF segregation in their progeny ranges from no symptoms as in the varieties Butte and Monterey, to severe expression resulting in the loss of commercial productivity as in the varieties Merced, Yosemite, Harvey, and more recently the variety Carmel. Historically, nursery budwood sources of these almond varieties have been carefully selected from healthy orchard trees, particularly from orchards and environments conducive to BF expression. Budsticks are collected in May for "June budding" to produce nursery trees in one year. The alternate UCD method of budwood selection (CDFA Deciduous Fruit and Nut Program Regulations) consists of maintaining pedigreed all trees to a single selected source that has been indexed as "virus-free" and from which clones of Registered and Certified nursery trees are produced. Foundation trees are then maintained in special high-density hedgerow plantings in quarantine plots. Results from long-term field trials now support the value of such properly selected and maintained pedigreed budwood sources in suppressing the epigenetic-like clonal deterioration characteristic of the bud-failure syndrome.

Table 2. But-failure development over time for various Carmel propagation sources. (Numbers denote incidents of BF in test blocks.)

FPMS#	Source ID	1997	1999	2001	2003	2004
3-56-1-90	D2	0	2	2	8%	8%
2	D7	2	47	85	92	92
6			Nursery			
7		Nursery		BF-field	BF-FPMS	BF-FPMS
3-56-8-92	D4	0	0	10	20	20
9	D8	0	0	40	>50	>50
10	VG 11-6	0	0	70	>90	>90
11	D21	42	85	92	>95	>95
12	VG 8-8	0	0	80	>80	>80
14	VG 8-12	40	80	90	100	100
15	VG 8-7	16	100	100	100	100
	VG 11-3	0	0	0?	20	20
	VG 8-13	0	30	60	>80	>80
	VG 8-14	0	10	60	>80	>80
	VG 8-18	0	0	40	>50	>50
	VG 8-23	0	10	40	>50	>50

Initially, several clonal propagation sources of the variety Carmel were chosen by cooperating nurserymen for testing in 1990. The propagation sources included the original Carmel seedling tree, first identified in 1964, as well as 6 sources growing under differing orchard conditions and determined to be 3rd generation vegetative progeny of the original tree (i.e. trees resulted from two, often independent, cycles

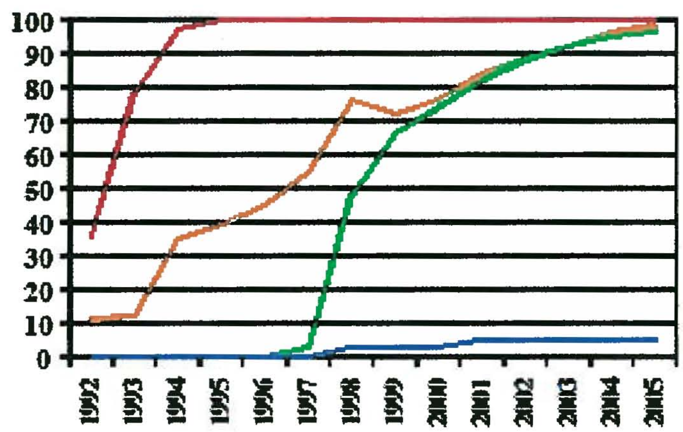


Figure 7. Incidence of bud-failure over time for selected Carmel propagation sources. (Lower blueline denotes the FPS#1source).

of propagation from the original seedling source). No source tree showed BF at the time of budwood collection. Two sources,#1 and #2, originally selected for low BF expression, were maintained as FPMS 3-36-1-90 and FPMS 3-36-2-90, respectively, under the CDFA protocol (Table 2). This protocol involved modified high-density, hedgerow plantings at FPMS foundation orchards at Davis, CA. All progeny trees resulted from single budding unto `Nemaguard` rootstock. Planting was carried out in random groups of ten trees each in January 1991 to a commercial orchard located in Kern Co., an area known for high induction of BF symptoms. The entire planting was rated for BF expression each March over the next 15 consecutive years (1990-2005) using a 0-4 rating scale (0=no bud-failure to 4= very severe bud-failure with 50 % or more of the tree affected).

The overall percentage of BF expression has increased more or less continuously beginning with the second year. Eventually all sources, including the original seedling tree, produced some vegetative progeny trees with BF, although the timing, severity and quantity differed significantly among sources. Most sources exhibited parallel patterns of BF development over the 15 years of the study Figure 7). The two sources (FPS #1 and FPS #2) showing the lowest final levels of Bud-failure expression as well as the lowest rates of BF increase over time (Fig. 7, Table 2) were the propagation sources maintained according to the modified 1984 CDFA protocol. Although all propagation sources were free of BF symptoms in the original trees, differences undoubtedly existed in their latent potential for BF which contributed to different rates of increase as well as final levels of BF expression. The conventional use of mature commercial orchard trees as sources of future propagation budwood appears to accelerate the expression of this latent potential. In this regard, it is significant to note that the level of BF expression in one of the two CDFA foundation protocol orchards (FPS #1) showed patterns of very low BF expression which were comparable to the original seedling source tree. The underlying mechanisms for the suppression of BF with increased time as well as increased generations of vegetative propagation remains unclear, though two aspects of this protocol appeared to play important roles. The extensive annual pruning-back to a hedge-row planting restricts new shoot growth to the basal part of the tree where latent BF potential is at its lowest. Similarly, the associated early spring flush of vegetative growth allows shoot (budwood) development prior to the high temperatures of late spring/early summer which have recently been shown to be associated with increased levels of BF expression in commercial orchards.

Bud-failure appears triggered by high summer temperatures. Recent research at UCD has identified a high correlation between the field level of BF and the occurrence of high temperatures during the previous growing season. The highest correlations were obtained between the level of Bud-failure expression and temperatures of the previous June. During this period, dryland almonds in its native desert conditions typically enter a stage of suppressed growth (summer dormancy or endodormancy. However, high inputs of fertilizer and irrigation water, as in the California system, will promote some continued shoot growth through the summer.

[Almond is native to dryland, dessert habitats and has been an important crop in Central Asia and in the dry Mediterranean areas where it has been cultivated for thousands of years under low input, dryland conditions. Similar to the early California dry-land plantings, BF is rarely observed under these conditions. These native conditions result in slow overall tree growth with suppressed growth during the dry, hot summer months with yields that are many times lower than the modern California system].

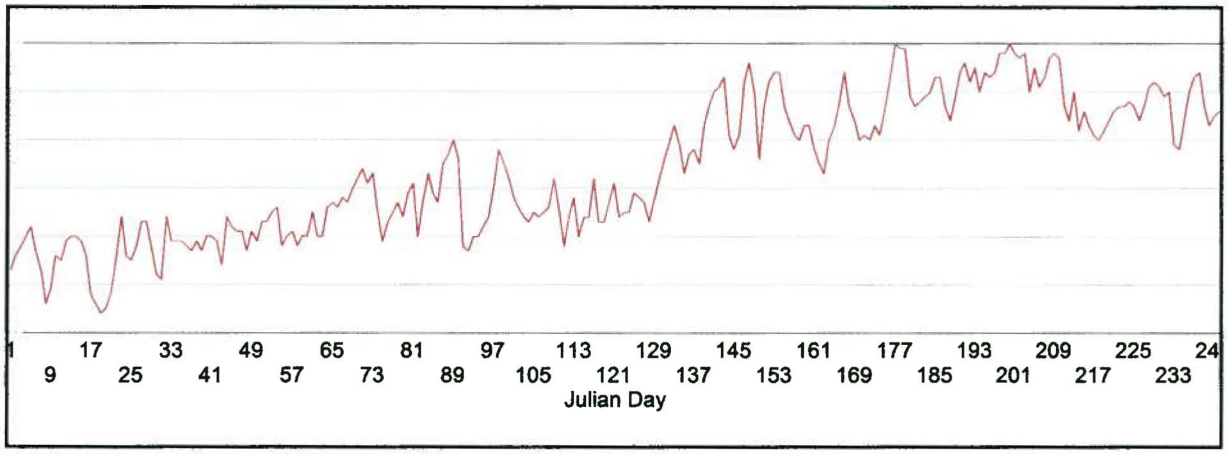


Figure 8. Plot of maximum temperatures for central San Joaquin Valley beginning March 1, 2004.

The UCD strategy for identifying the most promising propagation sources for the Carmel and other BF vulnerable varieties involves tests planting progeny from promising sources in sites were bud-failure is prevalent (typically the west side of Kern County). The strategy is based on previous work that showed present California propagation sources could be sorted out into groups based the rate at which they developed Bud-failure and the severity of BF incidence once it occurred. Continued monitoring of test plantings in Fresno and Kern County demonstrate consistency for this model over the last 12 years (Figure 7). While the great majority of Carmel sources have shown unacceptably high rates of bud-failure development (Figure 7, Table 2), individual sources showing a low incidence of bud-failure have been documented. Little change has been observed in UCD tested sources from 2003-2005 with the FPS #1 source remaining the most promising source at this time (Table 2). Several additional sources, notably D4, and VG11- 3, a show a low BF incidence of less than 25%. However, the rapid increase in incidence from 2001 to 2003 suggests that the rates will continue to rise to unacceptable levels when conducive environments occur. (Predicting conducive environments is thus crucial for the accurate prediction of Bud-failure levels as well as the accurate assessment of the performance of new propagation sources in different years).

Reports in 2005 of higher than expected bud-failure incidents on previously low BF-lines challenged the proposed correlation between increases in bud-failure expression and early summer temperatures from the previous growing season. Our monitoring of standard Carmel accessions in long-term test sites, however, did not identify any distinct upsurge in Bud-failure expression (Figure 7, Table 2). Similarly, while many young (second and third leaf) orchards derived from the Carmel FPS#1 source were occasionally found to have 5% or higher levels of BF expression, these were isolated orchards, with most growers reporting only moderately increasing levels of BF expression other in recently planted Carmel orchards. FPS#1 Carmel derived orchards showing high levels of BF expression in an early stage were always found to be one to three generations removed from the FPS#1 source (i.e. 1-3 mother block propagation increases separated the final orchard from the original FPS #1 source). While nursery increase blocks are essential because of the limited number of foundation trees and the large number of propagated Carmel trees requested by California growers, it has been well documented that these subsequent generations will differ in their BF-potential with significant erosion to unacceptable levels possible. Support for this view comes from discussions with nurserymen at affected orchards where it was revealed that separate orchards originating from other mother block trees showed differing levels of BF-expression, with expression levels for some sub-sources remaining comparable to the original FPS tree. Nurserymen, recognizing the nature of this BF-erosion, are presently keeping detailed records to allow the early rouging out of high-BF sub-sources, to identify the best performing sub-sources for future propagations and to identify the best foundation and mother block management practices to minimize BF development. Finally, despite the unusually cool spring and early summer temperatures of 2004, some areas (notably western Fresno County) were possibly exposed to BF-triggering high temperatures during the crucial early summer stage when lateral shoots typically transition to summer dormancy (which is presently believed to be the BF-triggering biological process affected by the high temperatures). A graph of maximum summer temperatures for this region is shown in Figure 8 (day #1 refers to March 1, 2004). Although the graph documents unseasonably cool spring and early summer temperatures, it can be seen that temperatures rapidly transitioned to the very high temperatures known to be conducive to bud-failure. While this transition occurred during early July or about two weeks later than the typical mid-June period of vulnerability, it needs to remember that the vulnerability is determined plant development stage rather than calendar date. The unseasonably cool spring and early summer temperatures in 2004 typically delayed tree development by approximately 14 days (based on peach fruit development times and almond shoot dormancy times). Consequently, while the high temperatures occurred approximately 2 weeks later than the typically cited June period of vulnerability, those orchards whose development was sufficiently delayed by the cool temperatures could have still been exposed to the triggering high temperatures during the critical summer growth/dormancy transition phase.

Self-compatibility

Development of locally adapted self-compatible breeding selections and effective molecular markers for rapid assessment.

Self-compatibility has become a major almond breeding objective with its promise improve pollination efficiency and so year-to-year production consistency. Self-compatibility refers to the genetic capacity of self-pollen to grow to fertilization after self-pollinations. Because the architectures of almond flowers vary both by variety and by time after anthesis, natural self pollination (i.e. without the use of insects pollinators) tends to be inconsistent. Thus, to maximize pollination, honeybee pollinators will still be required, but because every honeybee visit to the flower will only need move that flower's own pollen to its stigma, the efficiency of honeybee pollination should be greatly improved. While some of our advanced self-compatible breeding lines also show high levels of natural self-pollination, the genetics controlling self pollination (which involves both flower architecture, timing of anther dehiscence and stigma growth) is controlled by a large number of separate genes, making it difficult to transfer to breeding progeny. However, for self-compatibility, expression is largely determined by a single gene (S) which normally governs self-and cross-incompatibility of pollen growth through pistil tissue. In our breeding program, it has proven much easier to manipulate this single, major gene, especially after the availability of molecular markers for the self-incompatibility forms of this gene were developed in collaboration with Dr. Dandekar (as detailed in the 2003 reports). Although not reported to occur naturally in cultivated almond, a gene for self-compatibility has been naturally introgressed into certain very old Italian varieties from the native wild almond species Prunus webbii. Tuono has been the most widely planted of these varieties and is currently being used as a source for self-compatibility in many European breeding programs. Inbreeding associated with the extensive utilization of this germplasm, however, appears to reduce the levels of self-compatibility in some resultant breeding lines and varieties. At the UC Davis program, we have identified additional, unrelated sources of self-compatibility and have incorporated self-compatibility genes from different sources into advanced almond

Table 3. Rating of breeding value which combines both self-compatibility quality and horticultural quality. (1=best)

LeGrand almond	3
Supernova almond	5
P. webbii	6
P.persica-1	2
P.persica-2	1
P. argentia	4
P.fenzliana	7

breeding lines in California (Table 3). Selections for high field expression and high heritability (i.e. dependably transferred to progeny) have identified promising sources from Prunus dulcis (cultivated almond), Prunus persica, eastern European Prunus webbii, Prunus fenzliana, and Prunus argentina. We are now field testing advanced breeding lines combining improved adaption to California cultural and processing requirements with various combinations of these self-compatibility alleles, including those from Tuono and the irradiation-induced self-compatible Italian variety Supernova. Early results suggest differences in the breeding value for different self-compatibility sources (Table 3). The breeding value is determined by the consistency in the level of self-compatibility from year-to-year, and from parent to progeny, as well as a general horticultural quality of that source. For example, while the Tuono variety results in high numbers of progeny showing good levels of self-compatibility, most progeny also show poor kernel quality, particularly shriveled and creased nuts. Ongoing molecular studies with Dr. Dandekar have resulted in our development of molecular markers for some self-compatibility sources. For several important markers, however, it remains difficult to distinguish our self-compatible selections from from standard self-incompatible forms of the gene (Figure 9). While PCR based screenings were often successful in differentiating among several of the self-compatibility alleles, in other cases, S-alleles from different origins showed identical banding patterns (Figure 9). DNA sequences of individual alleles are presently being analyzed to further characterize differences among S-alleles. Interestingly, the size of PCR generated molecular bands for many of the important self-compatibility alleles are very similar to the Sb self-incompatibility alleles band (Figure 9). This finding and the generally small size of the Sb band suggests that it may be ancestral or a more primitive form of the the self-incompatible and later developing self-compatible forms of this gene.

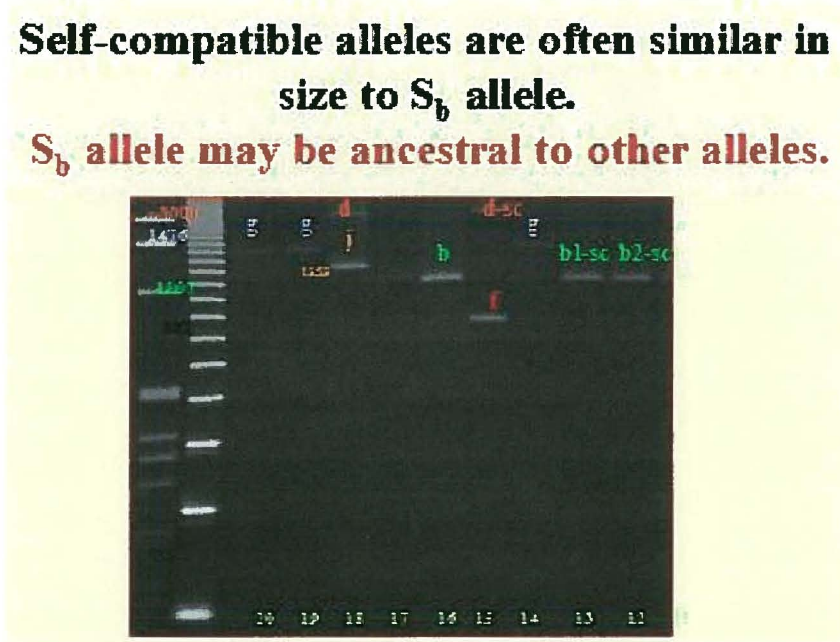


Figure 9. Image of gel separation of molecular markers based on size (larger to smaller from top to bottom).

Self-compatibility: field testing.
Self-compatible selections appear to differ in their final level of field expression of self-fruitfulness though high levels have been recovered from each source developed. The year-to-year expression of self-compatibility in other selections, such as UCD36-52, is less consistent and these inconsistently self-compatible types have been designated as partially self-compatible. (Despite its partial level of self-incompatibility UCD36-52 is still being considered for release to the industry because of its other positive attributes including very high kernel quality and market value, and high pest resistance). Differences in modifier gene complement, including genes for flower structure, appear to be more important to final level of self-fruitfulness than differences among the advanced self-compatibility alleles tested (Figures 10, 11, 12). Two advanced breeding selections which have been included in the 2004 grower test plantings: F8,7-179 (Figure 13) and F8,8-161 (Figure 14), illustrates the converging breeding efforts to develop self-compatible almond varieties from disparate genetic sources. While both F8,7-179 and F8,8-161 show immediate value for possible release to California growers as variety candidates, their major value is seen as parents for the next generation of progeny combining self-compatibility with consistent productivity and high horticultural quality.

F8,7-179. The initial source of self-compatibility in F8,7-179 was peach (Figures 10, 11). Eight generations of recurrent back crossing towards almond types with constant selection for almond kernel and tree characteristics has resulted in this selection that would be judged as pure almond unless molecular tests were used. The large number of backcross generations were required to sift out the peach-like genes for tree, fruit and kernel quality while concentrating those of almond. Although tree qualities, particularly size, branch architecture, and bearing habit, can be time consuming to eliminate, kernel size and quality respond very positively to selection for almond type, as demonstrated in Figure 11. Self-compatibility, because it is controlled by a single gene with a major affect, is very responsive to selection and so relatively easy to transfer to progeny populations. Despite its strong heritability, the level of self-compatibility can be seen to differ among

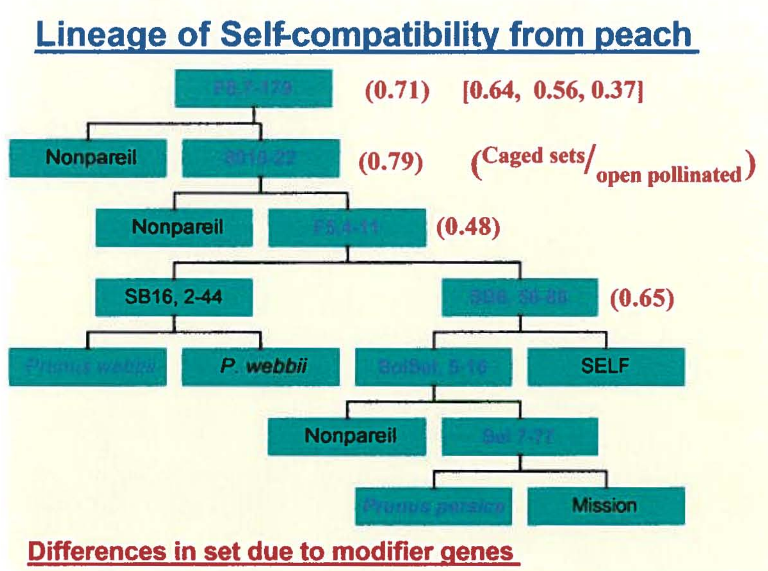
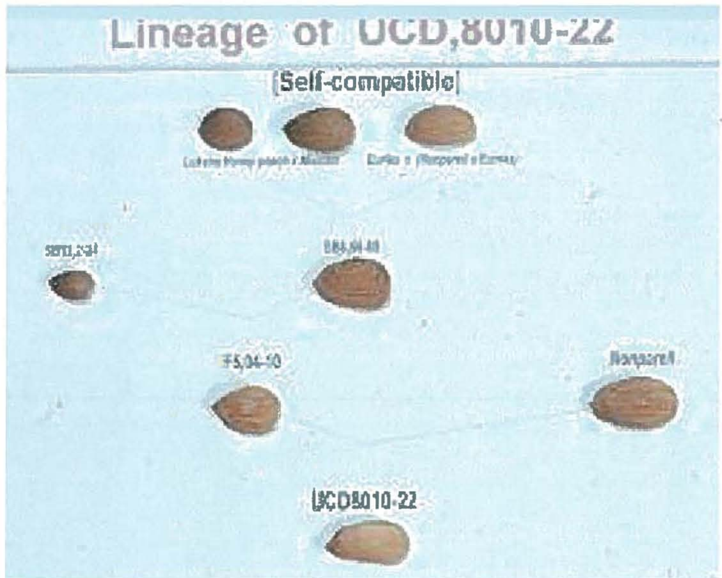


Figure 10. Lineage of selection F8,7-179. (self-compatibility proportion given in parentheses).



the different progeny generations (numbers in parentheses in Figures 10and 12) and in different years for the same selection [numbers in brackets in Figures 10and 12]. These differences are primarily due to the effect of modifier genes (i.e. separate genes whose action influences the final level of self-compatibility, for example, genes controlling anther dehiscence and/or flower structure). The PCR based molecular marker for the F8,7-179 self-compatibility allele (i.e. form of the self-compatible gene) is indistinguishable from the self-incompatible Sb marker which is present in Mission and many other California cultivars (lane 13 in Fig. 9). Currently, PCR based molecular markers are used primarily as a follow-up diagnostic to confirm results based on more traditional genetic analysis. In addition to high levels of self-compatibility, F8,7-179 also shows good tree and nut (Fig. 13) quality, high productivity and promising levels of disease resistance. It does appear to have moderate susceptibility to hull rot and while it has been a dependable parent for transferring both self-compatibility and good horticultural quality to breeding progeny, we have primarily paired it with more hull rot resistant parents in these breeding crosses. [The Sacramento and San Joaquin Valley testing of these breeding parents is particularly important to help identify susceptibilities to other diseases/pests/genetic abnormalities which may not be as apparent in the Davis test environments. This is particularly critical for breeding selections derived from wide crosses as undesirable plant characteristics may not become apparent until later production stages of the

Figure 11. Lineage of selection F8,7-179 parent UCD8010-22 showing changes and kernel morphology in response to breeding selection. (Lineages traces from top to bottom).

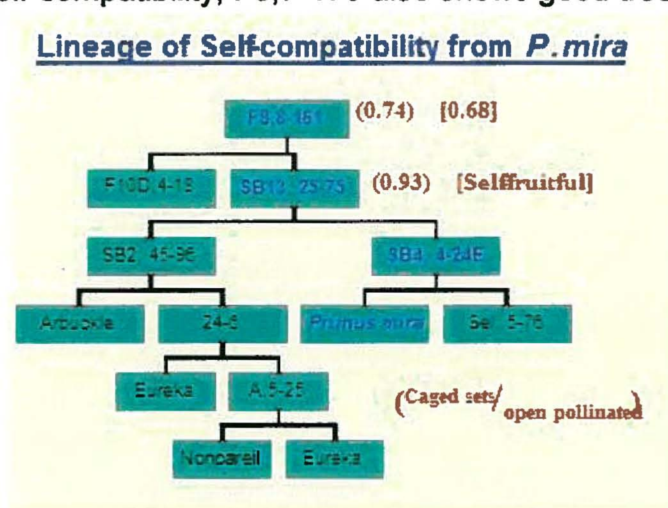


Figure 12. Lineage of selection F8,6-161. (self-compatibility proportion given in parentheses).

selection (as described below).]

Figure 14. Kernel and shell characteristics for selection F8,7-179 (Nonpareil and Carmel

F8,8-161. The source of self-compatibility for F8,8-161 was the related peach-like species *Prunus mira* (Figure 12). It's immediate pollen parent was selection SB13,25-75, which has been tested as UCD25-75 in the most recent Regional Variety Trials. UCD25-75 shows both high levels of self-compatibility and high levels of self-pollination [i.e. the proportion of seed set in enclosed or bagged branches without cross pollination or insect pollinator visits was only slightly lower than seed set in open-pollinated (i.e. insect cross-pollinated) adjacent branches, (the proportion of 0.93 in Figure 10)]. Selection UCD25-75 also had good early yields and moderately good kernel characteristics (comparable to selection F10D,3-64 in Figure 1). Tree architecture, however, was still somewhat intermediate between almond and it's wild peach great-grandparent. The peach-like architecture was particularly apparent in the more weepy growth habit and the more peach-like scaffold development. Consequently, as the tree aged, the overall architecture became more peach-like with excessive shading of interior wood and excessive breakage of bearing branches. Although we recognized these deficiencies, selection 25-75 was placed in Regional Variety Trials to test whether high levels of self-compatibility would confer year-to-year production consistency. As described in earlier reports, a greater year-to-year production consistency was clearly observed in this selection during the early years of production though tree limb breakage in following years led to subsequent yield reductions. After 12 years in production, many trees of selection UCD25-75 growing at the Chico Regional Variety Trials developed serious bark cracking at the trunk level which often resulted in limb and or tree loss. Distorted cambium or bark development resulting in subsequent cracking is occasionally observed in the progeny from wide crosses and represents a class

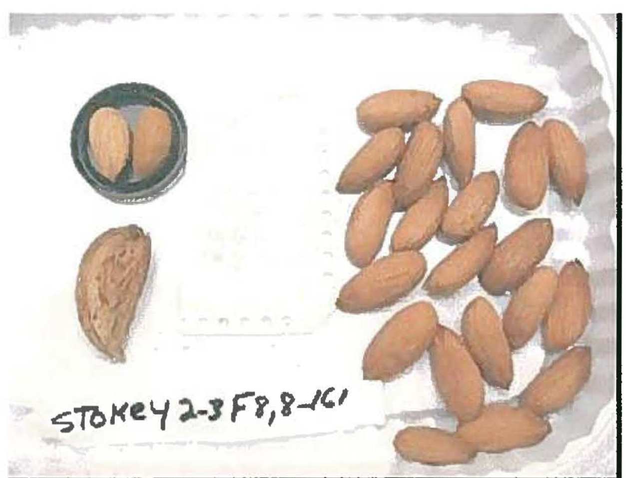


Figure 13. Kernel and shell characteristics for selection F8,8-161 (Nonpareil and Carmel kernels in black circle for comparison).

of genetic/growth abnormality which needs to be carefully guarded against in these types of crosses (i.e. while wide crosses offer the potential for novel positive traits, they're also at higher risk for novel negative traits which may take years to become apparent). Selection F8,8-161, combines the good horticultural quality and productivity of F10D,4-18 (seed parent) with the very effective self-compatibility gene from UCD25-75 but without the negative tree and bark characteristics. But the high level of self-pollination was also not transferred to this progeny as was expected because the complex genetics and so improbable inheritance (unless an exceptionally large large progeny populations are developed). After six years of testing at the UC Davis almond evaluation plots at Winters, California, selection F8,8-161 continues to show good kernel and shell characteristics (Figure 14) and good tree architecture, bearing-habit and productivity. The selection also appears to have higher levels of resistance to anthracnose, and has no known susceptibility to current diseases (no fungicides are sprayed in our test plots). Both F8,7-179 and F8,8-161 are being used extensively as parents in future crosses based on their good horticultural quality and their proven ability to transmit both self-compatibility and good tree and nut quality to progeny in test crosses. The use of these and other self-compatible breeding parents represent more advanced and consequently more locally adapted parent material than was available to the breeding program previously (as can be visualized in the transition of kernel quality in the lineage of F8, 7-179's parents in Figure 11). Where earlier breeding generations had targeted the rapid transfer and incorporation of new self-compatibility and disease/pest resistance genes from new genetic sources (typically resulting in intermediate tree and kernel types, see Figure 11), current and future crosses emphasize high-levels of horticultural quality necessary for commercial success. The anticipated consequence of using fewer, higher-quality parents is a much larger proportion of progeny having the necessary characteristics for commercial success. This newly introduced germplasm, however, inherently has risks for unanticipated deficiencies (as demonstrated with the bark cracking nature of UCD25-75) yet it has proven benefits as sources of self-compatibility, pest resistance (as demonstrated in 97, 2-240 and UCD36-52) and disease resistance (as demonstrated in F8,8-161 and UCD36-52) which are not available from traditional breeding lines.

Update on UCD13-1, released as the Winters variety.

Extensive grower plantings the of recently released variety Winters has taken place in 2004-2005 with most growers citing the high yields at the Chico Regional Variety Trials (RVT) as a major reason for their choice of this variety. Chico RVT yields for Winters in 2004 was 2425 kernel pounds/acre (Fig. 15). Only Carmel was higher with 2830 pounds/acre. Winters maintains a commanding lead in the accumulated yields (1996-2004) of 19,381 pounds-acre followed by Carmel with 16,425 and Nonpareil with 15,092 pounds per acre. Winters has shown only moderate to poor yields at the Manteca RVT and the Kern County RVT, resulting in the belief by some growers that it is best adapted for the Sacramento Valley. In the Manteca RVT, yields in the field section were Winters is planted (rows 20-30) are severely limited by adverse soil conditions as demonstrated by the dramatically lower yields of the alternately planted rows of Nonpareil within this section (Figure 16). In the Kern County RVT, Winters, while showing only moderate to low levels of late season leaf infestation with *Alternaria* leaf spot, consistently shows very high early *Alternaria* leaf defoliation (30% by September 2004) which significantly limits yield potential for the following year. Similar levels of defoliation and crop loss are also apparent in the variety Carmel at Kern RVT, a regional trial which is particularly vulnerable to *Alternaria* leaf defoliation owing to its microclimate (including high levels of tree canopy moisture from morning dews during late summer). In other, even nearby sites in Kern County, Carmel has proven to be a very productive and commercially important variety, suggesting that Winters' productivity at the Kern RVT site may also underestimate its true productivity in the San Joaquin Valley. In addition to Alternaria leaf spot, Winters has also shown high vulnerability to anthracnose at the Chico RVT during the wet El Niño spring of 1998. Standard fungicide sprays have effectively controlled the disease since that initial outbreak, even in the conducive cool, wet conditions of spring, 2005. Winters did show relatively high navel

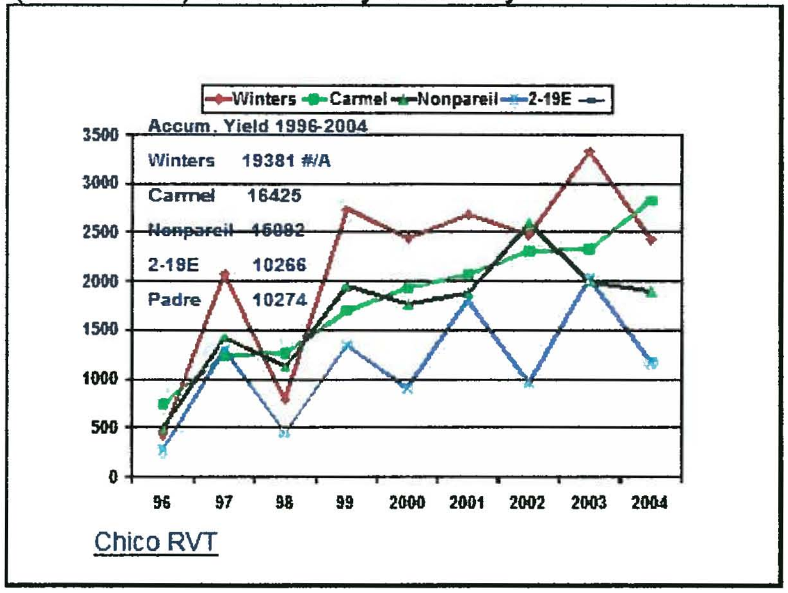


Figure 15. Plots of annual yields of selected items at the Chico RVT (accumulated yields given in text).

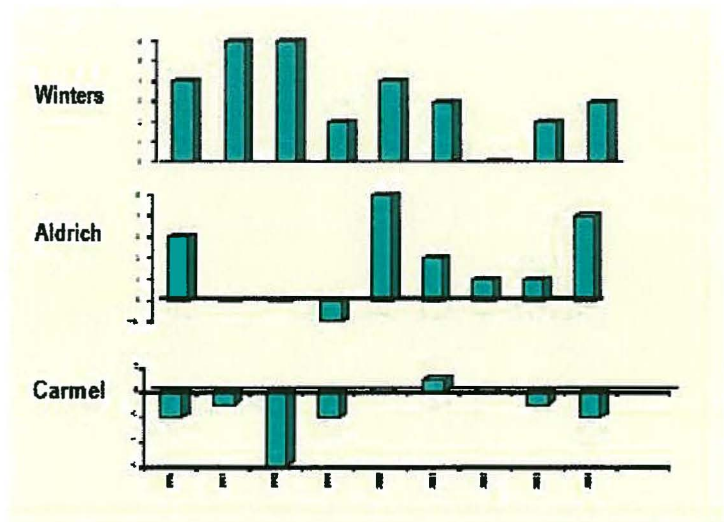


Figure 16. Graph showing time of flowering relative to Nonpareil. (Days before Nonpareil above axis; days after below).

orangeworm (NOW) damage (14%) at the Chico RVT in 2004. These numbers, however, do not reflect grower conditions, since the Chico RVT was not and has never been sprayed for navel orangeworm. Consequently there is high pressure for worm damage making this site very useful for evaluating NOW and PTB susceptibility. Winter's susceptibility to NOW results from an incompletely sealed shell (comparable to Carmel) and its late harvest with Carmel at most locations. Shell and hull split can begin days to weeks earlier than Carmel. This long period between initial hull split the harvest make Winters particularly susceptible to navel orange when this pest is a problem. Winters can also show a large number of kernels with gumming in the fields. This is usually seen in years showing a very heavy crop and may reflect the trees inability to fill all seed following exceptionally high sets. Kernel gumming and shriveling are most apparent in orchard-site evaluations since most of these poorly developed kernels are screened out by the pickup machines at harvest. Regardless of its ultimate yield potential, the major contribution of Winters to California almond production lies in its consistent bloom overlap with the early Nonpareil bloom. Because of the honeybees preference to aggressively work those varieties having a high proportion of open flowers, it is important to have a variety blooming before Nonpareil to ensure an adequate supply of cross-

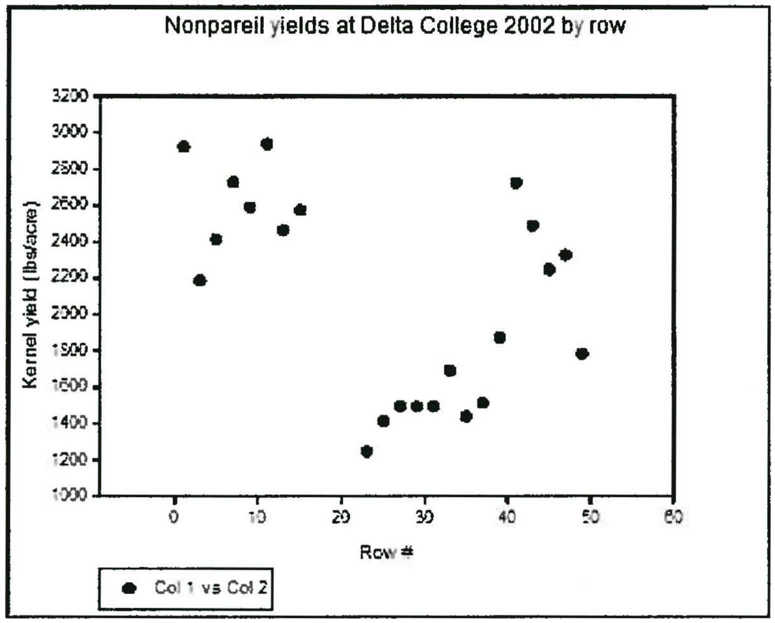


Figure 18. Scatter plot of the yields for alternate rows of Nonpareil at the Manteca RVT showing a dramatic yield decline for Nonpareil rows 20-30 (and presumably enter planted test selections).

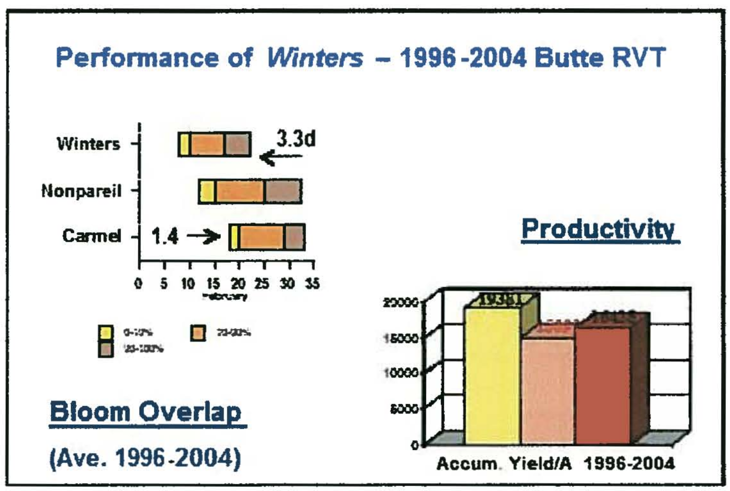


Figure 17. Plot showing bloom overlap and productivity of the Winters variety's average performance (1996-2004).

compatible pollen. Most current varieties used as an early pollinizer for Nonpareil will often flip- flop with Nonpareil in flowering times, particularly in those years having different winter chilling units/spring heat units (Figure 17). Typically when a variety such as Carmel flowers after Nonpareil (Figure 18), its crop is maximized at the expense of the Nonpareil crop (i.e. Nonpareil acts as the pollinizer). In the Sacramento and San Joaquin valleys RVT, Winters has consistently flowered approximately 3 days before Nonpareil bloom (Figure 17 and 18) with good overlap with Nonpareil full bloom. In the San Joaquin Valley with its warmer spring temperatures, Winters will sometime have a few flowers opening as early as Sonora though the main flowering including time of full-blown occurs approximately 3 days before Nonpareil. In these more southern areas, the Winters bloom will often completely overlap Nonpareil bloom beginning about three days before an ending several days after Nonpareil, thus insuring consistent supplies of cross-compatible pollen. Finally, since both of the factors controlling cross-compatibility in Winters (Sb/Si) differ from that of Nonpareil (Sc/Sd) all of the Winters pollen is cross-compatible on Nonpareil as compared to half of the pollen for most California pollinators. However, extensive testing at UCD has failed to identify any production advantage of full cross-compatibility versus 50% cross-compatibility (as detailed in Pollen Flow report for 2003/2004). These tests have also shown that Winters is partially self-compatible (frequently able to set seed after self-pollination), which enhances its value as an early-season pollinizer for Nonpareil. The self-compatibility is not consistent in certain years owing to still poorly understood environmental factors.

Advanced UCD selections in the almond regional variety trials.

Advanced UCD almond selections remaining under evaluation at the regional variety trials include UCD2-43W, UCD1-87, UCD102W and UCD2-19E. Although demonstrating good kernel quality and, in many cases, good bloom overlap with the later Nonpareil bloom, (and in the case of UCD1-87, improved disease resistance) these selections have not not proven competitive with the current best varieties at the different RVT sites. The possible exception is UCD2-19E, which is one of the highest producing varieties at the Kern RVT plot with an accumulated (1995-2004) yield of 23,030 pounds per acre following an exceptionally high crop of 4890 pounds per acre in 2003 (Figures 15 and 19). As can be seen in Figures 15 and 19, however, UCD2-19E shows 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. An alternate bearing habit is undesirable for California production, and usually breeding selections showing this behavior would be discarded. However, many Kern County growers have been successful in maximizing year-to-year production in other strongly alternate bearing varieties such as Price, by closely monitoring current season crop yield and providing increases in both irrigation water and fertilizer nutrients as needed. To evaluate this opportunity to capitalize on its very high cropping potential and because of its good kernel quality and bloom overlap with Nonpareil (as detailed in the 2003 annual report) additional grower plantings have been made in Kern County in 2004. Virus-free, nursery foundation plant material has also been provided to interested nurseries to facilitate greater grower experimentation with the selection.

In summary, following the release of the Nickels rootstock and Winters almond variety, we anticipate the further release of UCD36-52 Marcona-type almond selection within the next two years. UCD selection UCD2-19E is also being considered for release to the industry depending upon results from recently established test plots. In the following years, we will be considering the release of advanced self-compatible and/or disease resistant almond cultivars. While the thorough testing of current hybrid rootstock candidates will require an additional 10 years or more, this material is also being made available to interested nurseries and growers for local evaluation and possible use in regional rootstock improvement programs.

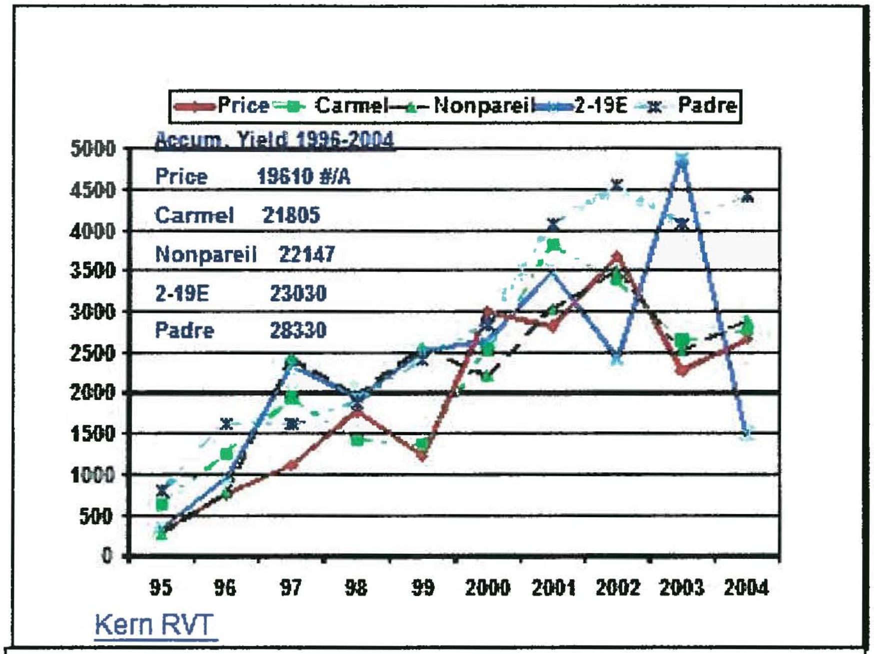


Figure 19. Plots of annual yields of selected items at the Kern RVT (accumulated yields given in text).

Update in recent fact-finding trips to China and Iran.

Besides California, significant almond production has been reported and Spain Greece, Italy, Turkey, Iran and China. With the exception of Iran and China, most of this production is well-documented in reports from the European Union and associated institutions. I recently have had opportunities to visit putative almond production areas in eastern China (August, 2004) and central Iran (May, 2005) and present my findings in the following summary.

Both western China and Iran lie within the center of origin for cultivated almond as well as the centers of diversity for wild almond germplasm. Because of the productivity, nutritional value, and ease of harvest of native cultivated and wild almonds, this temperate nut has been an important crop throughout the history of this area and has become increasingly important in modern times owing to its adaptability to hot, dry climates and its value as an export crop. Current constraints to increased production in these areas include inherent limitations in the region's climate, the limited availability of good irrigation water, and the limited availability of improved varieties and the technical expertise for optimizing cultural management of these varieties. Important climate limitations to almond production include the cold winter temperatures in theseproduction regions, and in particular, the occurrence of spring frosts during the crucial flowering and cross-pollination period. Damage from disease and insect pests is also a serious problem in many areas. While productive varieties with good market quality are available in the Mediterranean, Californian and Australian varieties, these varieties often lack the required resistance to the pests and diseases native to Central Asia. Since it is the center of diversity for almond germplasm, this region is also the center of diversity for many almond pests and diseases and so damage from native pests and diseases of might be expected to be more severe here than in other production areas. Local problems include Almond Fruit Drop and a range of pests and diseases, including *Tecaspis asiatica, Polyphylla olivieri, P. adspersa, Eurytoma amygdali, Anarsia lineatella, Nattrassia magniferae, Pseudomonas syringae, Cytospora leucostoma, Verticillum dahliae,* and *Armilaria mellea*. Similarly, a principle reason for my recent trips to these regions was to assess the wealth of potentially valuable almond germplasm that has been described in this region including the species *Amygdalus (synonym Prunus) orientalis, A. arabica, A. scoparia, A. kotschyi, A. lycoides, A. reuteri, A. haussknechtii, A. elaegnifolia, A. erioclada, A. salicifolia,* and *A. eburnae.*

Figure 20. Unknown leaf blight on almond tree in Xian China, 2004.

For export, high levels of consistency are required in the product's quality and in its food safety. Quality consistency refers less to the rating of sensory qualities such as taste, texture, etc. (since these will vary with region), but to the uniformity or predictability of the physical (size, shape, external and internal colour, texture, water content, surface roughness, etc.) and sensory (crunchiness, level of almond flavor (benzaldehyde) and bitterness (cyanide compounds), rancidity, etc.) characteristics of the exported product. This uniformity is necessary for the buyers to confidently predict the appropriateness of these often large volume shipments for a range of diverse end uses, including the processing of chemical and pharmaceutical extracts, as well as the development of almond based confectionaries and other food condiments and for the out-of hand consumption of whole almonds. Consistency in the area of food safety has traditionally emphasized the purity of the shipped product, that is, having low levels of extraneous material such as weed seeds, etc., and freedom from pesticide residue, excessively high cyanide levels and diseased material such as rots and fungal molds (particularly aflatoxin producing Aspergillus spp. contamination). An increasingly health conscious market will probably add to this list of health concerns new restrictions on additional fungal toxins and microbial contaminants, and possibly on genetically modified DNA (transgenic or genetically engineered tissue) in shipped products.

In addition to consistent quality, export markets demand a consistency of quantity or supply. Much of the difficult work of establishing new export markets will be lost if an inability to consistently supply this market forces it to go to other suppliers or other nut types. Supply consistency must be maintained both throughout the marketing season and from year-to-year. The development of effective storage facilities is key to maintaining a consistent supply within a marketing season. The key to maintaining year-to-year supply consistency is the development of good production efficiency.

Figure 21. Excessive gumming and canker development in an almond orchard which is used as the source of bud-wood for most almond propagations in eastern China. (Xian, China, 2004).

Finally, an often overlooked, yet very important orchard improvement strategy is the introduction of high performance yet locally adapted rootstock propagated trees. Over 80% of cultivated almonds in western China Iran are presently on seedling rootstocks. While this tremendous variability of rootstock types may buffer against widespread susceptibility to important soil-borne diseases, it also contributes to the high tree-to-tree and year-to-year yield variations observed in these fields. The introduction of high performance yet locally adapted and resistant rootstocks would optimize below-ground performance while the budding of high performance varieties to

Figure 22. Almond kernels reportedly harvested from a Nonpareil tree in Shanxi, China, 2004.

these rootstocks would optimize above ground performance and desired market quality. For the propagation of large numbers of such budded trees, however, a viable and credible nursery industry with the necessary technical expertise in propagation, marketing (to growers) and maintaining variety trueness-to-type and freedom from viruses would have to be established. Also the actual implementation of improved methods and/or varieties requires effective researcher-to-grower and grower-to-researcher communications. To maximize the chances of success, such communication needs to begin at the first stage of the improvement program; the prioritizing of research problems and proposed strategies. Productive communication between the researcher-and-grower is further complicated by the fact that researchers are often experts in narrowly defined disciplines, while good growers typically take a multi-disciplinary view of problems. Strategies successfully employed in California to address these issues include the funding of regional Extension Specialists/Farm Advisors whose responsibility is to act as a liaison between the multi-disciplinary growers and the often more disciplinary focused researchers. No such programs exist in either China or Iran and their absence often results in the poor implementation and frequent failure of University developed changes to their farming systems.

Almond production in China.

The People's Republic of China is a major importer and consumer of almonds. Recently, there has been much interest both within and outside of China for increasing almond production within China and recent reports have given annual production estimates of up to 450 metric tons per year (though all my Chinese sources indicate that this is highly exaggerated). Almond, however, is able to grow in only limited environments. Generally these environments are characterized as "Mediterranean" climate because of their mild and often wet winters and hot, dry summers. Mild winters and frost-free springs

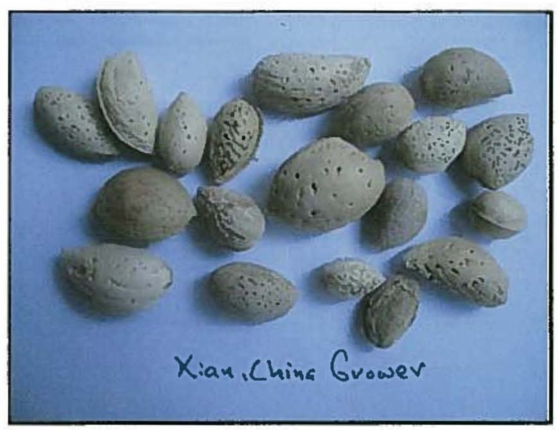


Figure 23. Representative nuts from a peach-almond and similar interspecies crosses showing a reduced quality in nut and kernel types.

are required because of almond's nature to flower very early in the springtime. In most northern latitudes, almond will flower in February and March, being approximately 1 month before cherries and two months before walnuts. The occurrence of late winter storms, or any freezing temperatures (including even short duration frosts) will lead to flower destruction and loss of crop. In addition to mild winters and warm springs, almond production requires freedom from rains during the summer growing season. This is because the almond leaves, branches, and roots are very susceptible to common bacterial and fungal diseases (which need wet conditions for infection). When grown in a more typical temperate to sub-tropical climate, such as the eastern coast of China, the almond tree will grow slowly for the first several years with tree death typically occurring within five to eight years owing to complex infections of the leaves (Fig. 20), flowers/fruit, branches (Fig. 21), roots and kernels (Fig. 22) by the relatively abundant plant pathogenic fungi and bacteria. During recent trips through eastern China, I have yet to see an almond tree greater than 10 years old. [Older trees of peach x almond hybrids are sometimes observed but these are also often sickly and, in any event, produce typically poor seed quality (Figure 23). Since crop production typically does not begin until year five or six in the slow growing trees, commercial production is not likely to be feasible. Despite the rapid decline and death of almond grown in eastern China, large numbers of trees are reportedly still being planted (as high as 40,000 trees per year by some estimates with most being planted in Xian Province and to a lesser extent Sichuan and Gansu Provinces). Plantings are being encouraged by the government to decrease the dependency on almond imports despite the repeated failure of almond plantings in this inappropriate climate.

While China is a very large country with many different climates, only the far western Xinjiang province has been shown amenable to almond production. Multiple efforts to produce almonds in the eastern coastal plains of China have failed primarily as a consequence of the heavy monsoon rains experience with these areas in the summer. As the rain storms move into the interior

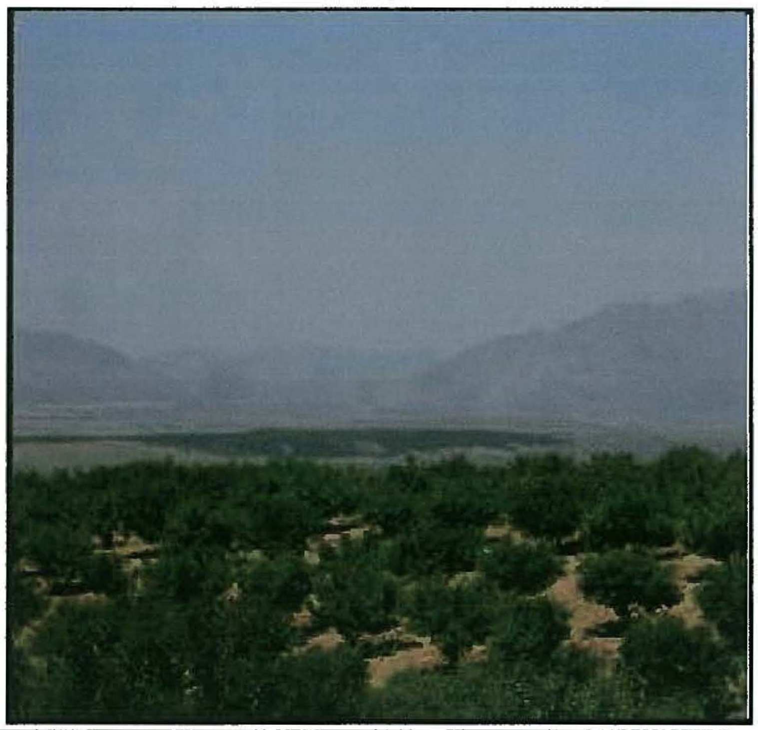


Figure 24. irrigated almond orchard in central Iran showing the predominant planting on high ground overlooking the more fertile valleys.

mountainous areas, the rains diminish, such that the more central and western areas of the Tarim basin are essentially deserts. While it is possible that some of these interior mountainous areas (including Gansu province) may have dry enough summers to allow almond survival, the scarcity of arable land and irrigation water as well as the greater frequency of spring frosts would probably make almond production difficult. (While I have not traveled extensively in these areas to verify this assumption, it appears supported by Chinese colleagues who are familiar with this region).

Figure 25. Irrigated almond orchard in the mountains of central Iran showing the rocky conditions and poor soil quality.

Consequently, only the far western Xinjiang province appears to have the basic climatic conditions for almond growth. However, a growing population in these regions combined with limited arable lands and very limited water for irrigation, has emphasized the production of more essential food crops in these regions. Extensive agriculture in these limited areas has also resulted in high salt accumulations in the desert-type soils. Almond is very susceptible to salt damage in such soils. An equally serious barrier to almond production in this province lies in cultural differences between the local Islamic population and Han Chinese that have migrated to the area during the past 40 years. Although not frequently discussed in western news, the political situation is very tense, and in many ways similar to that in neighboring Afghanistan. Very limited small plantings of almonds exist in this region, (mostly as windblock trees to protect crops from desert sand storms). Several attempts at large-scale commercial production have failed with the political/cultural and environmental conditions cited as the major obstacles. In recent (August, 2004) discussions with commercial almond handlers and processors in Beijing, China, I was told that most handlers had essentially given up on commercial almond production in Xinjiang province. This frustration with western (Xinjiang province) production has accelerated the establishment of orchards in the Han-Chinese dominated eastern coastal area (roughly from Beijing to Xian, particularly in the westernmost coastal regions adjacent to the north-south running central mountainous regions) despite the enormous environmental/climatic barriers to almond production in these typical summer monsoon areas. [Weather data, including minimum temperatures and rainfall is readily available for most parts of China through the Internet; thus allowing easy opportunities for the fairly accurate assessment of regional climates within China].

Almond Production in Iran.

Figure 27. Section of the semipermanent irrigation line feeding irrigated almond orchards in central Iran.

In 2004, Iran reported 165,000 ha of bearing almond land with an additional 45,000 ha in non-bearing almond orchards (see attached report by Professor Alireza Rahemi, Head of Almond Genetic Improvement, Temperate & Nut Fruits Office, Deputy of Horticulture, Ministry of Jihad -e-Agriculture, Iran). Of this total approximately 90000 ha is irrigated with the majority of production occurring in nonirrigated and typically small dry-land plots. While the acreage of both dryland and irrigated almond has increased moderately over the past 10 years, the largest increases are seen in irrigated orchards often located in the Shahr-e Kord region of central to southwestern Iran. Despite the continuing increase in acreage, almond production over the past 10 years has been erratic ranging from a low of 1,029,000 tons in 1995 to 1,000,873,000 tons in 2002 (with most of this for local/regional consumption). Production averages approximately 1500000 tons with very high year-to-year variability due to climatic conditions particularly during and just following bloom. Reported Iranian almond yields average approximately 900 kg per hectare with the highest yields

Figure 26. One of several pumping stations required to deliver irrigation water to the high elevation almond orchards.

occurring in irrigated areas. Major new plantings of irrigated almond are occurring in the Shahr-e Kord region in a massive government - supported planting. These new orchards are invariably located several thousand feet above the valley floor both to avoid spring frost and because the higher-quality valley land is already heavily planted to other crops (Figure 24). Because of the typical high-altitude, desert environments, soils at the planting sites are typically very rocky and of poor quality (Figure 25). Irrigation water is brought in at great expense from the Zion River to these high-altitude plantings using semi-permanent water lines which appeared prone to breakage (Figure 26). Because of the of the height and distance between of the river and the almond plantings, large pumping stations were frequently needed (Figure 27). This project was heavily subsidized by the Iranian government in the hopes that it would stabilize the local agricultural farming populations and reduced the exodus of particularly young people to urban areas where unemployment is already exceeding 30%. While the almond trees observed appeared relatively healthy, the crops were very small and probably not worth the effort of harvest. While it was unclear in my interviews with local researchers why the crop failed, a leading hypothesis appeared to be that stormy weather during boom dramatically reduced cross-pollination and so crops set. In addition, the occurrence of noninfectious bud-failure was verified on one of the new varieties developed for irrigated plantings (figure 28). The relatively high incidence of bud-failure relatively early in the commercial life of this variety suggests a high probability of its eventual abandonment.

Figure 28. Researchers from the Shahr-e-Kord University in central Iran documenting the presence of bud-failure in one of the new Iranian almond varieties. (Tree in background).

The frequency of almond crop loss appeared to be common enough in this region, such that several of the researchers I spoke with felt that the local farmers would probably abandon the orchards with one or two more crop failures and seek their fortunes in the already overburdened urban areas.