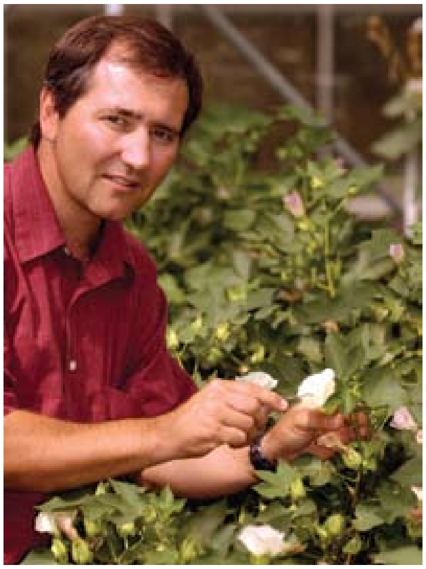
100 years of breeding

UC DAVIS Plant Breeding Program

UCDAVIS

A note from the editor



Summarizing 100 years of history in plant breeding at UC Davis is a formidable task. As a land-grant university, UC Davis has played a major role in developing and managing many of the more than 350 plant commodities now grown in California. The diversity of crops ranges across vegetables, fruits, nuts, grains, forages, ornamentals and turf. In the early 1900s the focus was on a few grain crops, and has expanded considerably since that time.

The application of plant breeding and training of breeders at UC Davis focused on the unique and diverse California environment, allowing not only California, but the United States and in many cases the world, to enjoy fresh produce throughout the year. This publication captures the impact that UC Davis has had on developing crops through plant breeding over the last century and just as importantly, highlights the people who have made this possible.

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In support of plant breeding

Plant breeding at the University of California, Davis, has been a priority since the beginning days of the campus. It was recognized early on that a program in production agriculture, which included plant breeding, was necessary for California farmers to thrive. In 1906, the University Farm — now the UC Davis campus — was established as part of the UC Berkeley campus.

By then, plant breeding was already well underway. In 1870, a selection was made for the almond variety Nonpareil that would remain the primary female almond variety for the next 100 years. Wheat improvement programs began at UC Davis in 1904, with selections from Spanish introductions. Both of these programs remain internationally recognized today. Our researchers are now using breeding techniques that were not even imaginable 100 years ago.

Key breeding developments have come from UC Davis that

> UC Davis researchers remain committed to plant breeding and working with the agricultural and food industries to enhance the economic vitality of agriculture.

have changed and improved many agricultural crops. Male-sterile lines were discovered in carrot and onion, thereby establishing their hybrid-seed industries.

The tomato industry was

established and transformed by the wild tomato germplasm collections made by Charlie Rick; these collections are still maintained on campus and used in international breeding programs. The tomato-processing industry in California came about as a result of the joint development of tomatoes that can be mechanically harvested and the tomato harvester — both were landmark research areas at UC Davis in the 1950s.

The basis of much of the plant breeding and plant genetics research in California is rooted at UC Davis. Robert Allard spent four decades (1940s–1970s) developing our understanding of the recombination of genes, quantitative genetics, and gene interactions with the environment.

Clonal selections of grapes were made at UC Davis by Harold Olmo in the 1950s and '60s that resulted in the success of the Chardonnay grape as a California crop — Chardonnay grapes are now grown on nearly 100,000 acres in the U.S. Our strawberry program provided the germplasm for 60 percent of the world's strawberries; more than 80 percent of the strawberries produced in North America are from UC Davis varieties. The alfalfa breeding program recently released varieties with the single-known source of resistance to whiteflies.

As leaders in virus treatment technology, UC Davis maintains clean seed stock of many of the genetic resources for the world, including tomatoes, strawberries, grapes, cherries, peaches, plums, pistachios, almonds, sweet potatoes, and roses.

These are but a sample of the many accomplishments of the thousands of plant breeders and students who have been affiliated with UC Davis. Our campus continues to evolve in training plant breeders with the recent introduction of the Plant Breeding Academy. It is only fitting that its inaugural class graduated on this centennial anniversary.

Researchers at UC Davis remain committed to plant breeding and working with the agricultural and food industries to enhance the economic vitality of agriculture and improve the health and quality of life for Californians and people throughout the world. UC Davis has progressed markedly from its early University Farm days to its current position as a premier international research university — our plant breeding programs reflect our rich heritage and our commitment to food and agriculture in California.

NEAL VAN ALFEN
Dean, College of Agricultural and Environmental Sciences

Oat *Avena sativa* L.

As top breeders, sowing our oats

Oat ranks just behind wheat, barley, and rice in cereal production in California, and is grown primarily for hay, secondarily for grain, and rarely for human consumption. UC Davis has been active in its development since the 1930s.

Oat production in California initially was derived from introduced landraces, such as **California Red**, **Coastblack**, **Fulghum**, and **Kanota.** UC Davis released a mass-selection purified stock source of California Red in 1937 which became the primary source of all subsequent production of that variety in California.

Early oat breeding at Davis consisted primarily of screening lines for adaptation as well as pest and pathogen resistances and releasing promising lines. For example, **Westdale** was released in 1942 by the Agricultural Experiment Station (AES) at Davis after screening showed it had resistance to a stem rust which was impacting Central Coast oat production. Another example is **Palestine**, distributed in the late 1940s by the AES for its drought resistance.

Cal Qualset and UC oat varieties.

Coit Suneson, a USDA breeder located at UC Davis, bred several oat varieties — **Indio** in the 1950s, selected from crosses that included Fulghum and Palestine in their parentage, and **Curt** (1958), the first short-statured cereal crop released in the U.S. He also exploited hybrids of cultivated oat varieties with wild oat, and released **Sierra** (1961), **Rapida** (1966), and **Montezuma** (1968).

DECADE	VARIETY	BREEDER
2000s	UC 113, UC 125, UC 128, UC 129, UC 130, UC 132, UC 142, and UC 148	Qualset
1990s	Pert, Bates 89	Qualset
1960s	Rapida, Sierra, Montezuma	Suneson
1950s	Indio, Curt	Suneson
1940s	Ventura, Palestine, Westdale	Suneson
1920s	Kanota, Fulghum	introductions
1910s	California Red, Coastblack	landraces

Calvin Qualset has led oat breeding at UC Davis since 1968, focusing on expanding genetic diversity; breeding and distributing oat varieties with disease resistance, good agronomic traits, and high grain and forage yield; and building a system of seed multiplication and distribution to ensure new varieties are widely available to California growers. In 1994, Qualset released **Pert** and **Bates-89**. By 1997, Pert had become the major variety planted in the state.

Other varieties from this program have recently been released: **UC 113**, **UC 125**, **UC 128**, **UC 129**, **UC130**, **UC 132**, **UC 142**, and **UC 148.**

Early researchers: W.W. Mackie, G.W. Hendry. *Breeders:* G.A. Wiebe, USDA (1920s–1934), C.A. Suneson, USDA-Dept. of Agronomy/Agronomy and Range Science (1936–1968), C.O. Qualset, Dept. of Agronomy and Range Science/Plant Sciences (1968–present).

OTHER TRITICEAE

Varieties put to good use

The grass-family tribe Triticeae consists of the cereal crop species of wheat, barley, rye, triticale, and many wild species often used as gene sources for crop improvement. UC Davis breeders have focused on rye and triticale and interspecific hybrids between crops and wild Triticeae species.

Triticale is a relatively new crop, produced by hybridizing wheat and rye and chemically doubling the chromosome number of the hybrid. Triticale has a place as feed and for human consumption as flour and in whisky. Research at UC Davis has centered on reducing height and lodging tendency and increasing fertility and grain quality. Calvin Qualset, a UC Davis professor of agronomy and breeder, released three spring triticales: the dwarf variety **UC-38** in 1973, **Siskiyou** in 1978, and **Juan** in 1984.

Rye (*Secale cereale* L.) is an outcrossing species, unlike the other Triticeae crops which are self-pollinating, and is a very minor crop in California. **Merced**, named and released in 1947, is a population derived from a landrace. It has been used widely as a forage grass and recently as a cover crop. **UC-90** was a dwarf winter rye released by Qualset in 1973, used primarily as a parent in triticale production with the goal of short-statured triticale lines.

Donald Kirby in the triticale and wheat plots at the Tule Lake field station.

Coit Suneson, USDA-UC Davis, worked from the 1940s into the 1960s to develop a perennial wheat. He created a bulk population of progeny from crosses between five different wheat varieties, which are annual, and two species of wheatgrass, which are perennial. The population was sometimes supplemented by additional crosses, with the mechanical removal of plants expressing undesired, primitive traits such as fragile stems or distorted seeds. The goal was a seed crop that did not need annual replanting. Commercial success was never achieved, but it was released as a bulk population (**CAS 10180**) and has found some use for feeding game birds during winters.

Breeders: C.A. Suneson, USDA-ARS/Dept. of Agronomy (1936–1965), C.O. Qualset, Dept. of Agronomy and Range Science (1967–1994).

Other Triticeae cereals

DECADE	VARIETY	BREEDER
1980s	Juan (triticale)	Qualset
1970s	UC-90 (dwarf rye population), UC-38 (dwarf triticale), Siskiyou (triticale)	Qualset
1960s	CAS 10180 (perennial wheat population)	Suneson
1940s	Merced (rye population)	landrace

Stakeholders tour a rice field at the California Rice Field Day held each year in August at the Rice Experiment Station in Biggs, Calif.

Rice *Oryza sativus* L.

Cooperation makes for nice rice

The rice industry in California distinguishes itself from the rest of the United States by growing short-, medium-, and specialty-grain rice destined for local and Japonica-type rice markets. The success of the California rice industry is based on the close collaboration of the industry breeding program at the Rice Experiment Station (RES) in Biggs, a USDA rice genetics program at UC Davis, and the UC Cooperative Extension (UCCE) rice variety evaluation program.

An important objective is to address the breadth of industry research needs, including support of UC and USDA research, by providing land, resources, and management for genetic, agronomic, weed, insect, disease, and other disciplinary research. The California Rice Research Board (RRB) funds the program through a grower-voted check-off system based on production.

UC Davis contributes

Before any new rice variety is released, it must be evaluated under real-world growing conditions over several years to ensure stability of traits relative to current reference varieties. At least sixteen preliminary and advanced breeding-line trials are conducted annually by UCCE across the California rice-growing region.

Foundation seed of California public rice varieties is produced in a cooperative program between the California Cooperative Rice Research Foundation (CCRRF), and Foundation Seed at UC Davis to ensure the availability of pure, weed-free, high-quality seed.

A large interdisciplinary team of scientists from UC Davis and the UC Cooperative Extension county programs continually evaluates new integrated strategies for sustainable rice production. These include research on integrated pest management to control filamentous algae, armyworm, rice water weevil, and tadpole shrimp in rice fields.

On-farm experiments show how nitrogen management needs to be modified as weed control and water management practices take on new directions. Rice variety improvement combines techniques in molecular biology with knowledge of conventional plant breeding methods to tap new sources of disease resistance.

Research is being conducted to optimize management and harvest conditions to maximize rice yield and quality, including investigation of milling methods. For example, recent studies show that moisture content of rice and milling at controlled temperatures affect milling yield.

The results of this work are shared with growers through annual rice field days, UCCE county grower meetings, websites, and information bulletins. Importantly, the research conducted at UC Davis in cooperation with the breeding program has trained dozens of students who will continue to advance the California rice industry.

Approximately one-fourth of the global rice crop is grown in rain-fed, lowland plots that are prone to unpredictable seasonal flooding resulting in annual yield losses estimated at more than $1 billion.

A research team lead by Pamela Ronald has identified a gene that confers submergence tolerance to rice while maintaining high yields. Development of submergence-tolerant varieties for commercial production in Laos, Bangladesh, and India is now underway. It is expected to increase food security for 70 million of the world's poorest people, and may reduce yield losses from weeds in areas like the United States where rice is seeded in flooded fields.

Breeders: Howard Carnahan, Kent McKenzie, Virgilio Andaya, Farman Jodari, Carl Johnson, Jacob Lage, and S.T. Tseng.
Breeding Support: Neil Rutger, David Mackill, Jim Hill, Thomas Tai, Albert Fischer, Jeffrey Oster, Jack Williams, Carl Wick, Steve Scardaci, Chris Greer, and Luis Espino.

The breeding program

From 1918 to 1970, California grew primarily only three tall-, short- and medium-grain varieties — Caloro, Colusa, and Calrose — with average yields of about 5,500 pounds per acre. An accelerated breeding program was initiated in 1969 and funded by growers through a marketing order by the California Rice Research Board. By 1972, more than 95 percent of California's rice acreage was planted to improved semi-dwarf rice varieties.

Since 2000, California rice yields have averaged 7,900 pounds per acre. The 42 rice varieties released since 1969 include very early- to late-maturing short-, medium-, and long-grain types (all major U.S. market classes), and specialty types such as waxy (sweet), premium medium and short grains, aromatic, basmati, and low-amylose rice.

Recent advances include development of Calrose medium grains resistant to one of the most important diseases in rice, Blast. Calamylow-201 is a newly released premium-quality short grain that has been introduced for use in chilled or frozen rice products popular in Japan.

In 1969, every effort was made to develop rice varieties in the shortest possible time. Initial crosses were made in the greenhouse, often during the winter months. Goals were short stature, lodging resistance, earliness, and grain quality. Research on insects and diseases was already being coordinated with UC Davis. Howard Carnahan joined the California Cooperative Rice Research Foundation in November 1969 as director of plant breeding.

Today, Kent McKenzie is the station director who directs four plant breeders, a pathologist, and support staff. The plant breeding program at the Rice Experiment Station is designed to develop rice varieties of all grain types and market classes with high and stable grain yields and quality that will sustain the profitability of rice with minimum adverse environmental impact. It focuses on agronomic traits, disease and pest resistance, yield, and kernel quality.

Wheat (bread) *Triticum aestivum* L. **Wheat (durum)** *Triticum durum* L.

Wheat that's worth its weight

Over the past 100 years, UC Davis has played a central role in developing varieties of both bread wheat and durum wheat, meeting the challenges of California markets and environments. As important as the varieties released from UC Davis have been to California's wheat production, equally vital have been the research, development, and verification of breeding practices: backcross breeding, bulk-pedigree breeding, and, most recently, marker-assisted selection, a highly efficient means to genetic gain.

Just 10 years after the Gold Rush, California became prominent in the United States for wheat production. By 1890, California ranked second in the nation for wheat production. In cooperation with the USDA, experiments to improve wheat varieties and cultural practices began at the University of California in 1904.

Prior to that, yield had been about 0.1 tons per acre and the varieties grown were landraces descended from Spanish introductions and others introduced in the early years after statehood. Initial yield increases were due primarily to improved cultural practices and introduced varieties, but by 1940, improved varieties accounted for most of the higher yield — then about 25 percent greater than at the turn of the century. Improvement objectives included enhanced disease and insect resistance. Today, yield can average 2.5 to 3.5 tons per acre.

Prevalent breeding practices have changed over time. Prior to 1922, the emphasis was on bringing in varieties from elsewhere and testing them under California conditions.


Jorge Dubcovsky selects wheat lines.

By 1890, California ranked second in the nation for wheat production.

There was some hybridization and selection from both the progeny of these crosses and from landraces. In 1922, the first backcrosses, driven by the goal of transferring specific new characteristics to established varieties, were undertaken. During this period, crossing between varieties with selection of new types from the progeny (pedigree method) was also practiced. However, by the end of the decade and for the next few decades, backcrossing became the primary breeding practice.

Beginning in the 1960s, in parallel and often in cooperation with the international wheat improvement program based in Mexico (CIMMYT), the bulk-pedigree method became the predominant breeding practice at UC Davis. All of the UC Davis bread-wheat varieties released from the 1960s through the 1990s had CIMMYT parentage.

In addition, in response to the stripe rust outbreak in California in 1960–1961, resistant CIMMYT varieties were screened for adaptability to California growing regions and released. The first durum wheat released in California (**Modoc**, in 1975) was also the first public short-statured durum wheat bred in the United States.

In the late 1990s to date, there has been a resurgence in the use of backcrossing, driven primarily by the availability of molecular markers for specific traits (i.e., marker-assisted

selection or MAS). Marker-assisted selection speeds up the breeding process because researchers can identify desirable traits with markers which are either the genes themselves or DNA which is very closely linked.

Since 2000, UC Davis has provided leadership of a national consortium to implement forward-breeding MAS strategies in public wheat-breeding programs. UC Davis cloned the first important agronomic genes regulating wheat flowering time and grain protein content. **Patwin**, a hard white spring wheat released from UC Davis in 2006, was one of the first wheat varieties in the United States to be produced by MAS. **Lassik**, a hard red spring wheat, followed and included the pyramiding of six favorable genes by MAS.

Early researchers: G.W. Hendry, W.W. Mackie, B.A. Madson, and V.H. Florell, USDA. *Breeders:* G.A. Wiebe, USDA (1920s–1934); C.A. Suneson, USDA-ARS/Dept. of Agronomy (1936–1965); F.N. Briggs, Dept. of Agronomy (1930–1952); C.W. Schaller, Dept. of Agronomy (1946–1961); J.C. Williams, Dept. of Agronomy (1961–1965); C.O. Qualset, Dept. of Agronomy and Range Science (1967–1994); and Jorge Dubcovsky, Dept. of Agronomy and Range Science/Plant Sciences (1995 to present).

Bread wheat

DECADE	VARIETY	BREEDER
2000s	Clear White (HWS), Lassik (HRS), Patwin (HRS)	Dubcovsky
1990s	Kern (HRS)	Qualset, Dubcovsky
1980s	Serra (HRS), Yolo (HRS), Tadinia (HRS), Phoenix (HWW)	Qualset
1970s	Anza (HRS), Portola (HRS), Tanori 71 (HRS), Yecora Rojo (HRS), Shasta (HRS)	Qualset
1960s	Lerma Rojo (SRS), Nainari 60 (HRS), Yaqui 50 (HRS), Chapingo 53 (HRS), Yaqui 54 (HRS), Lerma Rojo 64 (SRS), Pitic 62 (HRS), Sonora 64 (HRS), Siete Cerros 66 (HWS), INIA 66 (HRS), INIA 66R (HRS), Big Club 60 (SWS)	Schaller, Williams, Qualset Suneson
1950s	Poso 48 (SWS), Ramona 50 (HWS), Red Baart 52 (HRS), Onas 53 (SWS), Baart 54 (HWS), White Federation 54 (SWS), White Federation 57 (SWS)	Briggs, Schaller, Suneson
1940s	Big Club 40 (SWS), Poso 41 (SWS), Ramona 41 (HWS), Bunyip 41 (SWS), Awnless Baart (HWS), Escondido 41 (SWS), Onas 41 (SWS), Federation 41 (SWS), Awned Onas (SWS), Poso 42 (SWS), Big Club 43 (SWS), Poso 44 (SWS), Ramona 44 (HWS), Baart 46 (HWS)	Briggs, Schaller, Suneson
1930s	Poso (SWS), Ramona (HWS), Baart 35 (HWS), Big Club 37 (SWS), Pacific Bluestem 37 (HWS), Sonora 37 (SWS), White Federation 38 (SWS), Baart 38 (HWS)	Briggs, Suneson
1920s	Onas (SWS), Escondido (SWS)	Wiebe, Hendry
1910s	Baart (HWS), White Federation (SWS), Federation (SWS), Bunyip (SWS)	Wiebe, Florell

HWS=hard white spring, HRS=hard red spring, HWW=hard white winter, SRS=soft red spring, SWS=soft white spring.

Durum wheat

YEAR	VARIETY	BREEDER
2005	Desert King	Dubcovsky
1985	Altar 84	Qualset
1975	Modoc	Qualset

Barley *Hordeum vulgare* L.

High-yield crops, free of disease

DECADE	VARIETY	BREEDER
2000s	UC 933, UC 937, UC 960, Ishi, Tamalpais	Gallagher
1990s	UC 969	Puri, Gallagher
1980s	UC 337, UC 476, UC 603, UC 828	Schaller, Puri
1970s	Sutter, UC 566, CM 72, Atlas 74, Prato, UC Signal, Wocus 71	Schaller, Worker, Puri
1960s	UCD 27, UCD 1520, Harland, Grande, Briggs, Numar, CM 67, Atlas 57, Atlas 68, Blanco Mariout, Firlbecks III	Schaller, Suneson
1950s	Atlas 54	Briggs, Schaller, Suneson
1940s	Atlas 46, Rojo, Arivat	Briggs, Schaller, Suneson
1920s	Atlas, Vaughn, Hero, Sacramento	Wiebe, Hendry, Florell, Mackie
1910s	California Mariout, Winter Tennessee, California 4000	Madson, Hendry, Florell

Barley has been an important crop in California since the Spanish Mission period, more than 200 years ago. UC Davis had a significant role in improving barley yield and disease resistance beginning about 100 years ago. Barley yields in California were typically about 0.6 tons per acre in the early 1900s, but current yields can be as high as 3.5 tons per acre.

The earliest plantings were from landraces introduced by the Spanish for both malting barley and feed grain. Initial improvement came from selections with increased uniformity, special adaptations (such as disease resistance), and slightly higher yields from the earlier landraces and introductions. In the 1920s, researchers at the university began backcrossing — repeatedly crossing a hybrid with one of its parents — and for the next several decades, this constituted the primary practice for barley improvement. By 1940, average yield had increased about 25 percent.

During this period, crossing between breeding lines with selection of new types from the progeny (pedigree method) also began. A bulk-pedigree method is now used and the most common cross after the single cross is the three-way cross using the best parent crossed back to the progeny of a cross.

The main objective for barley improvement has been to develop disease-free, high-grain-yielding

feed barleys. By the mid-1980s, about 80 percent of the barley grown in California consisted of varieties that had been developed since 1946 in the UC Davis breeding program of Charles Schaller.

As pathogens keep evolving, the development of disease-resistant varieties has been a continuing challenge for breeders. For example, in the late 1990s, a race of stripe rust caused statewide losses in barley production. As in the past, genetic resistance was bred into new varieties by university breeders.

Varieties for particular niche markets are also now being pursued by Lynn Gallagher's barley breeding program. Targets include hooded forage barley, short-growing-cycle varieties for low-moisture environments, naked or hull-less varieties for human consumption, and malting varieties.

Early researchers: G.W. Hendry; W.W. Mackie; B.A. Madson; V.H. Florell, USDA. *Breeders:* G.A. Wiebe, USDA, 1920s–1934; C.A. Suneson, USDA-ARS/Dept. of Agronomy, 1936–1965; F.N. Briggs, Dept. of Agronomy, 1930–1952; G.F. Worker, Jr., Imperial Valley Field Station, 1940s–1980s; C.W. Schaller, Dept. of Agronomy/Agronomy and Range Science, 1946–1985, Y.P. Puri, Tulelake Field Station/Dept. of Agronomy and Range Science, 1962–1992; L.W. Gallagher, Dept. of Agronomy and Range Science/Plant Sciences, 1993 to present.

Cotton *Gossypium hirsutum* L. and *G. barbadense* L.

A crop with high-fiber quality

The U.S. Department of Agriculture (USDA), University of California, and private parties began joint experimentation with cotton in the San Joaquin Valley and nearby Southern California districts starting as early as the 1870s, but more widespread efforts began around 1910, with field tests of **Upland** and **Acala** types in Kern County, Los Angeles County, Imperial County, and at the Kearney Vineyard Station in Fresno County.

Field trials also included multiple Sacramento Valley sites from 1910 to about 1920. In 1922, the U.S. Cotton Research Station was established in Shafter by the USDA This station, now called the Shafter Research and Extension Center, is currently owned and managed by the University of California.

Over the years, UC scientists, both campus- and county-based, have been instrumental in identifying agronomic practices important to cotton yield and quality, best management practices, insect and weed management practices, and pathology work useful to breeders and agronomists in making selections suitable for field situations and market needs. Their work with irrigation and fertility helped establish crop management principles still used today. Work on mechanical pickers in the 1940s, in cooperation with the USDA, helped the industry move toward commercialization and more widespread adoption of mechanical pickers.

Cotton Cooperative Extension specialist Robert Hutmacher

UC research improved the understanding of dominant pests and beneficial insects, and provided guidelines for economic management practices important to sustainable cotton production. Cooperative Extension specialists were instrumental in extensive field evaluations in the 1980s to establish that large-scale **Pima** production — over 50 percent of the California crop today — could be successful in the San Joaquin Valley, opening the way to new opportunities with a different cotton species.

Since the 1940s, the UC Cooperative Extension specialist assigned to cotton has been located at the Shafter station to better coordinate efforts among the USDA, university, and industry. The variety testing program for approved Acala and Pima varieties jointly run by the University of California and the San Joaquin Valley Cotton Board has also been coordinated at the Shafter Research and Extension Center for many decades.

In recent years, multiple UC Davis researchers specializing in aspects of molecular biology have continued work to advance cotton genetics through efforts including identification of DNA markers potentially useful in breeding and development of information to better define control of diverse factors such as disease resistance and fiber quality.

A few cotton researchers through the years

DECADE	RESEARCHERS
1870–1910	Hilgard, Coit, and Packard
1920s	Beckett and Dunshee
1930s–1940s	Veihmeyer, Adams, and Brown
1940s–1950s	Fairbanks, Hoover, Smith, Bassett, Leigh, Stern, and Van den Bosch
1950s–present	George, Stromberg, Johnson, McCutcheon, Black, Kerby, Hake, Vargas, Weir, Goodell, Godfrey, Zelinski, Roberts, Munk, Wright, Keeley, Travis, Rains, Jernstedt, Ball, Van Deynze, Wilkins, and Hutmacher

Alfalfa *Medicago sativa* L.

Higher yield, pest resistance

Alfalfa was introduced to California by Mexican missionaries about the time of the Gold Rush. Early introductions have been traced to two different types known as Chilean and Peruvian that were brought to South America by Spanish explorers during the 16th century. These types were adopted by farmers and were widely grown throughout the southwestern United States for nearly 100 years.

During this time, seed of these genetically unimproved types was produced and shared among growers within regions. Ernest H. Stanford initiated the University of California alfalfa breeding program following World War II. The first variety released was **California Common 49** and possessed resistance to alfalfa dwarf (Pierce's disease).

Caliverde was released in 1951, adding resistance to bacterial wilt, common leaf spot, pseudopeziza leaf spot, and downy mildew, and demonstrating the use of backcross breeding in cross-pollinated species. That same year, Stanford published a seminal paper confirming autotetraploid inheritance in alfalfa, with four copies of each chromosome instead of the two that are found in diploids.

Caliverde was subsequently improved by adding resistance to spotted alfalfa aphid, stem nematode, and foliar diseases. This resulted in the release of **Caliverde 65** as one of the first multiple pest-resistant varieties.

William F. Lehman joined the program in 1958. He focused on improving non-dormant varieties adapted to production in the irrigated southwest desert. Lehman and Stanford released **UC Salton**, **UC Cargo**, **CUF 101**, and **UC Cibola**. CUF 101 was released to address a serious new problem in California alfalfa production — the blue alfalfa aphid.

California produces one-third of the U.S. alfalfa seed.

CUF 101 was first available to growers in the fall of 1977 and it was the most successful alfalfa variety ever released; it is still grown on significant acreage worldwide. It has a broad array of pest resistances and a very wide adaptation to different climatic zones.

In 1977, Larry Teuber joined the breeding program, emphasizing development of insect and disease resistance, breeding methodologies, and breeding for increased seed production. His studies on seedling development and fall dormancy contributed significantly to cultural practices, optimizing planting date to maximize forage yield. **Highline** was released in 1997 with increased pest resistance and hay yields that are 110 percent of CUF 101.

UC-Impalo-WF was released in 2000 in response to another new pest, the *Bemisia* whitefly. This variety was the first alfalfa species to exhibit resistance to this devestatng pest.

The UC Davis alfalfa breeding program has also released over 50 elite breeding lines that have contributed significantly to many varieties released by private plant breeders.

Table: University of California Alfalfa Variety Releases

CULTIVAR	YEAR SEED FIRST AVAILABLE	BREEDER	COOPERATING AGENCIES	FALL DORMANCY	RESISTANCE CHARACTERISTICS	COMMENTS
California Common 49	1949	Stanford	Calif. Ag. Exp. Sta.	7	Alfalfa dwarf	First UC alfalfa cultivar
Caliverde	1951	Stanford, Houston	Calif. Ag. Exp. Sta.	7	Bacterial wilt, pseudopeziza leaf spot resistance, downy mildew	Demonstration of backcross breeding in cross-pollinated species
Moapa	1957	Smith	USDA/ARS, Nev. Ag. Exp. Sta., Ariz. Ag. Exp. Sta., Calif. Ag. Exp. Sta.	8	Spotted alfalfa aphid resistance races Ent-A and B	Introduction of very non-dormant African germplasm
Caliverde 65	1966	Stanford	Calif. Ag. Exp. Sta.	7	Spotted alfalfa aphid, stem nematode, and foliar leaf disease resistance to Caliverde	First multiple pest-resistant cultivar
Moapa 69	1971	Hunt, Peaden, Lehman, Stanford	USDA/ARS, Nev. Ag. Exp. Sta., Calif. Ag. Exp. Sta.	8	Spotted alfalfa aphid resistance races Ent-A, C, E, and F	Introduction of very non-dormant Indian germplasm
UC Salton	1973	Lehman, Stanford, Erwin	Calif. Ag. Exp. Sta.	9	Phytophthora root rot, spotted alfalfa aphid resistance, especially Ent-F	
UC Cargo	1975	Lehman, Stanford, Erwin, Nielson	Calif. Ag. Exp. Sta., USDA/ARS	9	Higher in resistance than UC Salton, and spotted alfalfa aphid resistance, race Ent H	
CUF 101	1977	Lehman, Nielson, Marble, Stanford	Calif. Ag. Exp. Sta., USDA/ARS	9	Blue alfalfa aphid resistance and very non-dormant	First blue-aphid resistant cultivar, and very non-dormant
UC Cibola	1984	Lehman, Ede, Marble, Nielson, Radewald	Calif. Ag. Exp. Sta.	9	Nematode resistance	
Highline	1997	Teuber, Gibbs, Taggard, Phillips, Lehman	Calif. Ag. Exp. Sta.	9	Multiple pest resistance; High yield	First UC cultivar to receive Plant Variety Protection
UC-Impalo-WF	2000	Teuber, Taggard, Gibbs	Calif. Ag. Exp. Sta.	9	Multiple pest resistance; Resistance to *Bemisia* whitefly	First cultivar with *Bemisia* whitefly resistance

Berseem Clover *Trifolium alexandrinum* L.

Known for its water-use efficiency

Berseem clover, or Egyptian clover, is an annual clover that is well adapted to warm regions of California. It was introduced into California in the early 20th century. Breeding by UC Davis scientists began in the 1980s due to the need for nitrogen-fixing cover crops and rotational forage crops.

Bill Williams, a professor of agronomy whose career spanned six decades, tested many berseem clover lines for adaptation and disease and insect resistance. He worked closely with Walter Graves, a UC Cooperative Extension farm advisor, and UC Davis scientists Dan Putnam, Bob Gilbertson, Ivan Buddenhagen, and Larry Teuber.

Some original southern-adapted varieties (like **Bigbee**) were not appropriate for California, so **Multicut** and later **Joe Burton** were released in the late 1980s and 1990s. Multicut provided a significant improvement in yield over Bigbee and other lines, yielding 15 to 25 percent more in trials. Joe Burton berseem was named after the head of research for the Nitragin Company (of Milwaukee, now EMD Biosciences) who isolated the original strain of *Rhizobium* inoculant for berseem that allows it to efficiently fix nitrogen from the air.

Joe Burton berseem has significantly greater virus resistance than Multicut or Bigbee, and both Joe Burton and Multicut are significantly higher yielding than earlier lines. Both Multicut and Joe Burton appear nearly completely resistant to alfalfa weevil than previous varieties.

Working with Cooperative Extension farm advisors Rachael Long and Mick Canevari, the team discovered during the 1990s that berseem clover is an excellent candidate for overseeding into old alfalfa stands and for mixtures with grasses such as oats or ryegrass as an annual forage option, resulting in better yields in winter and higher water-use efficiency.

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Berseem remains a minor crop in California, grown primarily in the desert and Central Valley regions. However, berseem could have increased applications due to the need for water-use efficient forage crops of high forage quality, or as a cover crop in California's complex cropping systems.

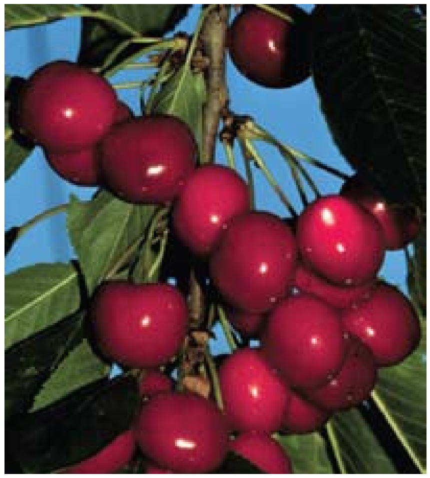
Cherry *Prunus avium* L.

Brooks helped expand production

UC Davis has a history of sweet cherry breeding dating back to 1934. Perhaps the program's greatest success was the release in 1984 of **Brooks**, a large, sweet, firm variety that matures earlier and produces fewer double fruits than **Bing**, the industry standard.

In 1964, UC Davis breeders Reid Brooks and William Griggs released five new varieties — **Mona**, **Jubilee**, **Berryessa**, **Bada**, and **Larian** — the latter of which is still grown today.

Paul Hansche was hired to continue the breeding program in the 1960s, but after several rounds of crosses, the program was discontinued in the early 1970s due to lack of funding. UC Davis researchers continued to evaluate



Hansche's crosses, and one variety — Brooks — showed promise. It was released in 1984 and had a major impact on the future of sweet cherry production in California.

Brooks matures about four days earlier than Bing and produces fewer double fruits when grown in the southern San Joaquin Valley. As a result, commercial cherry production could move to the warmer areas of the valley where earlier fruit could be produced. This has allowed California cherry growers to take advantage of excellent markets for fruit produced earlier than anywhere else in the United States.

Coral Champagne is another UC variety popular with cherry growers. It was never officially released but growers like it because, like Brooks, Coral Champagne cherries are sweet and firm, they mature early, and seldom produce two fruits on one stem.

Melon *Cucumis melo* L.

Breeding for disease resistance

UC Davis, through the efforts of vegetable crops specialist Frank Zink, contributed significantly to the melon industry in California.

As early as the late 1940s, Zink worked on defining the "melon virus complex," which has been updated since then but still plagues the industry.

In the 1960s, Zink turned his efforts toward developing improved melon varieties for the industry. He released varieties of several melons (cantaloupe, honeydew, crenshaw, and honeyloupe) that were industry standards and/or breeding lines that were used by others to develop improved varieties in the 1970s and 1980s.

Among Zink's releases were melon bush breeding lines **UC SR-91**, **UC Top Mark Bush**, **UC Perlita Bush**, **UC Honeydew Bush**, and **UC Crenshaw Bush.** He developed and released **UC Honeyloupe**, an orange-fleshed honeydew melon, a forerunner to the many specialty melons available to the industry and to consumers today.

Disease resistance was always an important component of melon breeding at UC Davis. In the

1980s, Zink and UC Cooperative Extension specialist Doug Gubler released three fusarium-wilt-resistant breeding lines, **UC PMR 45 Fom-e**, **UC Top Mark Fom-1**, and **UC Top Mark Fom-3.**


Redglobe and Chardonnay grapes

Grape *Vitis vinifera* L.

Whether wine or table, we deliver

You can taste the impact of the UC Davis grape breeding program every time you sip a glass of **Chardonnay** or eat a **Redglobe** grape. And that's only the beginning.

Starting with Harold Olmo's first crosses in 1934 and continuing today with Andy Walker at the helm, winegrape and table-grape breeding have had a rich and productive history at UC Davis.

Olmo released more than 30 grape varieties during his 33-year career at UC Davis, including 20 table grapes, nine wine grapes, and two rootstocks. His most widely planted varieties are the table grapes Redglobe**, Ruby Seedless**, and **Perlette**; the winegrape **Ruby Cabernet**; and the juice grape **Rubired**. Olmo developed varieties that would grow and ripen at various times and under different environmental conditions, a development that greatly expanded California's agricultural industry.

Throughout his career, Olmo traveled the world in search of rare or endangered grapevines, returning with cuttings to study and propagate. Wild grapevines that he brought back from Afghanistan in the 1940s were grown in UC Davis vineyards, and cuttings from some have recently been sent back to Afghanistan where they had become extinct.

As he accumulated grape germplasm for his breeding efforts, Olmo noticed the tremendous morphological and enological diversity within winegrape varieties. He was one of the creators of what is now recognized as the most effective means of improving winegrape varieties — clonal selection.

Chardonnay was an uncommon and unproductive variety when Olmo began practicing clonal selection on it (using clones that Louis Martini had collected.) Today, largely because of his clonal selection focused on improving fruit quality and productivity, Chardonnay is the most popular winegrape in the United States, planted on almost 100,000 acres.

Many of Olmo's winegrapes play an important role in California and internationally. His most popular winegrape is Ruby Cabernet, which he designed to increase crop yield and produce more acidic juice, and could be grown in California's warm San Joaquin Valley.

One of his varieties, Rubired, was initially released as a winegrape, but in fact created a new grape product category — red concentrate. Rubired is a red-juiced variety (most grapes have clear juice; the color in wine comes from the skins) that is very productive and is now used to produce a concentrated source of red sugar used in food products from juice to candy.

The two rootstocks Olmo released were selected by his colleagues Lloyd Lider and Austin Goheen because of their resistance to a viral disease called fanleaf degeneration. One of these two rootstocks, **O39-16**, is used in many California vineyards in the Rutherford area of Napa Valley, the Alexander Valley and Healdsburg regions of Sonoma County, across the northern San Joaquin Valley, and beyond.

Grape breeding at UC Davis continues to thrive under the direction of Andrew Walker. His work focuses on rootstocks for soilborne pest resistance and the development of fruiting varieties resistant to Pierce's disease. Funding comes from the California Department of Food and Agriculture Pierce's Disease Board.

The Walker breeding program released its first five rootstocks in 2008 — **GRN1** through **GRN5**. These rootstocks were bred to resist aggressive complexes of nematodes, microscopic root-feeding parasitic worms that can dramatically impede grapevine growth. These efforts are primarily funded by the California Grape Rootstock Improvement Commission.

Breeding efforts continue toward developing rootstocks with better resistance to the disease fanleaf degeneration and tolerance to drought and salinity, increasing problems as water becomes less available due to population pressure, environmental needs, and climate change.

Walker and his team also work to develop winegrapes and table grapes resistant to powdery mildew, a fungal disease responsible for the vast majority of the pesticides used on grapes. As demands increase for organically grown produce, grape growers will likely reduce their fungicide use.

Since it is not possible to grow vinifera winegrapes and table grapes without regular and frequent fungicide applications, breeders are beginning to focus on hybrid types that will grow without fungicides. The adoption of these grapes will require higher quality and greater marketing and promotion, but still, growers will likely soon look to hybrid varieties — and to the resources UC Davis continues to provide.

> Breeding efforts continue toward developing rootstocks with better fanleaf degeneration resistance and tolerance to drought and salinity, increasing problems as water becomes less available due to population pressure and climate change.

DID YOU KNOW?

Cabernet Sauvignon is actually the hybrid offspring of Sauvignon Blanc and Cabernet Franc.

16 fine-winegrape varieties, including Chardonnay, are the direct descendants of the classic Pinot variety and Gouais (goo-WAY) Blanc, a variety considered so mediocre that it is no longer planted in France.

The famous California Zinfandel, imported in the 1850s, was traced back to a vine named Crijenak Kastelanski found on a small island off the coast of Croatia.

UC Davis geneticist Carol Meredith used DNA fingerprinting and historical records to trace the origin of these California favorites.

Fig *Ficus carica* L.

Starring role in emerging market

Among tree fruit crops, figs are distinguished by having the largest number and widest range of naturally occurring varieties. It is therefore no surprise that figs have a long history of breeding.

A sustained fig improvement program was maintained by the University of California, Riverside, from 1928–1980s by Ira Condit and William Storey. Their objective was a drying fig with **Calimyrna** quality without the need for caprification (artificial pollination with wild fig), and with a small ostiole, or opening. Caprification and a large ostiole are major factors in insect infestation and fungal-disease development in figs.

At UC Davis, James Doyle maintained the germplasm and crosses made by Condit and Storey until the fig breeding program was revived in 1989. Since then, Doyle and Louise Ferguson made crosses and produced the open-release **Sierra** and patented **Sequoia** common fig cultivars.

Sierra is suitable for dry fig production and both are good fresh figs. They have yellow-green skin and reddish-amber pulp. This skin color is competitive with the yellow-green Calimyrna and **Kadota**, and complements the violet-black California **Brown Turkey** and **Mission** figs. Sierra and Sequoia produce a large second crop with large- to medium-size fruit and maintain fruit size well into the fall, in contrast to the small late-season fruit size of Mission and Kadota figs and the absence of fruit on Calimyrna.

The ostiole of Sierra and Sequoia figs is very tight, reducing potential insect infestation and the fungal diseases that are transmitted by insects. The fruit flavor and quality of both are as good or better than all four of the previously established varieties listed here with the exception of Calimyrna.

The increase in plantings and fresh-market sales of these new varieties demonstrates that both these figs will play a major role in the fresh fig industry which continues to grow in California.

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Rootstocks for stone fruit

Controlling size, vigor

For more than 75 years, UC Davis has been involved in testing and identifying superior rootstocks for stone fruits. Early research focused on selecting seedlings of various species for graft/rootstock compatibility and tree vigor, along with resistance and tolerance to the insect pests, diseases, and soil conditions specific to California.

In the 1930s, Leonard Day was instrumental in identifying **Myrobalan 29C** and **Marianna 2624** plum rootstocks as being particularly suitable for plum and prune culture. He also noted the compatibility of Marianna 2624 with apricots and selected almond cultivars.

An extension of the initial work with Marianna rootstocks resulted in the 1998 release of **M40** rootstock by Claron Hesse, Robert Fenton, and James Doyle. This Marianna rootstock has performance characteristics similar to Marianna 2624 but is much less prone to developing adventitious stems from root suckers.

Other work by Carl Hansen, Dale Kester, and Tom Gradziel identified several selections of peach-almond hybrid rootstocks as imparting high vigor and yields to almond trees, and the **Hansen** and **Nickels** rootstocks were released for almonds.

More recent research on rootstocks for stone fruits has focused on decreasing tree vigor and size of peach and nectarine trees in an attempt to reduce labor costs associated with ladder-work, such as pruning, fruit thinning, and harvesting.

Recently a collaborative effort between USDA-ARS and UC Davis researchers (David Ramming, Ted DeJong, James Doyle, and Scott Johnson) resulted in the release of two new size-controlling rootstocks for peach and nectarine (**Controller 5** and **Controller 9**).


UC Controller 5 reduces tree size to aid in pruning and picking.

Several promising new selections from research more recently initiated by Fred Bliss (formerly with UC Davis) and Ali Almehdi are currently being tested.

Stakeholders evaluate the quality of a new peach variety and share their feedback with Tom Gradziel (center).

Processing Peach *Prunus persica* L.

Dependent on public breeders

About half of the 2 billion pounds of peaches produced annually in the U.S. are processing peaches grown almost entirely in California's Central Valley. The lower price paid for processing peaches requires a consistently higher production of marketable fruit for a variety to be commercially viable. Growers are understandably reluctant to aggressively plant new, largely unproven varieties.

Consequently, unlike with the relatively high-priced fresh-market peaches where new varieties meet changing consumer preferences, processing-peach breeding has not been profitable in the private sector. It has therefore fallen on public breeders to develop varieties for this important and predominantly family-farm industry.

From its beginning in the early 1900s, the processing-peach industry in California has depended on varieties developed by public programs and on grower selections of seedling trees often derived from public varieties. **Carson**, **Carolyn**, and **Corona**, developed in the 1930s and 1940s by W.F. Wight of the USDA in collaboration with G.L. Philps of what was then the UC Berkeley research farm at Davis, remain heavily planted today and have been used as parents in many recent varieties. Initial selection was for local adaptation, uniform fruit size, shape, and golden-yellow flesh color, as well as a continuous sequence of ripening periods to supply canneries throughout the summer.

Breeding of **Clingstone** peach varieties continued in the 1950s under L.D. Davis, whose program was notable for its incorporation of germplasm to improve fruit flavor and canning quality, as well as its thoroughness and continued emphasis on high productivity. Three of his varieties, **Klampt**, **Tufts**, and **Andross**, were not released until after his retirement in 1964. All three remain commercially planted today.

Evaluation of Davis' breeding selections continued under Clarion Hesse (1970–1979), Andrew Kuniyuki (1979–1984), and Jim Beutel (1979–1987), resulting in the release in the mid-1980s of **Ross**, **Dr. Davis**, **Dee-Six**, and **Riegels**. Ross and Dr. Davis have become the industry standards for productivity and quality and remain the most heavily planted processing-peach varieties in California.

The importance of Ross to the industry was further enhanced with the release by Bill Tsuji, Ted DeJong, and Jim Doyle in 1990 of **Late Ross**, a late-maturing bud sport (a bud or shoot having a natural mutation) of Ross which extended its harvest season by one to two weeks.

In 1988, the program was continued and expanded under Tom Gradziel with funding from the California Clingstone Peach Marketing Board, California processors, and the UC Agricultural Experiment Station. Immediate objectives were to replace the historically important and extensively planted **Dixon**, **Andross**, **Halford**, and **Starn** varieties because of their deteriorating processing quality along with rapid development of varieties with improved pest resistance, ability to be mechanically harvested, and ease of orchard maintenance (to counter the dramatic losses in labor during this period).

In 1992, **Hesse** was released as a high case yield and high phytonutrient (pro-vitamin A) replacement for Starn. **Rizzi** was also released as a high case yield, mid-

season variety which could be held in cold storage up to eight weeks and still maintain good canning quality (to buffer the increasingly erratic raw product supplies to the canneries during this period).

The California Clingstone Peach Marketing Board also supports a permanent endowment for the UC Davis peach breeding program.

Goodwin (2001) combines improved case yields — in particular, freedom from red pit staining and associated pit fragmentation — with improved disease resistance. **Lilleland** (2002) combines high fruit quality with freedom from red pit staining and associated pit fragmentation.

Sources of resistance to flower blight, fruit rot, leaf curl, mildew, and green peach aphid have been identified in closely related *Prunus* species, including wild peach species, wild almond species, and cultivated almond. Progress towards mechanically harvestable varieties includes the identification in wild and domestic germplasm of sources of improved harvest and postharvest fruit integrity, single pass harvestability, and modified tree structure, size, and bearing habit. Modified tree structure and size is also being pursued by DeJong through various size-controlling rootstocks. Molecular markers for these traits are being pursued in collaboration with Carlos Crisosto.

Molecular-based research has transformed breeding program funding, with about half of current funds coming from competitive grants and the remainder from the Clingstone Peach Marketing Board, processors, and UC Agricultural Experiment Station funds. The California Clingstone Peach Marketing Board also supports a permanent endowment for the UC Davis peach breeding program.

Integration of advanced field- and lab-based technologies into applied variety breeding has made UC Davis an international center for peach genetic research with collaborations among scientists in the U.S., Europe, Canada, and Central and South America.

Strawberry *Fragaria × ananassa* Duch.

The bulk of the world's supply

Improvement in the production efficiency and product quality of any agricultural commodity results from the development of superior production environments and the breeding of varieties specifically adapted to these superior environments. Mainly due to such developments at the University of California, lead initially by Harold Thomas and Earl Goldsmith, later by Royce Bringhurst and Victor Voth, and for the last 22 years by Doug Shaw and Kirk Larson, California has become the dominant producer of both fresh and processed strawberry fruit in the world, providing varieties for greater than 87 percent of the strawberries consumed in North America. Varieties developed by this program produce approximately 60 percent of the strawberry fruit worldwide.

The Process

Improved strawberry varieties result from recurrent breeding, testing, and selection. Each cycle starts with 100–150 controlled crosses among selected parents for each production location, chosen based on a variety of production and horticultural traits. Initial evaluations are performed on the basis of seedling performance, with primary populations of 8,000–12,000 seedlings established at both UC South Coast and UC Davis field stations.

Approximately 300 genotypes (breeding lines) are retained from each primary seedling population, with subsequent evaluation of these selections based on plots of runner plants tested with planting treatments that simulate commercial conditions. Selections that are retained after initial screening are then tested using relevant cultural manipulations, and information is obtained about the cultural conditions that will optimize performance for each advanced selection. At present, all advanced selections are tested for a large number of pest tolerances.

Specific Objectives

The University of California program has released 56 strawberry varieties since its beginning in the 1930s. The standards required for success in a California strawberry variety have changed substantially during the past 75 years, due in part from the past success of the breeding program (Table 1).

Target traits for new varieties include improved production attributes (yield, production pattern, fruit size, and ease of harvest), superior quality for both fresh and processing markets (fruit appearance, color, shipping quality, shelf life, and flavor), and resistance or tolerance to important insects and pathogens. New varieties must meet minimum standards for all of the above traits and meet the specific needs of the California industry and similar environments worldwide.

Doug Shaw describes breeding trials at the Watsonville, Calif., research farm.

The University of California program has released 56 strawberry varieties since the 1930s.

The Future

At present, the rate of progress for all measurable traits is approximately double historical averages. Through careful management of genetic resources and proper application of genetic principles, the likelihood of continued progress for this program has been preserved.

Table 1. Improvement of strawberries in the UC breeding program

CULTIVAR RELEASE DATE	PLANT DIAMETER (CM)	FRUIT YIELD (G/PLANT)	APPEARANCE SCORE (1-5, 5=BEST)	FRUIT SIZE (G/FRUIT)	FRUIT FIRMNESS (N)
1945–1966	18.40±0.63	595±42	2.29±0.06	14.9±0.4	2.45±0.12
1993–2004	22.86±0.49	1,429±61	3.38±0.08	24.8±0.7	4.56±0.12

Prune and Plum *Prunus domestica* L.

Producing larger, tastier treats

A prune is simply a dried plum. UC Davis has released three promising prune varieties since its prune breeding program got underway in 1985.

In 1985, the California prune industry asked UC researchers Ted DeJong and James Doyle to start a traditional prune breeding program to try to develop new varieties that could extend the harvest season for the California prune industry. At that time the industry consisted of about 80,000 acres of a single variety — **Improved French**.

Muir Beauty was released to the dried prune industry in 2004.

A year later, DeJong and Doyle started a program and two varieties have since been released for the dried prune industry — **Sutter** in 2000 and **Muir Beauty** in 2004. Both of these varieties produce fruit that is larger, tastier, and earlier maturing (by 7 to 14 days) than Improved French. Substantial acreage of Sutter has been planted and interest in Muir Beauty is growing.

A third variety derived from this program, **Tulare Giant**, produces a very large fruit and was released specifically for the fresh market. It is currently the most popular fresh-market European plum grown in California.

The project is currently evaluating more than 80 advanced selections that have an interesting array of fruit color, flavor, and quality characteristics. External fruit colors range from yellow and pink to completely blue or purple, and dried flavors have hints of apricot, cherry, and even cognac. Several new varieties are expected to be released in the next few years.

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Doyle retired from the university in 2000, the same year Carolyn DeBuse became involved with the prune breeding program. In 2007, DeBuse took a UC Cooperative Extension county advisor position and is now co-managing the program with DeJong, while Sarah Bradley has taken over day-to-day operations of the program. This program receives substantial support from the California Dried Plum/Prune Board and many growers are routinely involved in evaluating advanced selections.

Foundation Seed Program

Maintaining pure seed supplies

In 1937, the UC Davis Department of Agronomy was home to active breeding programs on wheat and barley. Breeding programs on other crops (common beans, alfalfa, safflower, sunflower, etc.) soon followed. The vast majority of new varieties were developed by scientists working in Agricultural Experiment Stations or the USDA. Responsibility for maintaining and increasing seed of new varieties was associated solely with the breeding program, so the department institutionalized that role. Frank Parsons was hired in 1937 to establish this program.

In 1939, the Federal Seed Act was passed, followed soon thereafter by the California Seed Law — both designed to regulate seed labeling. These important pieces of legislation were critical to the University of California Foundation Seed Program (FSP) and the separate development of the California Crop Improvement Association (CCIA). Both of these programs grew out of the Department of Agronomy and were directed by Parsons for the next 40 years.

The Foundation Seed Program is now an organized service unit at UC Davis. Its mission is to 1) Grow, increase, and maintain seed of cultivars developed by the University of California and other public plant breeders, 2) Maintain genetic purity of these cultivars, and 3) Ensure that certified seed of cultivars in the program's charge is available to the public.

Foundation seed is produced from basic seed stocks (breeder seed) initially supplied by the plant breeder, sufficient to

The Foundation Seed Program warehouse at UC Davis

meet anticipated demand. All production must conform to the standards of the Association of Official Seed Certifying Agencies (AOSCA) and the California Crop Improvement Association.

The seed conditioning and warehousing facility located at UC Davis is a CCIA-approved and certified-organic seed-conditioning facility. It contains a conditioning plant with specialized equipment for sorting seed based on size, shape, density, and color. The facility is specifically designed for handling high-quality, low-volume seed stocks.

Foundation Plant Services

Healthy stock, new varieties

Though its name has changed since its inception in 1958, the mission of the Foundation Plant Services (FPS) center at UC Davis has remained the same — to provide researchers and industry with healthy, true-to-variety planting stock of many horticultural crops. As a result, the California grape and tree industries have benefited by the introduction of better scion and rootstock varieties from around the world.

However, too often as new plant selections were introduced to California, new pests and diseases appeared as well. These pests were often spread unwittingly through careless propagation and viticultural techniques. Because planting virus-free stock is an effective way to control many of these diseases, much of FPS' effort has focused on detection and elimination of virus diseases.

Plant pathologists from UC Davis and USDA-ARS stationed in Davis are international leaders in grape virus-disease detection, identification, and treatment. UC Davis viticulturists and pomologists provide expertise to ensure the FPS grape collection represents the great diversity of horticultural plant materials needed by a vital and ever-changing industry.

In July 1958, two programs — the California Grape Certification Association and the virus-free cherry stock program — were combined into FPS. Its goal was to maintain and distribute virus-tested cherry and grape stock. Over the years, other crops were added. By 1995, FPS crops included grapes, many fruit and nut trees, strawberries, sweet potatoes, and roses, with additional cuttings, seeds, and potted plants added in 2003.

Researcher Josh Chase making a grape meristem tip culture.

By 1995, FPS crops included grapes, many fruit and nut trees, strawberries, sweet potatoes, and roses, with additional cuttings, seeds, and potted plants added in 2003.

FPS now offers laboratory testing services for plant pathogens, DNA tests to determine cultivar identity, and custom services for grape importation and virus therapy.

UC Davis provides two faculty positions to Foundation Plant Services, as well as a prime location on campus for propagation and testing of plant materials. Beyond that, FPS is self-supporting, mostly by nursery growers, and continues to play a key role in distributing new crop varieties and healthy planting stocks throughout the world.

C.M. Rick Tomato Genetics Resource Center

Improving production worldwide

The tomato, a major vegetable crop in California, is an example of the many cultivated plants that suffer from a shortage of genetic variation. Throughout its history of migrations and domestication, the tomato lost a great deal of its original genetic diversity. As a consequence, tomato breeding progressed slowly and yields remained low until 1940 when the first high-level disease resistance was reported. Since then, great strides have been made in tomato improvement, roughly in proportion to the utilization of exotic germplasm (landraces, wild forms of the cultivated species, and other exclusively wild species). In California, yields of processing tomatoes have increased a spectacular five-fold since the 1940s.

Roger Chetelat, director of the Tomato Genetics Resource Center, collects seed of wild tomatoes in the Atacama Desert of Chile.

The C.M. Rick Tomato Genetics Resource Center (TGRC) is a seed repository of mutants, genetic stocks, and related wild species of tomato. The TGRC was founded by the late Charles Rick as a byproduct of his tomato genetics research at UC Davis. The TGRC has grown into a national and international repository of over 3,600 lines developed at UC Davis and beyond.

The wild species of tomato in the repository are the source of resistance of 44 major tomato diseases, at least 20 insect pests, improved fruit traits, tolerances to stresses such as drought and salinity, and other useful traits. Rick made 17 major collecting expeditions to collect tomato populations, many of which have since been extirpated in the wild. The majority of the tomato's mutants and chromosomal stocks are available nowhere else in the world. TGRC accessions are used by investigators for a wide variety of research and breeding on tomato.

Director Roger Chetelat and his team continue to broaden the genetic diversity accessible for tomato improvement, and to study biological processes relevant to biodiversity conservation, domestication, and plant breeding. The TGRC is supported in part by federal grants, the California Tomato Research Institute, UC Davis, and an endowment fund. To learn more, visit http://tgrc.ucdavis.edu.

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Almond *Prunus amygdalus* L.

Pollination discovery started it all

Almonds are one of the most successful crops grown in California today. With annual production over 1.25 billion pounds and a value well over $2 billion, almonds are the nation's largest specialty-crop export and California's top agricultural export. The birthplace of the modern California (and western U.S.) almond industry could be considered Suisun, located between UC Berkeley and Davis. It was there, in the late 1870s, that nurseryman A.T. Hatch selected the variety **Nonpareil**, which, because of its good kernel quality and high productivity, would become the industry standard.

Frequent crop failures were common until the 1920s when the classic work of W.P. Tufts and G.V. Philp at the Agricultural Experiment Station showed almond to be self-incompatible, requiring both pollinator varieties and honey bee pollinators to transfer compatible pollen between otherwise self-sterile varieties. From that time on, most breeding efforts have focused on developing pollinator varieties with good commercial quality to provide pollen for the late, mid-, and in particular, early bloom of the dominant Nonpareil variety.

From 1923 to 1948, almond breeding at UC Davis was a joint venture between Milo Wood of the USDA and Arthur Davey of the Agricultural Experiment Station. Their work resulted in the release of the widely planted, early-flowering pollinators **Jordanollo**, **Harpereil**, and **Davey**, which eventually failed due primarily to their susceptibility to disease and pests, thus demonstrating the need for improved resistance.

Dale Kester took over the UC almond breeding program in 1948. He targeted the development of more locally adapted pollinator varieties including **Solano** and **Padre**, which continue to have wide plantings. Kester also released the specialty-market varieties **Kaperiel** and **Milow**, developed to supply high-quality, small-kernel almonds required by the candy industry for chocolate bars, etc.

The industry faced a serious challenge at that time with the deterioration of the major varieties, particularly Nonpareil, from virus contamination and a poorly understood genetic aging disorder, now known as noninfectious bud-failure (BF). In response, Kester's program helped pioneer the development of clean-stock programs for supplying the nursery industry with virus-free plant propagation material as foundation stock.

Kester then applied this experience in vegetative clone deterioration to the bud-failure problem, perceiving it to be associated with the aging/deterioration of a critical gene function rather that resulting from virus/viroid contamination. His ingenious and now classic solution was to exploit the time-capsule effect of very early developed dormant buds at the base of Nonpareil trees (which could be over one hundred years old), which he showed to be suspended in genetic age to approximately that of the original seedling Nonpareil tree. This work led directly to the rehabilitation and continued commercial viability of the Nonpareil and **Carmel**, which currently make up over 50 percent of the total acreage of almonds in California.

Kester also developed a series of interspecific crosses between almond and related species, including peach, as potential rootstocks and sources of new germplasm. The **Hansen** and **Nickels** hybrid rootstocks, which exploited the hybrid vigor of the interspecies (almond × peach) cross, were bred to promote rapid tree growth in orchard replant situations and almond production on marginal soils.

In the early 1990s, Thomas Gradziel took over the almond breeding program. Using and expanding the interspecies gene pool developed by Kester, the current program continues to focus on developing pollinator varieties with improved resistance to diseases and insect pests with support from the Almond Board of California and the Agricultural Experiment Station. Climate change and the related insect pollinator collapse, however, have imposed the concurrent need to rapidly transform almond from a self-sterile to a self-fruitful crop. The development and early utilization of molecular markers, in collaboration with Abhaya Dandekar, has allowed accelerated breeding progress. The inter-species breeding platform offers rich opportunities for both basic and applied genetic research in the areas of gene mapping, gene discovery, and trait dissection.

Gradziel's team has released two partially self-compatible varieties — **Winters** and **Sweetheart**. Winters provides excellent bloom overlap with the early to mid-Nonpareil bloom. This also provided exceptional yields without the need for its own early-bloom pollinator. Sweetheart combines the self-compatibility and high kernel oil quality genes from peach with local adaptation and insect resistance from almond. The next generation of advanced almond selections that combine self-fruitfulness with a wider array of resistance, and quality and productivity genes from multiple species sources, are currently undergoing regional grower testing.

The continuing integration of advanced field- and lab-based technologies towards the goal of applied cultivar breeding has made the UC Davis program an international center for almond genetic research.

The next generation of advanced almond selections that combine self-fruitfulness with a wider array of resistance, and quality and productivity genes from multiple species sources, are currently undergoing regional grower testing.

A ripe walnut, ready for harvest.

Walnut *Juglans regia* L.

Chandler transforms the industry

When a grower plants a walnut tree, it is most likely a product of the UC Davis walnut breeding program. Virtually all of the walnut varieties sold in California nurseries are UC Davis varieties. One variety — **Chandler** — accounts for 90 percent of all nursery sales of walnut.

California produces 99 percent of the walnuts grown in the United States, and is the second-largest walnut-producing country in the world, behind China.

Chandler was patented in 1979 by Harold Forde, who co-created the walnut-breeding program in 1948. Chandler gave California growers what they needed to succeed — a highly prolific tree that produces leaves mid-season after most of the rains and freezing temperatures have passed, and produces nuts with the light-golden kernels that consumers love.

Forde and his colleague Eugene Serr started the UC Davis walnut breeding program using selected parents and controlled pollinations. The breeding program is still active, now under the direction of Gale McGranahan.

The goal of the Serr/Forde breeding program was to increase the yield of high-quality walnuts. Yield is closely related to the number of female flowers produced. Serr and Forde identified a unique flowering type in which flowering buds were produced not just terminally but along a branch. The first genotype (variety or clone) exhibiting this trait was **Payne**, which became an outstanding parent that conferred the lateral fruiting to many of its progeny.

Serr and Forde released ten varieties in 1968. The varieties **Vina**, **Serr**, and **Chico** stood out. Vina,

Eugene Serr (front left, holding the branch) helped start the walnut breeding program at UC Davis in 1948.

Growers now look to UC Davis to solve Chandler's one major problem: it is too popular. It harvests late in the season, and with the dominance of Chandler, processors are challenged by an end-of-the-season glut.

Virtually all the walnut varieties sold in California nurseries are UC Davis varietes.

which has high yields but average kernel quality, is still planted today. In 1978, just before he retired, Forde patented three new walnut varieties — **Sunland**, **Howard**, and Chandler. These were the control-pollinated grandchildren of Payne. Sunland had a lovely plump nut, but the tree was almost too vigorous and the kernel color was sometimes too dark. Howard is still a cultivar of interest, making up about eight percent of nursery sales. Chandler, however, took over the industry.

Growers now look to UC Davis to solve Chandler's one major problem: it is too popular. It harvests late in the season, and with the dominance of Chandler, processors are challenged by an end-of-the-season glut.

McGranahan has released two cultivars from crosses made by Serr and Forde. These are **Cisco**, a suitable pollinator for Chandler, and **Tulare**, which was released after 20 years of evaluation. Tulare is very precocious in bearing fruit and harvests mid-season, but does not have Chandler's light-colored kernels which have become the industry standard.

UC Davis' latest varieties include **Livermore**, **Sexton**, **Gillet**, and **Forde.** Livermore has a bright-red kernel bred from a darker-purple germplasm introduction. Sexton, Gillet, and Forde are mid-season cultivars that have high yields, jumbo light-colored kernels, and low susceptibility to walnut blight. They also do not have a seed coat shrivel, which can be a problem with Chandler.

"Forde is potentially the new Chandler," says Chuck Leslie, staff research associate with McGranahan's breeding program.

The Walnut Marketing Board has endowed the program, which is working to develop early-harvesting cultivars with all the attributes of Forde and Chandler. Field trials of promising early selections are underway.

Pistachio *Pistacia vera* L.

Protecting a $500 million crop

Machines now assist in harvesting pistachios, the third most important nut crop grown in California.

Pistachio is the third most important nut crop produced in California (behind almonds and walnuts) with more than 112,000 acres in production and another 60,000 acres planted but not yet producing. The California crop is worth more than $500 million annually but suffers from a classic case of genetic vulnerability. More than 99 percent of pistachios grown in California are produced from a single female cultivar, **Kerman**, pollinated by a single male cultivar, **Peters.** Under such conditions, an unknown disease or insect could potentially destroy the entire crop.

In 1989, a breeding program was initiated by Dan Parfitt in the pomology department at UC Davis and Joseph Maranto, a UC Cooperative Extension county advisor stationed in Kern County. After Maranto retired, Craig Kallsen replaced him as farm advisor and continued on with this project (funded by the California Pistachio Commission from 1989 to 2000.) Based on superior performance in replicated trials, two female cultivars, **Golden Hills** and **Lost Hills**, and one male cultivar, **Randy**, were released.

The new female cultivars flower earlier and perform better than Kerman under low chilling conditions. Both have significantly higher percentages of split nuts (a desirable consumer characteristic) and marketable yield, and they ripen a few weeks earlier than Kerman. Extension of the harvest season permits more efficient use of labor and equipment. Golden Hills shows decreased tendency for alternate bearing than Kerman.

Both cultivars have a more uniform maturity than Kerman, which suffers from irregular maturation, requiring multiple harvests. Lost Hills also has a larger nut than Kerman, but a higher percentage of loose shells (the kernel separates from the shells during processing).

An early-flowering male cultivar was selected to serve as the pollinator for Golden Hills and Lost Hills. Randy blooms about one week earlier than Peters and does not appear to be affected by low-chill winters. Pollen viability is much higher than for Peters and once shed, the pollen is more durable. The release of these new cultivars should help protect the pistachio industry from genetic vulnerability.

More than 99 percent of pistachios grown in California are produced from a single female cultivar, Kerman, pollinated by a single male cultivar, Peters. Under such conditions, an unknown disease or insect could potentially destroy the entire crop.

Safflower *Carthamus tinctorius* L.

Recognizing a crop's potential

Safflower has been grown commercially in California since 1949, thanks to the late Paul Knowles, a longtime UC Davis professor and researcher known as the "Father of California Safflower."

Knowles recognized the potential of safflower as a new crop for California in the late 1940s. Over his 35-year career at UC Davis, he worked to introduce the crop to California growers, develop appropriate cultural practices, and screen available variants for California conditions. He broadened the accessible gene pool by organizing and carrying out germplasm collection missions to 18 countries and conducted genetic and breeding studies.

In the late 1950s and mid-1960s, Knowles traveled more than 32,000 miles with his wife and son across North Africa, the Middle East, and South Asia, gathering germplasm of wild and domesticated safflower species, an effort which produced most of the accessions now in the USDA world safflower collection.

Safflower in commercial production near Davis.

Over his 35-year career at UC Davis, Paul Knowles worked to introduce safflower to California growers, develop appropriate cultural practices, and screen available variants for California conditions.

Knowles and his students and colleagues researched the genetic and chemical properties of the species and sought genetic resistance to pests. They characterized a mutant from an accession from the Ganges delta in India that produced the high oleic oil variant. The resulting varieties enhanced the safflower oil market in the health-food industry.

Safflower is used primarily as an oilseed crop but is also grown for seed meal for livestock and as a saffron substitute. There are two types of oil produced from different varieties of safflower: high linoleic oil (polyunsaturated) and high oleic oil (monounsaturated, similar to olive oil).

Notable varieties released by Knowles were **UC-26** (1959), a red-flowered, spineless type for use in dried flower arrangements, and **UC-1** (1965), the first commercial variety with high oleic oil content. A.L. Urie and Knowles released **Oleic Leed** in 1974, having bred the high oleic trait into an established variety, **Leed**.

Breeders: P.F. Knowles, Dept. of Agronomy/Agronomy and Range Science, 1947-1982; A.L. Urie, USDA-Dept. of Agronomy and Range Science, 1970s-1980s.

Arboretum All-Stars

Plants for eco-friendly gardening

In California, half of the water, fertilizers, and pesticides used in homes and businesses goes onto landscapes. These chemicals are often over-applied by home gardeners, and the excess contaminates soil or is flushed into waterways.

To make it easier for gardeners to choose plants appropriate for California's Mediterranean climate, UC Davis Arboretum staff identified and tested 50 tough, reliable plants to include in the All-Stars program. These plants are easy to grow, do not need a lot of water, have few problems with pests, and have outstanding garden qualities. Many of them are California-native or Mediterranean plants, and most provide food or habitats for native birds and insect pollinators.

These plants can be found on the website (arboretum.ucdavis.edu) and at the Arboretum gardens, each with a photo of the plant in bloom, a list of its outstanding features, and information on how to grow it. Also on the website, viewers can look for plants that meet specific criteria — for example, plants that grow in shade, have white flowers in June, or attract hummingbirds.

Although, not widely available for retail, the Arboretum is working with the UC Davis California Center for Urban Horticulture to develop partnerships with wholesale and retail nurseries in California to make the All-Stars available for home landscapes. Fifty additional outstanding plants will be added to the All-Stars roster in late 2008.

The Arboretum All-Stars program is only one facet of the Arboretum's mission to promote sustainable horticulture in California. Using these "green" plants can help reduce water and energy use in the landscape, reduce carbon emissions from power equipment, reduce chemical runoff, and support native pollinators. It's an easy way for home gardeners to help mitigate the effects of global climate change, and to benefit the long-term environmental, social, and economic health of the planet.

Storer garden, UC Davis Arboretum

Mexican tulip poppy

Heuchera "Lilian's Pink"

Buffalograss *Buchloe dactyloides* (Nutt) Engelm.

Taking advantage of the wild

Buffalograss is a fine-leaved native turfgrass species that has become popular for low-maintenance lawns in the midwest and southwest states. Buffalograss is so named because it was a primary food source of the American buffalo, found across the Great Plains into the Mexican region and in most of Texas. Being a native grass, it survives in many tough areas, is drought resistant, low growing, fine in texture, and survives in hot and cool temperatures.

Recognizing that the turfgrass industry has limited variation, Lin Wu, UC Davis, collected buffalograss germplasm over a wide range of geographic areas from Central Mexico to the North American short-grass plains. With extensive genetic variation in ploidy (chromosome number) levels, morphological and physiological traits have been found within and between germplasm collections.

As a result, Wu released four varieties of buffalograss; three were vegetatively propagated female varieties through mass selection. **HiLite 15** and **HiLite 25** were released in 1994. They were distinguished by their fine texture, high turf density, rapid stolon spreading rate, competitive growth, short height, improved winter dormancy, spring turf quality, drought tolerance, low maintenance requirements, and improved turf performance.

So named because it was a primary food source of the American buffalo, buffalograss survives in many tough areas, is drought resistant, low growing, fine in texture, and survives in hot and cool temperatures.

UC Verde (2002) is widely used today, especially on the coastal regions of California and lower valley of Arizona. It is well known for its ability to stay green throughout the growing season, spread rapidly, and compete with weeds, yet it is a low-maintenance turfgrass and grows only 4 to 8 inches tall. A drought-tolerant turfgrass such as UC Verde offers a bright future for both home lawns and golf courses in water-conscious California.

Wu also released the first commercial diploid seed-propagated buffalograss, **UCHL-1**, which is characterized by drought resistance, low growth, and an extended winter green color.

Artichoke *Cynara scolymus* L.

Thornless beauties, year-round

The world has become accustomed to having fresh fruits and vegetables year-round and the artichoke is no exception. Artichokes are available even in the winter, when 70 percent of the crop is grown in California. Perennial globe artichokes are grown along California's central coast and managed by cutting plants back to deliver fruit in spring, summer, and fall.

Winter annual production from seeded varieties in California was limited due to poor quality and yields until the mid-1990s. After 12 years of plant breeding and research, Wayne Schrader and Keith Mayberry, UC Cooperative Extension farm advisors, developed a widely adapted artichoke, **Imperial Star**, which is currently grown as a seed-propagated variety in Southern California, the Central Coast, and the Central Valley. It is also grown in several other states and countries.

Imperial Star is a thornless globe artichoke with distinctive bract glossiness. It was derived from a segregating line obtained from the USDA. Selection was for earliness, absence of thorns, uniformity, yield potential, bud appearance (glossiness, shape, and color), and the rate at which bracts spread open with increasing maturity. Mass selections were conducted for four generations and six additional years of selection work focused on uniformity, yield, and absence of thorns.

Imperial Star showed broad climatic adaptability and marketable yields three to four times higher than other varieties when it was developed, especially during winter production. Imperial Star is still one of the most widely grown varieties today.

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Artichokes in bloom

Carrot *Daucus carota* L.

Two seasons are better than one

UC Davis has been involved in carrot breeding for over 50 years — from the development of open-pollinated varieties to hybrids, and the selection of the long, slender types now used for "baby" carrots. Over 85 percent of the nation's $300,000 carrot industry is grown in California. The vast majority of varieties are hybrids developed by private companies — primarily, the long, thin **Imperator** fresh-market types.

The UC Davis program began in the early 1950s by Ted Welch in collaboration with Clint Petersen (USDA, later University of Wisconsin). By breeding carrots in the Midwest and in California's Imperial Valley, selections can be made two seasons per year in the field, resulting in rapid improvement and stable varieties.

Initially, the focus was to increase yield. Welch and E.L. Grimball changed the industry by selecting a plant with brown anthers that was male-sterile but produced seed. This resulted in significant increases in yield and uniformity of carrots and enabled the creation of the hybrid industry. More and more, growers eventually adopted these more expensive but highly profitable varieties. The focus then turned to developing breeding parents to license for hybrids with disease resistance and high quality such as sweetness, taste, and crunch.

In the mid-1960s, Vince Rubatzky joined the program and continued the joint venture and bi-seasonal breeding program with the USDA, now managed by Phil Simon in Wisconsin. Breeding focused on improving carotene content and resistance to root diseases. By the 1980s, the program was energized by the burgeoning baby carrot market which demands a long, thin uniform type that can be shaped into the popular snack forms.

Since the mid-1990s, Joe Nunez, a UC Cooperative Extension farm advisor in Kern County, has continued the program with a focus on resistance to nematodes and specialty types high in antioxidants.

Carrot seed production

The hybrid industry resulted in significant increases in yield and uniformity of carrots. Growers eventually adopted these more expensive but highly profitable varieties.

Since the inception of the UC Davis/USDA program, vitamin A in carrots has doubled, and dozens of inbred lines, breeding populations, and hybrid varieties have been released.

Celery *Apium graveolens* L.

Adapting to evolving conditions

California produces 50 to 60 percent of the total celery in the U.S. About 25,000 acres of celery are harvested each year in California, with a value of approximately $182 million. UC Davis is one of the few institutions in the world working on celery breeding and genetics.

In 1977, Thomas Orton founded a celery breeding and genetics program at UC Davis after finding celeriac accessions resistant to fusarium yellows.

In 1983, Carlos Quiros took over the program which produced its first fusarium-resistant line, **UC1**, in 1984. UC1 has served as the foundation material for further selection and release of the first commercial fusarium-resistant varieties developed by the seed industry.

Quiros and his team later released eight advanced lines, including **UC8**, **UC10**, **UC390S**, and **UC862** which have been the most popular for further improvement by seed companies. In 1994, the program produced the fusarium-resistant **Promise**, derived from UC10 after backcrossing it to **T.U. 52-75.**

About 25,000 acres of celery are harvested each year in California, with a value of approximately $182 million. UC Davis is one of the few institutions in the world working on celery breeding and genetics.

The breeding program has also produced celery lines with multiple disease and insect resistance which have been released to the seed industry for further development. The program is developing molecular markers and a genetic map useful for marker-assisted selection. With its broad germplasm base and comprehensive genetic information, the celery genetics program at UC Davis allows California growers to continue to grow celery in fusarium-infested soil with most of the existing resistant varieties derived from UC Davis' resistant lines.

Since its inception in 1976, the California Celery Research Advisory Board has supported UC Davis' celery breeding research. The program continues to adapt and solve present and future problems faced by the celery growers, such as leafminers and other insect pests and diseases.

Garlic *Allium sativum* L.

The sweet smell of collaboration

Collaboration between UC Davis breeders and the California garlic industry has contributed to the success of the annual Gilroy Garlic Festival, which attracts over 130,000 people each year and offers specialties like garlic shrimp and garlic-flavored ice cream. California grows over 85 percent of the commercial garlic in the U.S.

Garlic is primarily a vegetatively propagated crop — a commercial-scale breeding program is still in its infancy. Pollination and seed set, requirements of true breeding to make genetic gain, is difficult and rarely occurs naturally in garlic.

In the 1940s, UC Davis researchers identified two clones, an early-maturing processing type and a late-maturing fresh-market type that set seed. These clones, or varieties, still account for 75 percent of the garlic grown in California today.

Viruses are a major limitation to high yields of garlic in California and around the world. In the 1970s, Bob Shepherd, a UC Davis researcher, developed a method to eliminate viruses in garlic plants using meristem tissue culture. UC Davis Cooperative Extension specialists Ron Voss and Dennis Hall subsequently showed that yield can be increased by at least 30 percent in some varieties using virus-free seed garlic. With the California garlic industry adopting the technology, average yields increased from 6 tons per acre to 10 tons per acre.

UC Davis conducted a garlic selection and testing program for 15 years, until 2004, evaluating over 300 accessions from the USDA and international germplasm banks, characterizing these accessions for ability to form true seed, quality traits, disease resistance, and environmental adaptability. This research has supported a USDA program that is continuing the work.

Garlic drying at the UC Davis Student Farm.

Grain legumes

The principles of plant breeding

Grain legume varieties have been developed for many decades by UC Davis plant breeders to meet the need for well-adapted rotation crops in many and varied cropping systems throughout the Central Valley and the California coast. Most commercial legume production today utilizes more than 15 UC Davis public varieties, with a smaller but significant acreage of foundation and certified seed of private and non-UC public varieties.

The father of the internationally recognized UC Davis legume breeding program was Francis Smith, who was succeeded by several bean breeders, most recently Steve Temple. Many UC pest management researchers, UC Cooperative Extension county advisors, and growers have participated actively in UC Davis grain legume varietal development. The UC Davis breeding program has also benefited substantially from cooperation with UC pathologists, entomologists, and nematologists, along with the grain legume genetics and evolution research of Paul Gepts.

In 1946, Robert Allard was hired at UC Davis. He began his work by backcrossing mainly disease-resistance genes in lima bean (*Phaseolus limensis* L.). Allard expanded the germplasm diversity for breeding with a germplasm exploration trip to Latin America. He released several bean varieties in the 1950s, including the cultivar **Mackie**.

Allard developed the theory on gene interactions and recombination by studying variation in color of beans and later protein and DNA markers. This, along with studies on quantitative genetics in wheat and barley, led to many advances in our understanding of plant

Trait development and deployment has emphasized seed and canning quality.

breeding; Allard documented this in his 1960 publication, "Principles of Plant Breeding." This book still is one of the most comprehensive books on plant breeding.

Research at UC Davis focused on large and baby lima blackeye cowpea (*Vigna unguiculata* L.), and an assortment of *Phaseolus vulgaris* L. common bean classes. A large number of varieties have been released in all of these classes and grain types. Trait development and deployment has emphasized seed and canning quality, as well as host plant resistance to root knot nematode, lygus bug feeding damage, and to diseases (especially aphid-vectored viruses and soil pathogens).

The most significant recent releases feature resistance to bean common mosaic virus, root knot nematodes, fusarium yellows, and lygus bug. Germplasm for these traits was obtained from U.S. and international breeding and genetics programs.

Beginning in the early 1990s, a shift from public to marketing order support of breeding activities occurred, primarily due to UC budget constraints. UC Davis also yielded primary responsibility for blackeye improvement to UC Riverside breeders, and began a regular germplasm exchange and testing program with USDA/ARS (Pullman, Wash.) for chickpea (*Cicer arietinum* L.) breeding. This testing and selection work on winter legumes (chickpea, and to a lesser extent grain lupin, *Lupinus polyphyllus* L.), has led to the release of ascochyta-resistant varieties.

Bean cutting equipment

One of the initial grain legumes UC Davis focused on was the cowpea.

Lettuce *Lactuca sativa* L.

Decreasing disease with genetics

Lettuce ranks as one of the top ten most-valuable crops in the U.S. with an annual value of over $2 billion, 80 percent of which is grown in California. Lettuce is often grown over large areas, making it vulnerable to a variety of diseases. While chemical controls are available for some diseases, their ecological impact, regulations, and costs make them less desirable than genetic resistance. Therefore, the development of germplasm with resistance to the most important lettuce diseases in California has been a major priority for lettuce breeding at UC Davis and elsewhere.

The UC Davis lettuce breeding program was started in 1942 by Ted Welch in collaboration with the USDA. This program emphasized identifying genes conferring disease resistance, particularly to downy mildew, and incorporating them into crisphead horticultural types suitable for California. Since 1982, the program has been continued by Richard Michelmore, and the number of diseases targeted has increased, notably to include corky root, which was becoming a major problem in the 1980s.

In the late 1990s, the program was expanded to include breeding for improvement of leafy horticultural types in response to an industry shift to leafy varieties such as romaine. The program now includes breeding for resistance to downy mildew, corky root, lettuce mosaic virus, anthracnose, verticillium, and fusarium. The program involves extensive germplasm screens to identify new sources of resistance as well as surveys of pathogen populations, particularly downy mildew, to monitor pathogen variability and assess the efficacy of new resistances.

The program also emphasizes determination of the genetic basis of resistance to these diseases and the identification of DNA (molecular) markers for marker-assisted selection of genes for disease resistance and other agriculturally important traits. As in humans, DNA can be used to track the forms (alleles) of genes in plants. Determination of the global genetic architecture of disease resistance in lettuce and the development of an ultra-high-density genetic map are underway.

Initially, a series of breeding materials was developed and released to the seed industry and lettuce growers in the late 1950s. In 1960, the program released its first and highly successful variety, **Calmar**. Because of its genetic resistance to downy mildew, tip burn resistance, vigor, size, and wide adaptability, Calmar became the dominant variety in the Salinas Valley for fifteen years. Ten other varieties were released by the program but none proved as successful as Calmar.

Calmar's downy-mildew resistant gene was eventually overcome by evolving types of the pathogen, and the needs of the lettuce shipping industry changed. Calmar and its sister lines were used at UC Davis and elsewhere to develop new varieties that retained the quality and field performance but also met new industry needs. In 1975, Ed Ryder from the USDA released **Salinas**, which had Calmar in its parentage and replaced Calmar as the most commonly cultivated crisphead lettuce type. Salinas and its relatives remain the predominant type planted in California today.

Since 1982, the UC Davis program has focused on the release of advanced breeding material with new disease-resistance genes rather than the release of varieties. Twenty-nine breeding lines carrying several novel sources of resistance for lettuce downy mildew and combinations of other resistance genes have been released thus far (see Table 1). Resistance to corky root was shown to be determined by a single recessive gene, *cor*, which greatly accelerated the breeding of resistance to this disease; the majority of commercial varieties now contain this gene and the disease is rarely problematic. Numerous additional lettuce disease-resistance genes have now been identified and molecular markers have been identified for them providing a wealth of genes for future lettuce improvement.

The breeding program has been funded primarily by the California Lettuce Research Board. The USDA and National Science Foundation have also contributed to the program by supporting classical and molecular genetics of lettuce and the development of molecular breeding tools.

Table1: Historical events in the lettuce breeding program at UC Davis.

DECADE	PRINCIPAL INVESTIGATOR	EVENTS
1940s	Ted Welch	Initiation of the lettuce breeding program.
1950s	Ted Welch	Programs started for resistance to diseases, including lettuce downy mildew (LDM), lettuce mosaic virus, and big vein, as well as to peach aphid, an insect pest.
1960s	Ted Welch	Release of Calmar, a large, vigorous head lettuce cultivar of the Great Lakes type.
1970s	Ted Welch	Head lettuce releases: Calicel, Calrey, Calrico.
1980s	Ted Welch	Head lettuce releases: Alamo, Anza, Laguna, Ramona, Rita, Vega, and Vista.
	Richard Michelmore	Techniques established for transformation mediated by *Agrobacterium tumefaciens* and genetic mapping of lettuce with DNA markers.
		Detection of Ridomil insensitivity in lettuce downy mildew.
1990s	Richard Michelmore	Bulked segregant analysis developed for rapid mapping of resistance genes.
		Head lettuce releases: breeding lines UC201, UC204, UC205, UC206, UC207, UC209, and UC210 containing resistance to LDM and corky root.
		Head lettuce releases: breeding lines UC9602, UC9606, UC9607, UC9608, UC9612, UC9614, and UC9652 containing novel sources of resistance to LDM and corky root, anthracnose, and LMV.
2000s	Richard Michelmore	Leafy lettuce breeding program initiated.
		Head lettuce releases: breeding lines UC02100, UC02101, UC02102, UC02103, UC02104, UC02105 and UC02106 containing novel sources of resistance to LDM and various combinations of other resistant genes.
		Comparative genomics program initiated.
		Dm3 LDM resistance gene cloned.
		Head lettuce releases: breeding lines UC07107, UC07108, UC07109, and UC07110 containing novel sources of resistance to LDM.
		Leafy lettuce releases: breeding lines UC07100, UC07103, and UC07105 containing novel sources of resistance to LDM.

Potato *Solanum tuberosum* L.

Developing bulk of state's varieties

Although California is not a major potato producer, UC Davis researchers have developed potatoes that perform well in California. The UC Davis potato variety development and testing program was initiated in the 1940s by Glen Davis. The focus was on fresh-market, long white potatoes at a time when the variety **White Rose**, selected in the1890s, was still predominantly grown in California.

In the 1970s, UC Davis Cooperative Extension specialist Ron Voss organized a potato collaborative variety development and testing program that included breeders from the USDA and several land-grant universities. The program was coordinated with and funded by the potato industry. Seedlings were selected under the California environment and for California markets. Almost every potato variety grown for processing or for the fresh market in California was developed or introduced through this UC collaborative program.

Although only five or six species of potato are grown commercially worldwide, a wide range of characteristics are available in other *Solanum* species that can be introduced into the commercial species. These include disease resistance, colored flesh, and other characteristics. New selections were tested and licensed, broadening the spectrum of potatoes available for California.

Several new varieties were released including **Cal White**, a long white potato with smooth skin and high yield that replaced White Rose. Focusing on fresh market and chipping, red potato varieties — like **CalRed** — were released. The fresh-market **Russet Norkotah** was introduced, as well as the high-yielding, low-sugar content variety, **Atlantic**, that replaced the famous **Kennebec** for chipping.

In the 1990s, several specialty varieties were also selected and introduced from private and public programs. These varieties include colored-flesh lines such **Inka Gold,** high in anthocyanin and antioxidants, developed by UC Davis geneticist Carlos Quiros.

Sweet potato *Ipomoea battatas* L.

Clean seeds, healthy stocks

Contrary to its name, the sweet potato is not in the same family as potatoes. It is in the same family (Convolvulaceae) and genus (*Ipomoea*) as morning glory. UC Davis began its sweet potato breeding program in the 1950s. Jack Hanna released **UC779** ("yam" or "Jewel" type; i.e., moist flesh) that was grown exclusively in California in the 1960s through the 1980s for canning due to its sweetness and high yield. **Garnet**, a red-skinned, orange-flesh (Puerto Rico and "yam") type, was released to the industry in the late 1960s. The variety **Hanna Sweet**, a dry white/yellow-fleshed ("Jersey" or "sweet potato") type sweet potato, was released in the early 1980s for fresh market and is still grown today. A collaborative variety testing program, coordinated in California by the UC Cooperative Extension county advisor in Merced County, has resulted in several new varieties since then.

Perhaps the most significant contribution by UC Davis to the sweet potato industry was the development of a clean-seed program and the maintenance of disease-free seed stocks. UC Davis researchers developed the methodology for clean, disease-free seed stock for clonally propagated plants. Shoots from sweet potato are heat-sterilized to eradicate disease, then grown and propagated using tissue culture. These shoots are then transplanted and observed in nurseries for genetic stability and disease. Only plants that are "true to type" and disease-free are carried forward to release as seed stock for California. Deborah Golino manages the Foundation Plant Services facility on the UC Davis campus for sweet potato and many other clonally propagated crops.

The Jewel type sweet potato, UC7799, was grown exclusively for 20 years in California.

California produces the majority of world's processing tomatoes.

Tomato *Solanum lycopersicum* L.

New technology leads to boom

From the 1940s through the 1980s, UC Davis plant breeder and plant pathologist Paul G. Smith contributed to the development of varieties of cherry tomatoes, such as **Royal Red Cherry** and **Short Red Cherry**. Smith was perhaps the first person to successfully hybridize cultivated tomato with the wild relative *Solanum peruvianum*. He consequently transferred the economically important nematode-resistance gene, *Mi*, into cultivated tomato, which led to its identification. This trait is still widely used in commercial cultivars. Indeed, it is the only such gene available to growers today.

The first tomato varieties designed specifically for machine harvest were bred by Gordie (Jack) Hanna in the UC Davis Department of Vegetable Crops and released for commercial use beginning in the early 1960s. Prior to that, all tomatoes were picked by hand, requiring considerable labor in the fields. Foreseeing a need for machine-harvested tomatoes, Hanna began a breeding program in the late 1940s. His foresight was based on experience with other crops, such as sugar beets, in which labor shortages had also led to mechanized harvest.

In 1964, the Bracero Program, which brought large numbers of farm workers into the U.S. to pick tomatoes and other crops, was terminated by Congress. The resulting labor shortage in California meant that the canning companies could not be assured a steady supply of tomatoes, causing some companies to consider relocating out of the state. Fortunately, the California tomato industry was rescued by two UC Davis inventions: a tomato harvester and suitable tomato varieties.

The harvesting machine was created by Coby Lorenzen in the UC Davis Department of Agricultural Engineering. Later it was commercialized by the Blackwelder company. Hanna's varieties had to not only stand up to machine picking, but also meet the requirements of growers and canners. As prototypes of the harvester were developed, they were tested on fields of Hanna's tomatoes. These tomatoes had been selected for desirable characteristics such as firm fruit, high soluble solids, heavy fruit set during a narrow window of time (necessary because machine harvest was a once-over, destructive process), compact vines, good field-holding capacity, etc.

In addition, Hanna introduced resistance to some diseases prevalent in California, such as fusarium and verticillium wilts, as well as the ability to set fruit under the high summer temperatures common in the Central Valley. This led to the release of tomato varieties such as **VF145**, the first variety bred specifically for machine harvest, and later **VF13L** and **VFN8**.

The coordinated development of the tomato harvester and tomato varieties led to a great expansion of the processing tomato industry in California. Today, the state produces 95 percent of the national and nearly 50 percent of the world's supply of canning tomatoes.

The tomato harvester is a UC Davis innovation.

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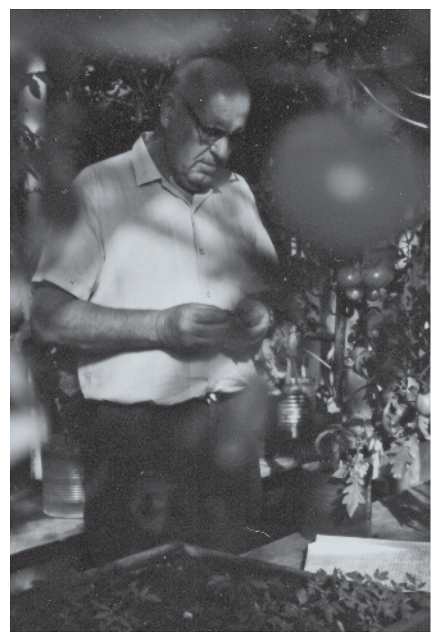

Jack Hanna was instrumental in developing tomatoes that can be mechanically harvested.

Onion *Allium cepa* L.

The mother of all onions

Most new onion varieties today are developed by international private companies. In California, the largest onion-producing state in the U.S., approximately 60 percent of the acreage is grown for dehydration processing and 40 percent for fresh market.

Henry Jones, a UC Davis researcher, began breeding onions as early as the 1920s, focusing on fresh-market types. Jones changed the onion industry in 1925 by discovering a male-sterile Italian Red plant in the UC Davis onion breeding plots. The development, distribution, and use of this male-sterility enabled the production of hybrid onions resulting in increased yields and uniformity.

The UC Davis source of male sterility was the basis of all hybrid onions for many decades. In the 1950s, Glen Davis released several red onions such as **CalRed**, from which **Fresno Red** and **Stockton Red** were selected and still grown today.

Pepper *Capsicum* spp.

Array of colors is in the genes

Pepper breeding at UC Davis was active from the 1940s to the 1980s, led by Paul G. Smith, a plant pathologist, breeder, and former member of the UC Davis Department of Vegetable Crops. Smith released bell pepper varieties including **Caloro**, a yellow wax type pepper, and **Summer Sunshine**, a yellow bell type. He identified a source of resistance to phytophthora root rot disease (*Phytophthora capsici*) still widely used in commercial varieties.

In addition to his contributions in plant pathology and breeding, Smith published research on *Capsicum* spp. taxonomy and described a new species of pepper from Peru. He also was an authority on the crossing relationships (sexual compatibility) of *Capsicum* species.

Smith and his colleagues also studied the inheritance of fruit color in peppers, and developed a model on how the diversity of colors is controlled at the genetic level.

The Plant Breeding Academy

Meeting demand for breeders

UC Davis is developing innovative programs to teach modern plant breeders. There is a worldwide shortage of skilled plant breeders due to both an increasing demand and a decreasing number of active public breeding programs. Furthermore, the skills required for public breeding are becoming divergent from those demanded by the private global seed businesses.

In direct response to industry concerns, the UC Davis Seed Biotechnology Center developed the Plant Breeding Academy (PBA). The course provides an opportunity for companies to invest in advanced training for dedicated personnel who are involved in breeding programs. The two-year program provides formal instruction in genetics, statistics, and plant-breeding theory. The course schedule allows students to maintain their working positions while enrolled. The goal is for academy graduates to be able to work as independent plant breeders or to direct regional plant-breeding programs upon completion of the course.

Inaugural class and instructors for the Plant Breeding Academy, 2006-2008.

The first class (Class I) of the Plant Breeding Academy began instruction in September 2006 with 15 students. Most were already breeding assistants with practical knowledge in plant breeding but not the theory behind it. They travelled from various locations in North America, and from as far away as Hong Kong, to attend six one-week sessions over the two-year course.

The goal is for academy graduates to be able to work as independent plant breeders or to direct regional plant-breeding programs upon completion of the course.

The UC Davis certificate course consists of lectures, field trips, discussions, homework, and a comprehensive final project for which students design a breeding program. The primary course instructors are Doug Shaw and Larry Teuber from UC Davis and Todd Wehner from North Carolina State University, all internationally recognized plant breeders.

Course curricula extend to all issues involved in plant breeding from genetics, statistics, trait selection, population development, resistance breeding, genotype by environment interactions, and biotechnology, to finishing varieties and seed production. Class I completed the course in June 2008, and 23 new students from around the world are enrolled in Class II, beginning in September 2008. Visit http://pba.ucdavis.edu for more information.

Research and Information Centers

AGRONOMY RESEARCH AND INFORMATION CENTER

AgRIC provides information on California agronomic crops, including alfalfa, winter cereals, corn, cotton, dry edible legumes, rice, safflower, sugarbeet, sunflower, and specialty crops.

CALIFORNIA RANGELANDS RESEARCH AND INFORMATION CENTER

Mel George, Director; Janice Corner, Program Representative

The CRRIC develops research and extension education initiatives and fosters collaboration between California rangeland researchers and educators.

ENVIRONMENTAL HORTICULTURE RESEARCH AND INFORMATION CENTER

Heiner Lieth, Director; Judy Sams, Program Representative

EHRIC is a resource created for research-based information on issues facing the horticulture industry in California. EHRIC acts as an umbrella organization coordinating activities of the Turf, Landscape, Urban Horticulture, and Floriculture and Nursery workgroups within the UC system.

ABOUT RICs:

The RICs listed are coordinated by the Department of Plant Sciences at UC Davis.

Chris van Kessel, *Chair,* Department of Plant Sciences

Ted DeJong, *Vice Chair,* Department of Plant Sciences Extension and Outreach

Louise Ferguson, *RIC Coordinator*

Sue DiTomaso, *Manager of Outreach*. For info, contact scwebster@ucdavis.edu or (530) 754-7333.

FIND US ONLINE:

rics.ucdavis.edu

FRUIT AND NUT RESEARCH AND INFORMATION CENTER

Louise Ferguson, Director; Judy Sams and Penny Stockdale, Program Representatives

The Fruit and Nut RIC aids in the coordination and dissemination of UC research-based information, and statewide research and extension activities related to fruit and nut crops.

POSTHARVEST TECHNOLOGY RESEARCH AND INFORMATION CENTER

Jim Thompson, Academic Director; Jim Gorny, Executive Director; Mary Reed, Program Representative

The Postharvest RIC provides relevant information and programs to California growers, shippers, marketers, carriers, distributors, retailers, processors, and consumers of fresh horticultural crops.

SEED BIOTECHNOLOGY CENTER

Kent Bradford, Academic Director; Mike Campbell, Executive Director; Susan DiTomaso, Manager of Outreach

The SBC is a focal point for interaction between the seed industry and the research and educational resources of the UC Davis. It coordinates research that interests the seed industry and provides continuing education in seed biology and technology.

VEGETABLE RESEARCH AND INFORMATION CENTER

Tim Hartz, Director; Gale Perez, Program Representative

VRIC's mission is to foster research, collect and disseminate information relevant to consumers, growers, and processors in the California vegetable industry, and serve as a leading source of research and information for the vegetable industry.

WEED RESEARCH AND INFORMATION CENTER

Joe DiTomaso, Director; Gale Perez, Program Representative

WeedRIC fosters research in weed management and facilitates distribution of associated knowledge for the benefit of agriculture and for the preservation of natural resources.

PLANT BREEDING PROGRAMS

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Department of Plant Sciences
(530) 752-1703
www.plantsciences.ucdavis.edu

Department of Viticulture and Enology
(530) 752-0380
wineserver.ucdavis.edu

Graduate Group in Horticulture and Agronomy
(530)752-7738,
ggha.ucdavis.edu

CENTERS, INSTITUTES, AND PROGRAMS

Agricultural Sustainability Institute
(530) 752-3915
www.asi.ucdavis.edu

California Center for Urban Horticulture
(530) 752-6642
ccuh.ucdavis.edu

California Crop Improvement Association
(530) 752-0544
ccia.ucdavis.edu

C.M. Rick Tomato Genetics Resource Center
(530) 754-6059
tgrc.ucdavis.edu

Foundation Plant Services
(530) 752-3590
fpms.ucdavis.edu

Foundation Seed Program
(530) 752-2461
fsp.ucdavis.edu

Genomics Facility
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www.cgf.ucdavis.edu

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