

PERSIAN WALNUT BREEDING IN CALIFORNIA

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ABSTRACT—For over 50 years the University of California Davis Walnut Breeding Program has worked to address the needs of California walnut growers by identifying genetic approaches to problems and developing improved cultivars. The breeding program is a cooperative endeavor that draws on the efforts and resources of university researchers and facilities, USDA germplasm programs, the statewide Cooperative Extension program, grower, and nursery funding sources, and the extensive participation of individual growers, processors, and nurserymen in all aspects of the program.

CALIFORNIA WALNUT INDUSTRY

Production

Persian walnut production in the United States is concentrated almost entirely in the State of California. California growers account for 99% of all domestic Persian walnut production (Walnut Marketing Board 1997). There are now approximately 200,000 bearing acres of Persian walnuts in California, an increase during the last 15 years of about 20%. In that same time period production per bearing acre has increased about 20% to a current statewide average of 1.5 tons per acre and total production of Persian walnuts has increased about 30% to nearly 300,000 in-shell tons annually (California Agricultural Statistics Service 2003).

About 60% of this production is consumed domestically but exports are an important component of marketing the crop and maintaining price to the grower (Siebert 1998). Concerted marketing by grower organizations and processors, in some cases with the assistance of government programs supporting development of export markets (Siebert 1998), have helped increase the proportion of the crop exported from only 25% 20 years ago to about 40% in the last 4 years.

Growers

California walnut growers farm an average of 50 acres of walnuts but farm size varies widely (Hasey 1994). Large growers farming 100 or more acres account for 60% of the acreage but constitute only 12% of the growers. Nearly 60% of growers farm fewer than 20 acres while producing only 10% of the crop. Production over the last several years has averaged 1.5 tons/acre. Prices can vary widely from year to year but recently the crop has returned about \$1,000/ton to growers (California Agricultural Statistics Service 2003).

About half of the California walnut crop is produced by growers who belong to Diamond Walnut, the largest growers' cooperative (Beede and Hasey 1998). Diamond has field representatives statewide who work with the member growers, a central shelling and processing facility, and its own product development and marketing programs. Approximately 70 independent shellers and handlers, varying widely in size and services, market the other half of the production. Economic conditions are contributing to increasing numbers of vertically integrated grower-handlers who market their own production.

The ability of cooperative members and independent growers to collaborate on issues of mutual interest such as product standards,

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development of export markets, and investment in research has contributed greatly to the success of the industry. These issues are coordinated through two grower organizations, the California Walnut Commission, responsible for export development (Siebert 1998), and the Walnut Marketing Board.

The Walnut Marketing Board oversees implementation of the Walnut Marketing Order established in 1949 under the 1937 Federal Agricultural Marketing Act (Hasey 1994). The marketing order was established and approved by growers in response to low prices and absence of enforceable quality standards. By law, the board's activities are conducted under USDA oversight but board members are walnut growers and handlers elected by the growers. The board oversees quality and grade standards, monitors collection of industry production statistics, and regulates commodity volume. In addition to these functions, the order established a mechanism for funding marketing and production research. Growers assess themselves at the handler level on merchantable crop tonnage and the board allocates a portion of these funds annually to fund horticultural and post-harvest research (Beede and Hasey 1998).

Nurseries

Commercial walnut nurseries are another key element of the industry. Nurseries vary widely in size and scope of activities from large multi-crop operations with international sales to small family walnut operations and growers who produce seedlings only for their own use. There are no State or other public nurseries.

Persian walnuts are a clonally propagated crop in which production is almost entirely from scion varieties grafted to seedling rootstocks. Rootstocks in California are either seedlings of California black walnut (*Juglans hindsii*) or hybrids derived from black walnuts pollinated with Persian pollen (*J. hindsii* x *J. regia*). These hybrids, known as Paradox, have superior vigor but are more susceptible to crown gall disease (Catlin 1998).

Nurseries collect seed from trees known to produce Paradox seed, establish seed orchards for this purpose, or purchase seed from suppliers. Seedlings are either sold ungrafted after one year for growers to graft on their own or they are grafted or budded in the nursery to the desired scion variety and sold as 2-year-old grafted trees. Recent advances in rooting methods have contributed to very limited production of Persian cultivars on their own roots and clonal rootstock.

Nurseries are regulated by the California Department of Agriculture (CDFA). The CDFA sets standards for nursery stock, oversees production and distribution of certified stocks, and addresses some nursery interests in research. The nurseries, through their organization, the California Fruit Tree, Nut Tree, and Grapevine Improvement Advisory Board (IAB), assess themselves a fee based on plant materials sold and dedicate a portion of these funds to research.

WALNUT RESEARCH FUNDING

Research and technological development is an important component in maintaining a growing, profitable, and competitive walnut industry. Funding for walnut research is derived from a variety of sources.

The State of California, through the University of California, particularly the UC Davis Pomology department, has long contributed support through its funding of faculty, research staff, extension specialists, and county-based farm advisors, infrastructure including research farm operations, greenhouses and laboratories, and funding for equipment.

The USDA-ARS has contributed funding for research positions, some as adjunct faculty, research programs, and particularly funding through the National Clonal Germplasm Repository for an extensive walnut germplasm collection. Some research is also funded through State and university competitive grants intended to support biotechnology development and foster technology transfer to industry.

As State and university funding for agricultural research has come under pressure in recent years, direct grower funding through the Walnut Marketing Board has become increasingly important. Through the Board the growers provide substantial annual funding of research proposals and have endowed a permanent staff position for the Walnut Breeding Program. Nurseries, through the IAB, fund research that addresses their concerns including clean stock, trueness-to-type, and propagation. Contributions from individuals in the industry have also been important and have included funding for a graduate student assistantship specifically for walnut research.

RESEARCH-INDUSTRY INTERACTION

Industry input and participation has been an essential element of walnut research success. The annual Walnut Research Conference has become

a key component in coordinating walnut research efforts and industry-researcher interactions in California. This conference originated as an annual training meeting for the UC Cooperative Extension Service county farm advisors. Farm advisors, roughly the equivalent of county agents in other States, are responsible for working directly with growers to solve problems and to disseminate research information from university, USDA, and other sources. They are also expected to conduct some applied research of their own. This meeting was originally an opportunity for university researchers at all levels and perspectives to internally share information, update skills, and address new problems and directions. This meeting also acquired the function of reviewing and recommending proposals to be submitted to the Walnut Marketing Board for funding.

As grower funds became an increasingly important component of research financing, members of the Walnut Marketing Board Research Committee were invited to see the presentation of proposals first hand. Initially they were invited as observers but over the years their role has expanded to full participants, speakers, and members of panel discussions. As proposals began to involve coordinated funding with the nursery industry as well, nursery board members were also invited. USDA-ARS researchers working on walnuts also attend.

The USDA Juglans Crop Advisory Committee, a group with diverse expertise in all species of walnuts and which advises the USDA National Clonal Germplasm Repository on germplasm collection and maintenance issues, generally holds its annual meeting in conjunction with the Walnut Research Conference and committee members with interests in black walnut and butternut have also participated in the conference in recent years.

The result is a 3-day conference with a wide array of participants assembled to review current research results, discuss industry problems, and debate directions for new research. The combination of formal research presentations, structured discussions, and a series of social events supported by industry funds, help cement relationships and define directions for the coming year's work.

Research discussed at this conference covers a broad array of topics. Last year, for example, reports, proposals, and panel discussions included codling moth control methods, husk fly, bacterial blight, crown gall control, integrated pest management research, nematodes, blackline virus, tree training, mechanical hedging, light management, water relations and irrigation

methods, replacements for post-harvest fumigants, rootstock selection, propagation methods, tissue culture, genetic engineering, field performance of self-rooted plants, DNA finger-printing, and development of new varieties.

This cooperation and interaction occurs not just at the annual research conference but also throughout the research process. Close industry and researcher cooperation is essential, not just in setting direction, but in implementation and transfer to the growers. Information discussed at the conference is disseminated statewide to growers through a series of annual county grower meetings organized by the farm advisors. In addition, new information is summarized in extension publications and every several years Cooperative Extension organizes a weeklong Walnut Short Course for interested growers. This course is taught by faculty, farm advisors, and innovative growers, includes lectures and field tours, and provides participants with an updated version of the Walnut Production Manual (Ramos 1998), the University of California textbook on Persian walnuts.

This entire process ensures a clear understanding of industry needs in research, a comfort level with progress in the work being funded, and a rapid transfer of results back to the growers. An examination of how the walnut breeding program functions illustrates the importance of this interaction and steps where it occurs.

WALNUT BREEDING PROGRAM

History

The Persian Walnut Breeding Program began at UC Davis in 1948. In the following 30 years under the direction of Gene Serr and Harold Forde crosses incorporated the lateral bearing trait responsible for precocious high yield into 15 released cultivars (Serr and Forde 1968; McGranahan and others 1990, 1992; Tulecke and McGranahan 1994). Several of these are leading varieties today. 'Chandler', notable for its light kernel color, high yield of halves, and relatively low input requirements is the leading cultivar in the State.

Objectives

The breeding program has continued since 1982 under the direction of Gale McGranahan. The current breeding program seeks to address a variety of industry concerns by developing both improved scion varieties and clonally propagated rootstocks.

Growers and handlers are interested in obtaining new scion varieties with early harvest dates and reduced need for chemical inputs. Over 60% of current production is from late harvesting varieties (California Agricultural Statistics Service 2003). The most popular variety, ‘Chandler’, is relatively late harvesting, constitutes 27% of current bearing acres, and is increasing as a proportion of total plantings. Hartley, another relatively late variety, comprises an additional 25% of current acreage. Early varieties (Payne, Ashley, and Serr) represent only 20% of bearing acres and have declined in popularity due to insect and blight susceptibility or, in the case of ‘Serr’, poor yield. Concentration of crop production at the end of the season results in poor utilization of harvesting equipment and processing capacity. Late harvest also results in increased risk of rain during the harvest operations and a tight time-line for drying and shipping product to Europe before the holiday season.

Development of scion varieties resistant to cherry leafroll virus, the causative agent of blackline disease is of particular concern for growers in the cooler areas of the State where the disease is most prevalent.

Rootstock qualities of greatest interest include vigor, tolerance for blackline virus, and resistance to crown gall, nematodes, and *Phytophthora* root and crown rots. Developing commercially viable rootstock propagation methods that would allow nurseries to replace the industry’s current dependence on unimproved seedlings with clonally propagated improved rootstock is a high priority.

Germplasm

Collection

A breeding program depends in part on a diverse collection of germplasm as a source of raw material from which traits of interest can be identified. Persian walnuts are native to the mountains of Central Asia (Leslie and McGranahan 1998) so considerable effort has been directed towards collecting material from that area. Funding and participation in this work has included a century long plant introduction endeavor by USDA plant collectors, and more recent trips by USDA and university researchers. Collecting has been funded in part by California growers, USAID exchanges, and USDA-ARS Germplasm exploration funds. Material has also become available for use through international research contacts, private breeders, hobbyists, customs confiscations, and observant growers in the State who have noticed useful seedling trees.

Maintenance

Both the University of California and the USDA National Clonal Germplasm Repository maintain walnut germplasm collections. The intent of the USDA collections is to include as broad a diversity of all walnut species as possible and it is maintained for public distribution of material. It will not accept proprietary material and is managed primarily for wood and nut distribution to researchers worldwide. The UC Davis collection includes a representation of California commercial varieties, advanced selections, and some proprietary material and is focused primarily on material of interest for breeding purposes. It is managed for a variety of activities including crossing, breeding evaluations, and graftwood distribution of advanced selections. While there is some overlap of material, duplication is generally avoided and the two collections are used cooperatively.

Evaluation

Germplasm in these collections has to be evaluated and characterized to determine its useful attributes. Some of this work is done specifically for the breeding program and is funded through grower support of the program. Part of this work, particularly evaluation of the broader USDA collection has been funded through USDA-ARS Germplasm evaluation funds. These data are collected and made publicly available on-line through the USDA GRIN database.

Crossing Methods

The UC breeding program has used two distinct procedures for crossing parent material. In the first method, wind-blown pollen is excluded from female flowers of interest by covering them with tightly secured bags with small plastic windows. Pollen is collected from the other parent of interest and stored until use. When bagged female flowers open and are receptive, pollen is applied through the bags with a hypodermic needle. Bags are later removed and nuts marked for collection in the fall. The male parent is known with this method, but the costs are high and seedling production is low.

The second method is to locate geographically isolated young trees to avoid wind-blown pollen. This requires the cooperation of a grower with a recently planted orchard. Any male flowers on these trees are removed by hand before opening to prevent selfing. Once the female flowers begin to open, pollen of the desired male parent or parents is applied by airbrush several times during the bloom period. At harvest the cooperating grower either donates or is compensated

for the nuts. This method produces many more seed at lower cost but with low certainty of the male parent. Male parents of selections can be determined later by DNA analysis.

Seedling Evaluation

Seed collected from these crosses is then stratified and grown to produce the next generation of seedlings. These are screened as they mature for traits of interest (Forde and McGranahan 1996). Commercial walnut nurseries have generously donated growing ground, time, resources, and expertise to assist this aspect of the program.

After 1 year in the nursery, trees are dug and replanted on wider spacing for evaluation. At this stage, trees are grown on their own roots, not grafted to rootstock. Most commonly these trees are planted on UC Pomology department ground and farmed by department staff supported by university and grower funding. In some cases growers have assisted the program by donating orchard space for this purpose and have farmed these trees during the evaluation process. This has been done by planting between rows in an existing widely spaced orchard, or more effectively, by interplanting in available open space in a newly established orchard and then removing the breeding program trees as evaluations are completed and the grower's orchard matures to fill the canopy.

As seedling trees mature they are evaluated in the field for traits of interest including leafing, flowering, and harvest dates, yield, and growth habit. When the trees are grown in university orchards they are left unsprayed so that variation in resistance to insects and disease can be observed. When grown within commercial orchards this is not normally possible. Nut samples are hand collected from each tree at maturity. Samples are dried, cracked by hand, and evaluated for percent kernel, kernel quality, kernel weight, shell characteristics, and yield of halves. Data is entered into a database and summarized for multiple years. In addition, samples of promising individuals are sent to the Diamond Cooperative and other interested handlers for their independent evaluation.

Collected data is presented to farm advisors, growers, and nurserymen in several ways. The first is at the annual Walnut Research Conference as part of the Walnut Improvement Program's annual report. Data on selections is presented orally to attendees and published in the annual proceedings of the conference.

The breeding program also holds an annual Crackout Meeting in the spring attended by farm advisors, handlers, nurserymen, and growers. Growers, handlers, and nursery attendees generally have an expressed interest in development of new varieties, are interested in assisting with evaluation of material, or are otherwise active in research activities and the marketing board. At this all day meeting the data reports are distributed and kernel samples and intact nuts of the material under evaluation are displayed. Attendees are asked to review the material, examine the samples, and provide written comments. In an ensuing discussion period they provide valuable input on priorities from their varying perspectives, help rank material, and suggest which should continue in the program.

The program also regularly invites interested parties to view selections in the field, either through a formal field day or by scheduling informal visits at their convenience. Progress in the program and information about selections is also presented periodically to a wider range of growers at annual county grower meetings held around the State.

Selection Trials

Once an individual seedling shows promise and is selected for further trials, graftwood is collected from the original seedling and grafted to rootstocks. Nurseries have often provided assistance at this stage by donating rootstock, supplying grafters, and in many cases growing the grafted trees for the program.

Grafted trees of each selection are then planted in test blocks on orchard spacing at diverse locations for further evaluation. Currently these test blocks are located at the Chico State University Farm in the northern part of the State, on the UC Davis campus in the central region and at the UC Kearney Field Station in the south. These blocks are managed by Cooperative Extension farm advisors and are used to evaluate the performance of selections on rootstocks under a wide range of conditions, obtain a better look at yield, and allow farm advisors and growers to see selections in their local area.

In addition to the university plots, interested growers around the State have volunteered to establish trials ranging in size from several trees to several acres. Farm advisors assist in identifying suitable growers, establishing plots, and observing performance. Graftwood is distributed to these growers under test agreement and they are asked to participate in its evaluation and to attend the crackout meeting. This gives the program valuable

input on performance under a variety of conditions and in commercial settings from observers with extensive experience. Growers feel they are assisting the process and get an early look at the material that is most interesting for their situation.

As new selections begin to show promise, commercial nurseries are encouraged to acquire graftwood from the program to test the varieties for themselves and to begin increase-blocks of their own. This ensures nurseries have adequate input into final selection, firsthand knowledge of the material, particularly of its grafting performance, growth habit, and training requirements, and builds an adequate supply of production wood by the time the new variety is released. As with grower trials, nurseries receive wood under test agreement. This allows them to propagate for testing purposes, including grower trials, but trees cannot be produced for sale until they are patented.

Release

Selections that continue to show promise in test blocks and grower trials become candidates for patent and release as new varieties. The patent disclosure process requires an extensive description of the selection, a summary of available data, and identification of attributes distinct from existing varieties.

Once a selection is patented as a new cultivar, nurseries may obtain a commercial license from the University of California that allows sale of trees. A per-tree royalty is assessed at the time of sale from the nursery and returned to the university. After patenting costs are recovered, part of this fee is assigned for overhead and part is returned to the department and breeding program. Patenting provides a return to the inventor and the university but also seeks to protect the growers from unlimited distribution. Patented material is not allowed to be sold or grown outside of California for five years after release. After that period, overseas licensing provides a return to the program that would not otherwise occur.

SUMMARY

In an increasingly globalized marketplace, technological advancement and improved efficiency is essential for survival. The UC Davis Walnut Breeding Program is but one aspect of a long-term, highly cooperative, and broadly based research effort in California, designed to solve problems for the State's walnut growers and to maintain a competitive and profitable industry. The contributions and cooperation of all interested parties has been the cornerstone of success.

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