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BREEDING IMPROVED PECAN SCION CULTIVARS

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ABSTRACT

Pecan breeding remains a long-term genetic improvement process. It produces high yield returns per research dollar invested. This paper describes the USDA-ARS pecan genetics and improvement program to develop improved scion cultivars. Some discussion of breeding theory and strategies is also included.

Pecan is diploid (n = 16), monoecious, and heterodichogamous. The complete heterodichogamy of pecan makes it almost completely cross-pollinated, resulting in very high heterozygosity with severe inbreeding depression when selfed. Hybrid vigor has been selected naturally in the evolution of this species. Pecan seems to be a naturally vigorous, wood-producing tree.

From a breeding standpoint, we know more about agronomic crops which are usually annuals than about tree crops that have much longer generation times. Impressive improvement has been obtained in pecan through selection, in only a few cycles of crossing. In other crops, breeding cycles usually mean more than one generation and usually involve selfing.

Every species has advantages and disadvantages to improvement through breeding. For instance, in maize (corn) breeding, a single good plant may be developed in a relatively short time, but there remains the problem of mass reproduction of this plant, while at the same time maintaining hybrid vigor and uniformity. In maize, this involves utilizing cytoplasmic male sterility to make the hybrid reproducible. This takes time to perfect in the hybrid combination desired. In breeding annual crops, a large portion of breeder time is spent perfecting a system to allow this reprocuction.

In pecan, by contrast, a single improved clone takes years to test, but during this testing phase, plants are genetically stable, since the genes of the clone are fixed. They do not change since asexual propagation (budding and grafting) is used to increase the number of individual trees. As a result, genetic variability is zero in evaluation trials.

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As mentioned earlier, pecan is diploid. This makes genetic selection more direct for both qualitative and quantitative characters. Hopefully, we can determine segregation ratios for more simply inherited traits in the future. For example, a single gene determines type of dichogamy in pecan. This knowledge is used to produce either protandrous or protogynous clones in the breeding program as needed. There may also be specific genes conditioning resistance to different races of the scab organism. The inheritance of many other traits is probably quantitative. Included here are such things as precocity, length and time of season of nut fill, and some disease and insect resistance mechanisms.

The ideal pecan cultivar should also make regular crops of high quality nuts. A major challenge in current orchards is the exaggerated pattern of alternate bearing. One possible strategy to achieve the goal of regular production is by selecting early maturing cultivars and selection for distribution of the crop throughout the canopy. Also, nut quality is difficult to maintain in very large fruited cultivars. Moderate size nuts (6-9 g/nut) borne in clusters of moderate size (2-4 nuts/cluster) that are well distributed throughout the tree, may facilitate consistent production of quality pecans. Trees which mature nuts in September may have the ability to regenerate exhausted energy reserves prior to dormancy, allowing for more consistent return crops. In addition, early pecans often receive higher prices, and generally mature under more favorable harvest conditions.

For its future economic survival, we believe the improved pecan industry needs high yielding, precocious cultivars. Cultivars should begin to bear in 4-5 years rather than 7-8 as in many older cultivars. Pecan orchards are capital intensive, long-term investments which become increasingly hard to justify as the length of time to economic return increases. Precocious cultivars are therefore a necessity. Increased yields are required to provide the incentive to bear the risk of orchard management. Currently, the costs of managing an improved pecan orchard in the southeastern United States are only barely exceeded by the sale of the crop (Wood et al. 1990). The most direct methods of addressing that situation by breeding are to increase the size and quality of the crop. Madden and Malstrom (1975) stressed the need for trees capable of being grown at high densities. Cultivars are currently being evaluated for differences in productivity as a function of tree size and shape. Ultimately, it is the responsibility of state researchers and pecan growers to develop orchard configurations which optimize productivity under existing management constraints.

Since most pecans are shelled before they are sold to the consumer, the ideal nut is one which performs best for shelling. Desirable attributes of shelling pecans were described in detail by Romberg (1968). The ideal nut shape is moderately elongated with a symmetrically rounded (not angular) apex and base. Shells should be thin, but not to the point of being damaged by routine harvest or handling

procedures. Sutures of the shell should not separate before harvest or during normal handling. When cracked, kernels should separate easily from the shell without adherence of shell parts. Kernels should be "golden" to "light brown" in color, to use the terms of the National Pecan Growers Association Standards. Other industry terms for those colors include "bright", "cream", "light amber", and "fancy". Kernels should be of good edible and storage quality and free of adhering "fuzz" (residual ovarian wall tissue), even when poorly filled.

Ideal cultivars will require a minimum of management input for the control of diseases and insects. Disease resistance has long been recognized as a necessity for the humid Southeast and has been a high priority of the breeding program as outlined by Crane et al. (1937), Romberg and Smith (1950), and Romberg (1968). Unless disease resistant cultivars can be developed, the southeastern pecan growing region is in jeopardy. The high economic and environmental cost of routine fungicide sprays places that region at a tremendous disadvantage in relation to the arid southwest where disease pressure is reduced. The challenge of developing disease resistant cultivars lies in thoroughly evaluating potential clones for disease resistance prior to release. This challenge has been addressed in the formation of the advanced selection testing program, and in the establishment of the College Station Pecan Breeding and Genetics Research Unit in humid East Texas.

Improved cultivars must be propagated on resilient rootstocks which contribute to the productivity and longevity of orchards, being adapted to both the climatic and edaphic region in which they are planted. As a first step, rootstock as a variable should be recognized and controlled in research and test orchards, as is the current practice in our test orchards. Improved rootstocks can be incorporated and tested as a normal part of scion clone evaluation.

CURRENT BREEDING PROGRAM

The U.S. Department of Agriculture, Agricultural Research Service, in cooperation with state agricultural experiment stations, state extension services, and private growers, conducts the only pecan breeding program in the world. The breeding efforts at the USDA Southeastern Fruit and Tree Nut Laboratory, Byron, Ga., are an important part of this single breeding effort to produce improved cultivars.

All of the above improvement dialogue relates to populations and fairly large numbers of plants. We feel that to continue the pecan breeding success, we must test large numbers of seedlings. The probability of producing a cultivar with a minimum level of genetic traits is the product of the individual probabilities. For example, if the probability of the progeny having at least a kernel percentage of 55 is .25 and the probability of nut size being at least 8 g is .5; then the probability of any clone produced meeting both these selection criteria is (.25) (.5) = .125, or 1 in 8. Thus 7/8 of the clones would be discarded. Additional genetic requirements would lessen the selected proportion. This is why we have essentially two selection cycles: the Basic Breeding Program (BBP) and the National Pecan Advanced Clone Testing System (NPACTS). Large numbers of seedlings are produced and eliminated in BBP based upon highly heritable, easily selected characteristics, while NPACTS tests are longer and test more for yield as mature trees.

The following selection scheme is currently being used:

Phase	Description	Years	No. Clones	Spacing (ft.)
I	Seed Production from crosses	1	5,000	—
II	BBP	10	5,000	10 X 15
III	Scab Screening	1	50	cont.
IV	NPACTS	15	5-10	35 X 35

PHASE I

The traditional crossing technique is used to produce up to 5,000 seed each year. Parents are selected on the basis of production, quality, and other performance considerations, recognizing that different geographic regions of the pecan industry have different requirements. The 20 cultivars released by the program (Table 1) represent the following 21 parents (with the number of released progeny in parentheses): 'Alley' (1), 'Barton' (2), 'Brooks' (2), 'Burkett' (2), 'Carmichael' (1), 'Clark' (1), 'Curtis' (1), 'Desirable' (2), 'Evers' (4), 'Halbert' (1), 'Mahan' (5), 'Major' (1), 'Mohawk' (1), 'Moore' (1), 'Odom' (2), 'Risien #1' (1), 'Schley' (5), 'Success' (4), 'Starking Hardy Giant' (1), 'Wichita' (1), USDA Selection 48-13-311 ('Moore' × 'Schley') (1). The 21 parents represent clones from six states: Florida ('Curtis' and 'Moore'); Georgia ('Brooks'); Kentucky ('Major'); Mississippi ('Alley', 'Desirable', 'Mahan', 'Odom', 'Schley', 'Success'); Missouri ('Starking Hardy Giant'); Texas ('Burkett', 'Carmichael', 'Clark', 'Evers', 'Halbert', 'Risien #1', 'Wichita', 48-13-311). Four parents, 'Barton', 'Mohawk', 'Wichita', and 48-13-311 are products of the U.S. Department of Agriculture breeding program. The parents reflect a broad range of the species distribution. Seven of the parents ('Burkett', 'Carmichael', 'Clark', 'Evers', 'Halbert', 'Major', and 'Starking Hardy Giant') are direct selections from native populations. Therefore, adequate genetic diversity is presently maintained. To some extent, progeny are used in the area of parental origin.

Crosses are made at Brownwood and College Station, Texas. The large amount of seed is possible due to im-

proved techniques of tree preparation and care, so that each crossed cluster produces more seed. Some trees in our crossing program routinely produce 2-4 nuts per cluster, compared with the average of less than 1 per cluster a few years ago. Seed from controlled crosses made in the breeding program is collected from mature clusters, numbered to reflect the year, parentage and seed number, and individually weighed and measured. Nuts are stratified for six weeks at 3C, then planted in the greenhouse. Height and stem diameters of young trees are recorded. Young seedlings are transplanted to the field during their first dormant season which begins Phase II (BBP) and are evaluated for 10 years.

PHASE II - BASIC BREEDING PROGRAM

Phase II, the BBP, is the initial field selection phase at Brownwood and College Station, Texas; for yield, precocity, nut quality, desirable leaf and tree structure, disease and insect resistance, etc. These trees are grown at relatively close spacing, and we plan to eliminate trees beginning in the 6th or 7th year based upon precocity, nut size, etc. This early elimination will allow more room for the more desirable clones to develop and be more adequately evaluated.

Seedlings are evaluated for resistance to scab and other diseases when they develop sufficiently in the breeding nursery. Nuts are harvested and a nut sample is evaluated. Measurements include nut weight, nut volume, nut length and width, kernel weight, and kernel color. Samples are also rated for adherence of packing material and fuzz. Initial selection is on the basis of yield, precocity, nut size, % kernel, shelling quality, and scab resistance. Threshold levels of nut measurements for initial selection, regardless of target region, are 7 gm/nut and 55 % kernel, with wide and open dorsal groove formation which permits complete removal of shell particles. Only 1 or 2 of these clones are saved per thousand for Phase III or Phase IV NPACTS testing.

PHASE III

The purpose of this phase is to determine the scab resistance level of superior clones from Phase II. Through a cooperative agreement between The USDA-ARS Southeastern Fruit and Tree Nut Research Laboratory at Byron, Ga., and Simpson Nursery of Monticello, Fla., 50-100 clones are grafted onto container trees, and these stions are grown in a severe scab disease environment. Resistant clones are identified and these trees are transplanted to the field at the Byron Lab and at other NPACTS sites where they undergo further production testing (Phase IV, NPACTS, described below).

PHASE IV - NPACTS

In NPACTS, elite clones from Phase II and III are tested in replicated trials across the entire pecan belt, mainly for environmental adaptation. NPACTS consists of four testing areas, each with a horticulturist conducting this testing work:

Area	States	Scientists in Charge
Area I	Fla. Ga. Ala.	Dr. Morris Smith, Byron, Ga.
Area II	La. Miss.	Dr. Mike Smith, Stoneville, Miss.
Area III	C. Texas Okla. Kan. Mo. Ark. Neb.	Drs. L.J. Grauke and T.E. Thompson
Area IV	W. Texas N.M. Ariz. Calif.	Drs. L.J. Grauke and T.E. Thompson

Testing is often done cooperatively with growers, state experiment stations, state agricultural extension services, and universities. These NPACTS tests are production tests, and are conducted using the standard cultural and production recommendations for each NPACTS location. Selected individuals are propagated on standard rootstocks in replicated, randomized complete block orchard configurations for intensive testing for 15 years. Selected clones are propagated on standard rootstocks for each NPACTS area and are compared to industry standard cultivars, such as 'Desirable', 'Western Schley', and 'Wichita'. Aspects of production, nut quality, phenology, growth, and insect and disease resistance are systematically evaluated in relation to outstanding cultivars in each region. Trunk diameter, mean previous-season shoot length, canopy width, and tree height are determined during the dormant season. Budbreak and dichogamy are determined to estimate suitability of clones to serve as pollinators for other clones, and to access the probability that they will be well pollinated by clones of opposite dichogamy. Disease damage is rated during the growing season as damage from scab, vein spot, fungal leaf scorch, shuck disease, etc., becomes apparent. Normally, insects are chemically controlled, but genetic differences are rated as the opportunity arises.

Yield determinations are of greatest importance with actual yield for each tree being recorded every year. Date of shuck split is recorded to determine harvest date for each clone. Mean number of nuts per cluster and percent terminals with clusters are determined. Time of leaf drop in the fall is recorded since trees which hold healthy leaves longer are less likely to alternate bear. Methods of evaluation are standardized across locations, with evaluation procedures

being continually refined. Clones which perform well in these NPACTS tests, compared to industry standard cultivars for the area, are released as new cultivars. A new cultivar could possibly be released every 2-5 years. This means that about 10,000-25,000 clones may be screened in the entire breeding program to produce a single new cultivar. This figure seems quite realistic from a genetic standpoint when projected heritabilities of different traits are considered. Table 1 shows the pedigree and other information for the USDA-ARS/state released cultivars.

RELATED RESEARCH

Basic research related to the breeding program consists mainly of techniques to improve breeding efficiency. One of the most direct needs is a technique to induce early flowering in juvenile clones at perhaps 2-3 years of age. Currently, most pecan seedlings flower at 6-7 years of age. We have induced early flowering in pecan on 15 month old clones (time of germination to pistillate flower production). The frequency, however, was very low, and to be useful as a standard breeding technique, the frequency must be greatly increased. Early flowering has been accomplished in some other tree species, but specific techniques to accomplish this in pecan have not been developed. The benefits of such techniques are obvious in selection programs to radically alter gene frequencies which control important traits; such as yield, nut maturity time, and disease and insect resistance.

Pecan is considered by some to be a relatively inefficient food production crop. We feel the main reason for this is its late nut filling period. The pecan kernel begins to form about August 15. This is a period of the year when the days are becoming shorter (less light for photosynthesis), the leaves have been damaged by insects and diseases all season, the roots are competing with the nuts for photosynthate to replenish root carbohydrate reserves for winter and spring growth, and perhaps soil moisture and nutrients have been exhausted by six months of active growth. This heavy masting effect late in the season also induces the absence of flower production the following spring which accentuates the alternate bearing syndrone in pecan. Perhaps this alternate bearing was needed in the wild to escape nut feeding insects, but it is definitely not needed in improved orchards.

The basic consideration here is that the pecan tree is designed wrong for maximum nut production. It is too much a forest tree designed to effectively compete with other species for space in forest canopies. This is mainly related to fast vegetative growth which is needed for competitive survival in the wild, but exactly what is not needed in developed orchards where competition is artificially removed. The idea is to direct more photosynthate into the earlier production of nuts and less into the production of unneeded wood.

We feel late nut development in pecan has resulted from selection induced by animals feeding on the earliest maturing nuts. This effect is obvious in stands of clones, some of which mature early. These nuts are completely destroyed by feeding animals in the area. Clones with nuts maturing later partially escape this severe feeding pattern, and a portion of the nuts are stored underground by squirrels or otherwise allowed to germinate the following Spring. It is interesting that pecan is one of the latest species, as far as developing nuts, in the *Carya* genus. We believe this is the result of animal selection. We would guess that time of filling is largely a quantitative trait, and a few sexual generations will be needed to radically alter it. The importance of a technique to artificially induce early flowering here is obvious.

The nut filling period may also be too short in pecan. Lengthening this period in some other crops has improved yieldability.

The xenia effect or the immediate effect of the pollen on nut filling and development is also being studied. The presence of this effect in species related to pecan has been documented and some studies have been completed on pecan. It seems obvious that pollen source is important in nut development. We need to determine the value of this effect so that specific cultivar recommendations can be made when new orchards are established. We also now know that pollen from some cultivars reduce premature nut sprouting or vivipary. In the past, good pollination meant any viable pollen to effectuate fertilization. We now know that some pollen sources are much more effective in producing more and larger nuts after fertilization.

A need to control or reduce tree size is generally recognized in pecan. There has been some past reference to dwarf varieties that are currently available. For example, 'Cheyenne' is sometimes considered "dwarf-like." This terminology is unfortunate because 'Cheyenne' and some other clones are only slower growing, and are not really dwarf-like at all. Whether tree size can be reduced most effectively by discovering and using dwarfing rootstocks or by developing dwarfed cultivar (scion) clones is debatable. There are advantages to each. In Persian walnut production in California, small tree size results from genetic characteristics of the scion growing on a very vigorous rootstock. This should also work in pecan. In any event, hopefully future cultivars will be partially dwarfed by nut production or the absence of so much photosynthate available for vegetative growth in the Spring when most shoot extension growth occurs.

Heritability studies of different genetic traits are also conducted as a part of the breeding program. This knowledge allows the effectiveness of the breeding program to be improved, by more accurate prediction of how many clones of each cross will be lost due to inadequate yield potential, nut size, disease resistance, etc.

You can see that the USDA-ARS pecan breeding program conducted cooperatively across the entire U.S. production area consists of many varied and interrelated activities by breeders, geneticists, horticulturists, pathologists, and entomologists. It is the largest, and essentially, the only pecan breeding program in the world. To date (and in cooperation with state agricultural experiment stations), 20 improved cultivars have been released. Conservative estimates show that 1/10 of the extra crop value produced by just 'Wichita' is adequate to fund the USDA-ARS Pecan Breeding Program. Public funding of pecan breeding research is obviously an excellent investment in the future well being and nutrition of mankind.

Table 1. Cultivars developed cooperatively by the U.S. Department of Agriculture and state agricultural experiment stations.

Cultivar	Parentage	Selection	Released	Dichogamy
Barton	Moore X Success	37-3-20	1953	I
Comanche	Burkett X Success	37-8-22	1955	II
Choctaw	Success X Mahan	46-15-276	1959	II
Wichita	Halbert X Mahan	40-9-193	1959	II
Apache	Burkett X Schley	40-4-17	1962	II
Sioux	Schley X Carmichael	43-4-6	1962	II
Mohawk	Success X Mahan	46-15-195	1965	II
Caddo	Brooks X Alley	Philema 1175	1968	I
Shawnee	Schley X Barton	49-17-166	1968	II
Cheyenne	Clark X Odom	42-13-2	1970	I
Cherokee	Schley X Evers	48-22-27	1971	I
Chickasaw	Brooks X Evers	44-4-101	1972	II
Shoshoni	Odom X Evers	44-15-59	1972	II
Tejas	Mahan X Risien #1	44-10-293	1973	II
Kiowa	Mahan X Desirable	53-9-191	1976	II
Pawnee	Mohawk X Starking H.G.	63-16-125	1984	I
Houma	Desirable X Curtis	58-4-61	1989	I
Osage	Major X Evers	48-15-3	1989	I
Oconee	Schley X Barton	56-7-72	1989	I
Navaho	48-13-311 X Wichita	74-1-11	1994	I

Average Development time from crossing to release is 25 Years (Choctaw = 13, Caddo = 45).
Parentage: Mahan = 5; Schley = 5; Success = 4; Evers = 4.