California Avocado Society 1992 Yearbook 76: 61-75.

The Origin, Nature, and Genetic Improvement of the Avocado

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Presented by the author at the biennial Conference of the Australian Avocado Growers' Federation, Gold Coast, Australia, September 28-October, 1992.

Abstract. Discussion of avocado botany, including the three horticultural races. Three root characteristics and their consequences. Race differences in root traits. The avocado's historical importance. Its world spread. Present world distribution with relative rankings. The unique avocado flower behavior. Breeding methods: self-pollination, cross-pollination, pollinators, pollination methods, artificial mutation, spontaneous mutation (and budwood cutting). Breeding results. The 'Gwen'. New selections. Biotechnology. Propagation and tree structure.

Origin and Botany

The avocado *(Persea americana* Mill.) is in the Lauraceae family. The *Persea* species are classified into two subgenera, *Eriodaphne and Persea. Eriodaphne* contains most of the hundred or so probable species, including a few with iron-clad resistance to the great world-wide avocado scourge: root rot caused by *Phytophthora cinnamomi. Subgenus Persea* contains the commercial avocados, in genus *Persea,* species *americana.* Unfortunately, the two subgenera have so far proven totally incompatible; we can only hope that future biotechnology will enable us to bridge this chasm and so benefit the avocado with *Eriodaphne* genes.

The exact number of genus *Persea* species is unknown. There have been reports of *Perseas,* or closely related species, in the Japan-Taiwan-southern China region. There is even a rumor that a form from there, tentatively described as genus *Machimus,* is actually graft-compatible with *P. americana,* and may even have rootstock advantage. The whole matter needs early, thorough investigation.

Subgenus *Persea* includes the avocado, *P. americana,* and a few related taxa. These taxa range from an apparently good species, *P. schiedeana,* through several questionable species (Zentmyer and Schieber, 1990), to several forms that are probably best considered to be additional subspecies of *P. americana (Berg et al.,* 1973).

These close relatives of the avocado, in subgenus *Persea,* all occur primarily in the same region: central Mexico through Guatemala into adjoining Central America. Moreover, primitive avocados have been found in a few places in the same general areas, supporting the evidence for it as the center of origin of the avocado and the whole subgenus *Persea* complex.

The Three Horticultural Races

The commercial avocado, *P. americana,* is classified into three subspecies (or botanical varieties): *americana, guatemalensis, and drymifolia (Bergh* and Ellstrand, 1986). These three types are also referred to as ecological races, and for several decades they have been known as, respectively, the West Indian, Guatemalan, and Mexican horticultural races. Thus, *P*. *american* subsp. *drymifolia* is the Mexican race of avocado. Both the Mexican and Guatemalan races are thought to have originated in the countries for which they are named. However, there is now good historical evidence (Storey *et al.,* 1986) that the so-called West Indian race actually originated along the Pacific coast of Central America; so it would more accurately be named the "Lowland" race of avocado. For the same reason, the West Indian race might better be designated *P. americana* subsp. *"occidentalis ";* we now know that in all probability it was not the first avocado form discovered by Europeans-the assumption that caused it to inherit the subsp. *americana* designation more or less by default.

Williams (1977) placed the Guatemalan race into a species separate from the other two races; but all the available evidence considered jointly rather clearly points to a preferable conspecific designation: the three are one species, with the subspecies about equally distinct (manuscript in preparation).

The racial order of increasing tropical adaptation is Mexican, Guatemalan, West Indian. In truly tropical climates, only the West Indian race is well adapted: Guatemalan and especially Mexican lines usually set poorly and any fruit is more subject to pests and diseases. Conversely, in the coldest avocado regions, only Mexican-race lines will survive, and in the less rigorous climate of California, the tender West Indians fail to fruit, or even to flower, in spite of good growth and apparent good health; the cause is apparently not day-length, and merits study. However, these limitations are largely limited to pure lines: hybrids of lines of contrasted adaptation usually have wide adaptation.

These differences in climatic adaptation of the three races are reflected in the observations of Popenoe (1952 and earlier references therein) on respective performances at constant Torrid Zone latitude. From sea level to about 1,000 in altitude, the West Indian race is adapted, with such other fruits as mango and breadfruit. From about 1,000 to 2,000 in, the Guatemalans are adapted, with citrus, cherimoya, etc. From about 1,500 to 3,000 m, the Mexican lines do best, with apple, peach, etc. However, all three races do well side-by-side in parts of Israel, Morocco, and perhaps elsewhere.

The three races (subspecies) differ in many respects additional to that of climatic tolerance. There differences are detailed in Table 1.

Table 1. Comparison of the three horticultural races.

TREE- GENERAL	Mexican	Guatemalan	West Indian
Native Region	Mexican Highlands	Guatemalan Highlands	Tropical lowlands
Climactic Adaptation	Subtropical	Subtropical	Tropical
Cold Tolerance	Most	Intermediate	Least
Salinity Tolerance	Least	Intermediate	Most
Iron Chlorosis Tolerance	Intermediate	Least	Most
Alternate Bearing	Less	More	Less
FORM			
Internodes	Longest	Long	Shortest
Twig Lenticels	Pronounced	Absent	Absent
Bark Roughness	Less	Less	More
Stem Pubescence	More	Less	Less
LEAF			
Size	Smallest	Large	Largest
Color	Green	Green	Pale Green
Flush Color	Greenest	Reddest	Yellowish-green
Anise	Present (usually)	Absent	Absent
Underside waxiness	More	Less	Less
FLOWER			
Season	Early	Late	Early/Intermediate
Bloom to maturity	5-7 months	10-18 months	6-8 months
Perianth Persistence	Greater	Less	Less
FRUIT PEDICEL			
Length	Short	Long	Short
Thickness	Medium	Thick	Thin
Shape	Cylindrical	Conical	Nailhead
FRUIT			
Size	Tiny-Medium	Small-Large	Medium-V. Large
Shape	Mostly elongate	Mostly round	Variable
SKIN			
Color	Usually purple	Black or green	Pale green – maroon
Surface	Waxy coating	Variably rough	Shiny
Thickness	Very thin	Thick	Medium
Stone cells	Absent	Present	Slight
Pliability	Membraneous	Stiff	Leathery
Peeling	No	Variable	Yes
SEED			
Size ratio	Large	Often small	Large
Coats	Thin	Usually thin	Thick
Tightness in cavity	Often loose	Tight	Often loose
Surface	Smooth	Smooth	Rough

PULP			
Flavor	Anise-like, spicy	Often rich	Sweet, mild
Oil Content	Highest	High	Low
Distinct Fibers	Common	Less common	Intermediate
COLD STORE TOLERANCE	More	More	Less

The Guatemalan has overall the highest horticultural quality, but hybridization with the other two races confers two major advantages. First, harvest season: The Mexican and West Indian are much earlier-maturing, so varying hybrid mixtures greatly extend the maturation period. Second, climatic adaptation; here the other two races extend in opposite directions, with the West Indian conferring good adaptation to tropical regions and the Mexican providing greater frost tolerance. The leading 'Hass' cultivar is considered an unusually cold hardy (and early maturing) Guatemalan- my study of its seedlings from self-pollination suggest that it is perhaps 15 % Mexican.

Avocado evolution was probably under three circumstances that affect the present nature of its roots. First, frequent good rains, as shown by its marked drought sensitivity. Second, rapidly draining soils, as shown by its great sensitivity to asphyxiation. Third, a rich surface organic mulch, as shown by the striking tendency of the healthiest roots to work up into any decomposing litter. All three probable circumstances are compatible with reasonable assumptions of the climate and soil under which the avocado has evolved to its modern forms.

The first two avocado needs are widely known, since their absence has prompt, dire consequences. The third is seldom recognized, at least in much of the avocado world, because the postulated harmful affects of its absence are much less obvious. Indeed, it is not clear that a surface mulch is of real benefit in all avocado-growing regions. From my subjective observations of rooting habit and tree behavior in California, I am convinced that at least here such practices as leaving low branches to hold leaf litter, and even adding other inexpensive organic matter at the tree drip-line, have various advantages for the tree that together well outweigh their disadvantages. However, to my knowledge, there have nowhere been the careful experiments needed to test this, apart from root rot considerations.

In certain other soil-related characteristics, the three races differ. The Guatemalan and especially the Mexican forms are highly sensitive to free salts; this also fits in with our assumptions of ample rainfall with good soil drainage. The Mexicans and especially the Guatemalans are highly subject to chlorosis. West Indians are much more tolerant of both adverse conditions; their salt tolerance is presumably related to their lowland origin, with perhaps seasonal periods of salty inundation-in Raratonga I saw oceanside trees with watersoak marks many cm up the trunk. Always, with a plant as genetically highly variable as the avocado, there are considerable differences within each race for all of these root characteristics (and indeed for most of the traits in Table 1). One example: above I noted the avocado's 6 4marked drought sensitivity"; the apparent remarkable drought tolerance of Guatemalan seedlings in the hills by Lake Atitlan needs thorough study.

Importance

Burger and Werff (1990) agreed with earlier assessments that the avocado is the most nutritious of all fruits. "The high food quality of the avocado is probably due to coevolution with birds that are fruit-eating specialists and depend on these fruits for nearly all their nutrition." Presumably, the coevolved gain to the avocado would be seed dispersal, from strong-winged birds carrying the fruit away to nests and other feeding sites.

For thousands of years, the avocado has had an important place in the native diets of Mexico and Central America; Mexican archaeological evidence indicates that there already was human consumption nearly 10,000 years ago (Smith, 1969 and earlier). A common saying in Latin America is some version of: "A taco and an avocado makes a good meal." And, it has long been referred to there as "the butter of the poor." This presents a couple of ironies: its monounsaturated fat makes it a much more wholesome spread for breads than the true butter of those who could afford it; and, in developed countries away from its lands of origin, the avocado often costs more than dairy butter per usable portion.

Its widespread usage among many native tribes resulted in a plethora of local names by the time that Europeans reached the "New World." The conquistadors picked up on the Aztec 'ahuacatl', corrupting it to 'ahuacate ('aguacate'), which English listeners further corrupted into 'avocado’. For a time in early California, three names vied for support: avocado, aguacate, and (because of the rough skin of some forms) alligator pear. Fortunately, "avocado" triumphed, became the standard in the English-speaking world, and also led to similar names in some other European languages.

Its long history of usage in Latin America explains why the avocado is so near-universally liked and therefore so avidly eaten in those countries. It has a unique flavor among fruits, being neither sweet like most nor tart like citrus; this uniqueness makes it more difficult to introduce to adult consumers. But when people are exposed to it from childhood, most will become enthusiastic eaters. Thus, it may require generations to build up to its consumption potential.

In spite of this growth impediment, by 30 years ago (Ochse *et al.,* 1961), the avocado has spread around the world where the climate is suitable, rising from general obscurity to become the fourth most important tropical fruit apart from citrus. It continues to increase in importance in many places. Farm value of California production is now about $200 million per year. Yet, much of the United States remains an undeveloped or at least underdeveloped market, as is true of most of the world.

Production distribution

When Europeans came to the Americas and discovered the avocado, they were sufficiently impressed with the fruit that they began spreading it around the tropical and subtropical world. It is now distributed world- wide where adapted and is among the top half-dozen contributions of the New World to the human diet. However, because of its unique character, as noted above, its popularization is slower; the western hemisphere still accounts for about 3/4 of world production (Fig. 1).

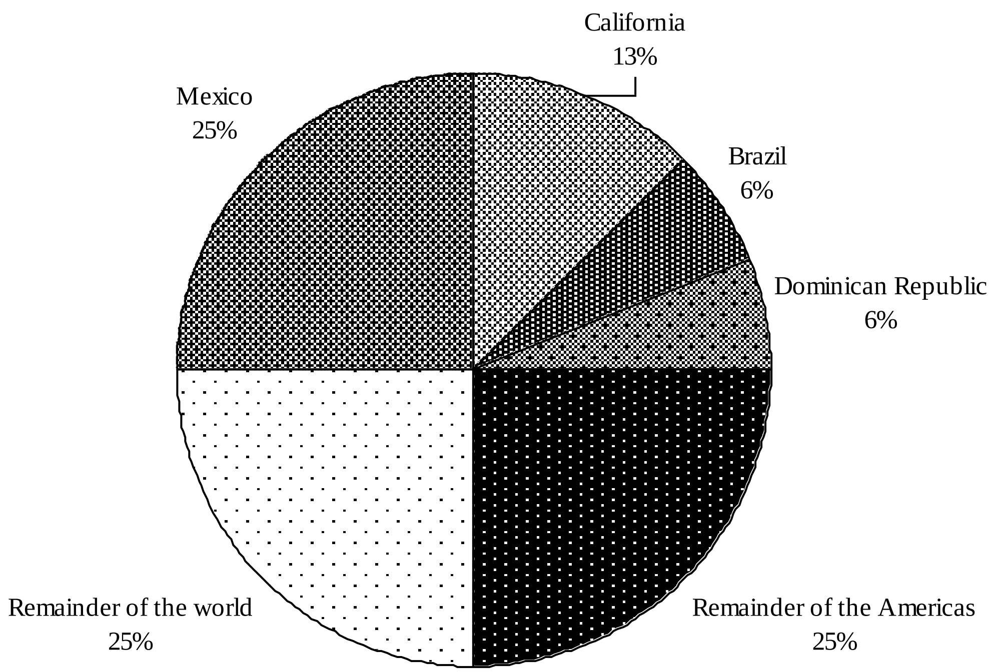

Fig. 1. Relative World Avocado Production.

Everywhere, production varies from year to year, and estimates from some countries are much less accurate than from others, but the pre- eminence of Mexico (Fig. 1) is clear. This pre-eminence is due to three factors. First, the accident of botanical history that located the avocado here where people have been eating it for millennia-much longer than needed to overcome the inherent obstacles to its popularization that we have noted. Second, the fact that its climate is suited to one or more of the three races over much of the country; in particular, that it has an immense area adapted to the outstanding cultivar from California, the 'Hass'. Third, just the country's large size. So Mexico produces roughly one-quarter of the world's avocados.

California is in second place, with about one-eighth of the total (Fig. 1). For a time in the early 1980s, the California industry expanded rapidly. However, California acreage is now slowly declining, under the twin pressures of population influx (the small United States acreage suitable for avocados is limited to the climates most preferred by humans); and escalating water costs and scarcity (aggravated by several years of drought).

Next come the Dominican Republic in the West Indies and Brazil in South America with a little over 1/16 of world production each. The Dominican Republic illustrates the combination of the first two advantages of Mexico (many generations of consumption plus general climatic suitability) with absence of the third-it has less than 1/10 as many people (yet, produces about 1/4 as many avocados). Brazil illustrates somewhat of the reverse: nearly twice the population of Mexico, but with a shorter history of consumption and with its climate largely tropical; much of its production is from seedling trees of the west Indian race, so that highly variable, mediocre fruit is crowded into a short market season at low prices - here as some other places there is great need for the introduction of better cultivars to improve quantity, quality, uniformity, and seasonal distribution.

Thus, just four states account for a good half of world avocado production. And half of the remainder also comes from the Americas. Significant amounts are grown in Florida in the United States, Haiti in the West Indies, Guatemala, El Salvador and Costa Rica in Central America, and in South America a counter-clockwise sweep from Venezuela through Colombia, Ecuador, Peru, and Chile.

The rest of the world shares the remaining quarter. In Africa, the leader is South Africa, followed by Madagascar and several west central nations. In Europe, Spain has an expanding industry. In Asia, Israel has a large one. In the western Pacific Ocean, the chief producers are Philippines, Indonesia, and Australia. Many other countries have smaller but significant avocado enterprises. Only Israel and South Africa are major avocado exporters; Mexico's foreign sales are increasing.

Genetic Variability

The avocado exhibits "protogynous dichogamy" (Bergh, 1974). Each flower opens twice: in the first opening it is functionally female (pistil receptive), after two or three hours it closes, and then the next day when it opens again it is functionally male (pollen shedding). With up to a million flowers per tree, there may be thousands opening either male or female each day. All flowers that have their first (female) opening that day will tend to open and close at the same time. Similarly, all flowers that had been functionally female the previous day and are therefore now having their second (male) opening will open and close in near-unison. Moreover, the female and male open periods are usually discrete (often on opposite sides of noon), making self-pollination difficult. Finally, avocado seedlings and cultivars are of two contrasted flower types: 'A' female in the morning and male in the afternoon, and 'B', just the reverse; so the two types provide "synchronous daily complementarity" for pollination-each is pistil- receptive when the other is shedding pollen.

As the avocado occurs naturally, there would probably be a mixture of A and B seedlings, and so abundant cross-pollination. There are different means for circumventing this anti-selfing mechanism, as nature provides a "fail-safe" means to permit fruit (seed) formation in the absence of foreign pollen. But, nature also has a second way of favoring hybrids-a sort of reverse fail-safe to minimize selfing as much as possible: when both selfs and hybrids set on a tree, the selfs are much more likely to abscise during subsequent fruit development (Degani *et al,* 1989).

Thus, nature has designed avocado mechanisms that maximize outcrossing, thereby maximizing genetic variability, and so maximizing adaptation to the maximum number of environments. That is, nature advances by biological evolution; and in the case of avocado it has thereby given us a genetically highly heterogeneous plant. We humans have increased this diversity further by planting together genetic types that were geographically discrete in nature, thereby combining the three races and also permitting hybridization of genetically distinct forms within the races.

Breeding Methods

Avocado breeding is discussed in detail elsewhere (Bergh and Lahav, in press). Any approach must reckon with the genetic great variability noted above.

Self-pollination. Because of this immense heterozygosity, any one cultivar or seedling tree is likely to have genetic potentialities for a broad array of root, shoot, and fruit characteristics. Thus, self-fertilization can be expected to provide a wide spectrum of offspring differing in fruit size, shape, skin color, flesh color, seed size, and all the other traits of commercial interest. When a single parent has all potentialities desired, cross-fertilization is unnecessary. Initial selfing followed by less severe inbreeding has probable advantages:

1) better evaluation of breeding worth,
2) elimination of harmful recessive alleles for future breeding,
3) greater homozygosity and so more predictable breeding behavior,
4) reduction of excess vegetative vigor, and
5) requiring self-fertilization, to reduce the commercial need for cross-pollination.

In spite of nature's favoring avocado outcrossing as noted earlier, selfing is successful in varying degree.

Cross-pollination. It can have two significant advantages: (1) if overdominance or epistatic interactions prove of importance, and (2) with phenotypic extremes, where optimal segregants are unlikely or impossible. An example is extending the marketing season or climatic adaptation of the superior Guatemalan-race avocados, by hybridizing with either of the other two races. Again, a cultivar or selection may have outstanding breeding traits, but be so large- or small-fruited, or so far from the optimum for some other commercial trait, that one could expect very few of its selfed progeny to be commercially acceptable; one can greatly increase the chances of commercial success by hybridizing such an avocado with one that had the opposite phenotypic extreme (plus other good qualities).

Pollinators. The avocado is insect-pollinated-pollen tends to clump and fall to the ground rather than dispersing in air movement. In the less tropical regions where are found most of the world's production and a still higher proportion of avocado research, the chief pollinating agent is the honey bee *(Apis mellifera).* However, this insect was introduced only recently to southern North America-where the avocado evolved; we need a study of avocado pollination in this region, with the hope of identifying a pollinator that is fonder of avocado flowers and more efficient at their pollination, as well as manipulatable by humans. In the meantime, bee- proof caging materials are used in the established breeding programs.

Pollination methods. There are basically three:

A) Hand pollination, inside light-transmitting tree cages (or branch sleeves) to exclude bees. This procedure seems highly inefficient, because an avocado tree may have a million flowers of which less than 0.1% can possibly yield mature fruit. However, by limiting pollination to the most promising flowers and using a number of other helps (Bergh and Lahav, in press), this approach may be feasible. Its usage is largely restricted to hybridization, and it is the only way to obtain positive hybrids. The availability of heavier- setting selections like the 'Gwen' makes hand pollination more practicable in breeding (S. Gazit, private communication).

B) Caged tree(s) with bees (and water). For self-fertilization, have only one breeding parent inside the cage. For cross-fertilization- which will also give an uncertain mix of selfs- have paired breeding trees, or cross-pollination grafts in the basic tree(s). Requires much less labor than does hand-pollination.

C) Isolated open-pollinated trees. This is much easier yet; the bees do it unbidden. For self-fertilization, simply locate tree(s) well removed from any other genetic line. How "well removed"? We can say with certainty only "the more isolated the better." Isolation involves any impediment to bee flight, especially distance. In California at least, bees can cross-pollinate more than 1 km (Torres and Bergh, 1978). Cross-fertilization is again obtained by combining two (or more) genetic lines in the isolation plot, again obtaining a variable mix with selfs.

Artificial mutation. This is not a promising approach for a highly heterozygous plant like avocado. However, fast neutron radiation of 'Duke' scions produced a selection, D9, that has some resistance to the root rot fungus, *Phytophthora cinnamomi,* and some early dwarfing of scions grafted to it. It also has produced offspring with an unusually high proportion of resistance seedlings.

Spontaneous mutation. This is probably much more important than is generally recognized. Sports affecting avocado fruit shape and surface are easily recognized; none has proven of commercial value to my knowledge. Much harder to identify and likely much more important are mutations that affect tree productivity. These can be demonstrated only by large-scale testing (Hodgson, 1945; Ben-Ya'acov, 1973); the great majority of productivity mutations would be expected to have relatively small (but economically important) effect, and so go unrecognized. Aggravating the situation is the notoriously erratic nature of avocado production apart from genetic differences-due to differences in weather, soil, care, etc. Even within a tree, purely environmental differences in previous bearing, or light, or unknown factors, can cause set differences.

A perpetual danger is this: The propagator goes out to cut budwood from a tree with a favorable yield record. As a good propagator, he knows good buds, and selects accordingly. Usually, his superior buds are such because that branch or branch-sector happens to have been in a low year for fruiting. But, sooner or later, superior buds will be the result of permanently reduced set from genetic mutation. Without detailed yield records for preferably four years, environmental versus genetic causes of 'low set-good buds' may be confounded. Long-time California Farm Advisor Don Gustafson has opined that the productivity of California avocado varieties tends to deteriorate with repeated propagations; he suggested that propagation might gradually accumulate yield-reducing viruses-no such viruses have been as yet identified, and I consider yield-reducing mutations to be more likely. I think that I may have observed the striking results of one such, in New Zealand.

However, this danger can be reversed into ultimate yield advantages. By careful tree-branch records, the propagator can sooner or later pick *up yield-increasing* mutation. Beneficial mutations are probably less frequent than deleterious ones, but should occur.

Breeding Results

Nearly all avocado cultivars world-wide have arisen as chance seedlings, including the increasingly dominant 'Hass' 'The Israeli breeding program has produced the 'Iriet' 'which they do not expect will achieve major importance, plus a number of newer selections for which a prognosis is premature. The 'Ardith' is being planted on a moderate scale in Israel; it was produced by the California breeding program but appears to have no real value here.

The University of California-Riverside program also produced 'H287' which has been planted on a small scale, and 'H670'. The latter is so much like 'Hass' that neither fruit nor tree can ordinarily be distinguished; it may be a 'Hass' mutation, or just a virus-free 'Hass'. Some growers consider it superior to 'Hass'. Then there are three heavy-bearing patented cultivars from California: 'Gwen', 'Esther', and 'Whitsell'. The latter two have encountered problems, especially regarding fruit quality, and are no longer recommended for California.

'Gwen'. Its future is uncertain, even in California. It is a 'Hass' "grandchild," a little larger-fruited, of equally high quality, and remaining green-skinned when ripe. For weeks after the flesh has matured to palatability, the skin continues to shrivel as the fruit ripens, delaying its commercial maturity to later than that of 'Hass'; it remains quite palatable later in the season than 'Hass' '

A few hundred 'Gwen' trees have been grown on University property, mixed with other cultivars and seedlings, in different climates, soils, fertilization regimes, and irrigation methods. Every tree has set heavily and consistently. In California, the 'Hass' standard averages barely 9,000 kg/ha on mature trees. In the major, replicated comparison of 'Hass' and 'Gwen', 'Gwen' set one year after topworking at a calculated rate of 21,000 kg/ha, and the following year at just over 49,000 kg/ha. Subsequent production has varied somewhat, especially with adverse weather, but has averaged quite high. The 'Hass' grafts under similar conditions have set about as expected-much less precocious than 'Gwen’, but settling down to average about 12,000 kg/ha calculated, compared with 'Gwen' at about 30,000.

However, on private commercial properties 'Gwen' fruit set has been erratic. A few places it has been so disappointing that the trees have been topworked to 'Hass'! The 'Gwen' tree is much slimmer than the 'Hass' (so about twice as many can be planted per acre) and also considerably shorter as grown and producing on University property. But where it fails to set properly it is even slimmer and much taller-approaching 'Hass' height; its favorable tree becomes unfavorable. Moreover, even when 'Gwen' has set well it has sometimes dropped immature fruit to a serious degree, leaving a mediocre crop or worse.

Why this erratic performance? One explanation is exceptional weather: in the past few years parts of California have experienced their worst freeze in over 40 years, and an anomalous heat wave during one blooming period wreaked havoc; the generally younger and naturally smaller 'Gwen' trees were more susceptible to both temperature extremes. But this is only a partial answer; some 'Gwens' have set poorly or dropped fruit in spite of seemingly normal weather.

Another explanation is lack of cross-pollination. We now know that probably every avocado cultivar in California will bear better with suitable cross-fertilization. This certainly included 'Hass'; but 'Gwen' may need it much more-at least under some conditions. This explanation fits with the heavy University production, and also with the heaviest 'Gwen' yield that we have ever seen: a private grower who had a small commercial set just eight months after topworking and a calculated yield of over 60,000 kg/ha the following year. In both cases there were a number of other cultivars close at hand.

More direct evidence is provided by the large Markle grove of topworked 'Gwens'. Production has been well below 'Gwen' expectations, with inclement weather considered the likely culprit. The trees had originally been 'Zutanos', of which a few were still scattered irregularly around the grove because of graft failure. This past season, Tom Markle made laborious fruit counts on the 'Gwens' and then by computer analyzed set in relation to cross-pollination opportunity: the greater the opportunity the greater the average set, and 'Gwens' closest to 'Zutano' averaged several times as much fruit as those farthest away.

But again there are caveats. One 'Gwen' grove has had only moderate production in spite of nearby plentiful trees of 'Fuerte'-which is more cold hardy as well as being of the contrasted "B" flower type. And it lone 'Gwen' tree at Riverside, so far from any possible cross-pollinator that we would expect little if any benefit, set heavily year after year.

We have closely monitored the largest known grove of 'Gwen' nursery trees, managed by Warren Currier, planted in 1985. The grove is quite isolated; we have hunted in vain for cross-pollinators within a km or two. In 1988, by fruit count it produced about 24,000 kg/ha-over ten times what would be expected from 'Hass' trees of that age. But the next three springs, with or following unfavorable weather, saw disappointing set twice and severe fruit drop the third year. This past spring, following an only fair crop on these 'Gwens' as in the industry generally, weather conditions were fine, and California 'Hass' trees are bouncing back with what so far appears to be their heaviest average yields ever (15,000 kg/ha?). The Currier 'Gwens' are carrying a crop now estimated at a harvest of 48,000 kg/ha.

What are possible conclusions from all this?

I. The 'Gwen' (and perhaps other very heavy producers?) may be more sensitive to the need for cross-pollination, for normal weather, and perhaps for different aspects of tree care. (There may be complex interactions-the University 'Gwens' continued to bear well through the off-climate seasons).

II. Therefore, superior 'Gwen' performance in test plots anywhere, such as if this occurs in Australia, should be treated cautiously; cross-pollination may be needed, at least with some weather or some other conditions.

III. With any new variety, it may take considerable time and experimentation before the requirements for optimum performance are identified. I am far from certain that cross-pollination and weather are the full explanations of the unpredictable 'Gwen' behavior-possibly some mineral nutrient or some factor as yet unthought of would remove the need for both.

IV. Although 'Gwen' bugs remain to be worked out-and may never be fully-the 'Gwen' and several of our other selections clearly show that 'Hass' productivity is far below the avocado potential. At least in California, I do not expect the 'Hass' to be the dominant cultivar indefinitely.

New selections. Unfortunately, freezes wiped out about half of our breeding trees. With other losses on private properties, we are now down to about 12,000 seedlings. Fortunately, some of these lines, particularly 'Gwen' progenies, are of higher breeding value, and so are giving us good numbers of new selections.

These selections are based on a total of 40-some criteria. They can be summarized as an avocado that "bears well, looks well, ships well, and eats well." We aim to maintain 'Hass' quality while sharply increasing its productivity. That this aim is realistic is indicated not only by selections like 'Gwen', but more broadly by increased general seedling precocity and productivity that have led over three decades to an approximately 3-fold increase in breeding efficiency: seedling spacing reduced in-row from 3 to under 2 m, and seedling retention reduced (barring set mishap) from 10 to about 6 years. We consider increased productivity essential to the maintenance of a large and profitable California industry, against the competition from both other foods and other avocado producers-especially in the face of huge and growing water costs and shrinking land availability. As production per hectare goes up, production cost per kilogram goes down. We believe that smaller trees like the 'Gwen' make possible greater productivity by exposing more leaf surface to sunlight-besides advantages in fruit picking costs and tree spraying, etc.

Some two-dozen new selections were made this past year. Grafted selections from recent years set significantly for the first time last spring. Better information on productivity, season, and fruit quality (including commercial-type storage of those that look best) is now coming in rapidly. I will be mentioning a few outstanding selections, but ratings are changing from month to month and will probably do so with disconcerting rapidity for the next year or two.

Biotechnology

This promises to be a powerful new tool for expediting a breeding program. M. T. Clegg of Riverside is making good progress developing avocado DNA markers. Such have already been used to positively "fingerprint" new selections, and to identify parentages. The hope is that eventually such markers will locate chromosome gene regions segregating for commercial traits, thereby making avocado breeding much more efficient.

A different aspect of new biotechnology is devices such as protoplasmic fusion for uniting germ plasms that are at present hopelessly separated. Much greater resistance to *Phytophthora cinnamomi* root rot comes immediately to mind, by incorporating in the avocado the abundant resistance that now sits unavailable in *Persea* subgenus *Eriodaphne.* The fruit itself seems unlikely to be improvable by this means, but other rootstock traits may well have valuable breakthroughs: dwarfing; resistance to salt, chlorosis, asphyxiation, drought; better utilization of the soil profile; productivity itself.

Propagation and Tree Structuring

These topics arise from the need to test out selection trees. So we published a detailed booklet on avocado propagation (Whitsell *et al.,* 1989). Since then, we have made a number of new advances of which the most important probably are the use of:

- parafilm for wrapping grafts,
- aluminum foil for greatly extending our summer grafting season,
- next-year rootstock suckers for topworking large old trees, rather than bark-grafting the stump, or sucker-grafting the first summer, and
- after-graft care involving a central leader.

After topworking the usual procedure is to stake the new shoots, or at least head them back to prevent wind breakage, and then just let the multiple branches "sort themselves out." We have found that it works better to select one good shoot, nip back the others, and eventually remove them. Later in the summer, or more likely the following spring, stimulate strong side branches on the developing trunk by nipping out its growing point; there may need to be a follow-up nipping of terminals or side branches to get a good tree structure. Any subsequent branch with excessive dominance can usually be corrected by just bending it down manually.

The same ideas are applicable to trees that are stumped because of crowding-again, rather than permitting a crowded jungle of often weak growth, it may be better to develop one trunk and then give it strong side branches. (However, any such stumping should probably be practiced only when the grower has erred by leaving his trees until they become so crowded that lower branches are killed out by shading. Instead, it is usually best to *remove* every other row diagonally, as soon as crowding *begins;* sadly, this is the great culture weakness of California growers.)

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