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BREEDING AVOCADOS FOR COLD HARDINESS

Robert J. Knight, Jr.[1]

Interest in cold-tolerant avocados has a. long history in the United States (2) and considerable research on selection and breeding for cold hardiness is currently in progress (4, 8, 9, 13). The possibility that increasing urbanization may force subtropical horticulture in southern Florida to move into colder areas (5) adds some urgency to efforts to obtain useful cultivars of enhanced hardiness. An examination of world climatological data indicates that every continent but Antarctica encompasses agricultural areas where high-quality avocado cultivars, able to withstand occasional temperatures as low as -8°C without severe injury, would materially raise the potential for production of this desirable and nutritious fruit (14). Bergh considers "delay in developing the superior cultivars possible on the basis of available germplasm" to be one of the chief factors limiting avocado consumption worldwide (4).

Outstandingly cold-tolerant avocado cultivars have been discovered in both California and Florida. Bergh reports that 'Yama' "is usually considered 1 of the hardiest Mexican cultivars, taking -8.5°C without severe injury" (4). We have used 'Brooksville' at Miami since 1964 because twig and leaf samples of this Mexican seedling have withstood artificial chilling (to -8.5°C) more successfully than other plant introductions in the U.S. Department of Agriculture avocado germplasm collection (7). Krezdorn found that 'Gainesville' withstood temperatures as low as -9.4°C in field plantings (9) and Scorza and Wiltbank (13) found this to be the hardiest cultivar of 5 they chilled artificially. Cuttings of 'Gainesville' had a freezing point of -7.8°C when hardened, as compared to -6.7°C for 'Mexicola' and 'Topa Topa' (13). Efforts are now underway to combine genes for extreme cold hardiness evident in these selected cultivars with the genes for dependable productivity and outstanding quality.

Breeding Methods

Controlled Breeding

Controlled breeding of avocados began at the University of California at Riverside in 1937 (1). Two pollinations made by J. W. Lesley in 1952 produced 'Haston' (CRC 17-51, 'Hass' x 'Clifton'), reported 'hardy to cold", and Teague' (CRC 14-11, 'Duke' x 'Fuerte'), said to be "very cold hardy" (11). Avocado breeding on the campus of the University of California at Los Angeles (U.C.L.A.) began in 1939. Two methods were used, hand pollination (selfing and crossing) and placing bees inside cages containing trees of 2 cultivars of complementary flowering type (A and B) for crossing, or only 1 cultivar for selfing. Caging with bees came to be the procedure of choice for selfing and was used at Riverside as well as U.C.L.A., but hand pollination in the field or greenhouse was used for most crossing work (2). Success from hand pollination varied from 0.7 to 3.8% (1).

[1] Research Horticulturist, USDA, Agricultural Research Service, Subtropical Horticulture Research Station, Miami, FL

Open Pollination

Trees isolated about 150 m from other avocados provided an inexpensive source of seed from self-fertilization (1). Bergh and Storey (3) also demonstrated the feasibility of producing racial hybrid (Mexican x West Indian) progenies by placing Mexican scions ('Arturo', 'Jalna' and 'Clifton') in a Hawaiian planting of West Indian avocados. The seeds that resulted from open pollination of the flowers on the Mexican cultivars by pollen from the surrounding West Indian cultivars produced progenies whose hybrid origin could be confirmed by the morphology of the seedlings.

The 'Brooksville' cultivar (M-18686) is growing in the avocado germplasm collection at Miami surrounded by West Indian, Guatemalan and non-Mexican hybrid cultivars; no other Mexican cultivar is close enough to pollinate it effectively We began growing seedling populations of 'Brooksville' in the mid-sixties and because of its cold hardiness and the probability that it would produce hybrid progenies with its surrounding neighbors. The first population was set in the field in 1967. Approximately 800 first-generation (F_1) and 350 second-generation (F_2) seedlings of 'Brooksville' have been field-planted at Miami to date. Our belief that hybrids would be produced was justified by the results—very few of the 'Brooksville' seedlings appear to be pure Mexican in race. We now have evaluated nearly 25% of the F_1 seedlings for fruiting characters and selected the most outstanding ones for further testing and breeding work. Field planting of F_2 seedlings began in 1973, but too few have fruited to date to permit definite conclusions of horticultural value.

Caged Parent Trees

All avocado seedlings grown at USDA's Miami research unit have come from open pollination, but successful production of seeds on mango trees caged with flies at Miami in 1976 encourages us to plan for better control of future operations by caging selected avocado parent trees. We believe the use of flies deserves serious investigation because these insects are among the natural pollinators of the avocado (10, 12) and bees, when caged with flowering avocados, are admitted to "act quite demoralized and spend most of their time crawling around the cage ceiling rather than working the avocado flowers" (1). The question of what proportion of avocado seeds may result from selfing and from crossing when complementary (A and B type) avocado trees are caged with insects, under Florida conditions, remains to be answered. We should expect a proportion of useful seedlings to result, whether the seeds come from self- or cross-pollination of the caged selections, when we cage a complementary pair of outstanding selections of marked heterozygosity (as these first-generation seedlings obviously are).

Evaluation of Selections

We are propagating the most outstanding selections chosen here to be tested by cooperators in the field at colder locations because winters at Miami are not ordinarily severe enough to permit evaluation of avocados for cold hardiness. We are pursuing the following 5-stage program with the goal of selecting, evaluating and breeding improved cultivars of outstanding cold hardiness:

1) Initially screening seedlings by exposure of leaf or twig samples to artificially produced cold in randomized, replicated tests.

2) Re-screening hardiest seedlings to confirm original determination.

3) Selecting and propagating the hardiest seedlings of outstanding horticultural quality.

4) Distributing propagated selections to cooperators in colder areas for field evaluation.

5) Caging the selections that have proved to be the most cold-resistant (either alone to be self-pollinated or with a complementary selection or cultivar to be cross-pollinated) together with pollinating insects to produce improved seedling material.

We are in the initial phase of stage 4 at the present time, having distributed 4 selections from the F_1 seedling population to cooperators in Florida and Texas. We plan to distribute at least 2 more selections in the immediate future. Any selection that performs sufficiently well at stage 4 to justify its introduction may be named and released if sufficient information can be assembled to confirm the desirability of such action. All the material we are distributing at present is of F_1 origin, but we believe that named cultivars are less likely to result from this material than from F_2 material. The rationale behind our planning for stage 5 is based on the assumption that segregation in the F_2 generation will produce favorable genotypes that will combine outstanding horticultural quality with cold tolerance.

The artificial cold screening of stage 1 permitted slightly less than 20% of 66 F_1 seedlings of 'Brooksville' to emerge undamaged (4.5%) or slightly damaged (15.2%), compared with the same total percentage for these 2 combined categories (10.6% undamaged, 9.1% slightly damage) of an F_2 population composed of 66 seedlings of WB3-14-24, a seedling of 'Brooksville' (Table 1). Seedling WB-14-24 is growing within a population of its sister F_1 seedlings of 'Brooksville', so chances are that most seedlings of WB3-14-24 resulting from pollination of that selection with its sister seedlings comprise a true F_2, population that is segregating for the factors that determine tolerance or sensitivity to cold. The genetic segregation could account for the fact that a greater percentage of F_2 than F_1 seedlings either were undamaged (10.6 *vs.* 4.5%) or were killed outright (24.2 *vs.* 10.6%).

Table 1. Cold damage to first- and second-generation avocado seedling populations; entire plant artificially chilled overnight.[z]

	% Damage				
Population	None	Slight	Moderate	Severe	Killed
Brooksville o.p. first generation	4.5	5.2	42.4	27.3	10.6
WB3-14-24 o.p.[y] second generation	10.6	9.1	34.9	21.2	24.2

[z]Each population consists of 66 plants derived from open pollination of the seed parent.

[y]WB3-14-24 is a seedling of Brooksville.

Bergh considers 300 g (approximately 11 oz) to be the present optimum size for most avocado markets (4), although all major Florida commercial cultivars at the present time are considerably larger, yet continue to find a ready market. 'Nadir', an early-season variety, comes closest to the considered optimum with an initial market weight of 386 g (6). We have no plan to discard otherwise outstanding selections whose fruits weigh more than 300 g.

Table 2. Fruit of cold-tolerant avocados compared with ‘Waldin’.

Cultivar or Selection	Date mature	Fruit wt (g)	Seed wt (g)	Ratio seed: fruit wt	Seed tightness in cavity	Skin color[z]	Anthrac-nose[y]
Brooksville	7 Jul	95	21	.22	No	Bl	5
WA3-7-44[x]	1 Aug	375	80	.21	Yes	R-G	7
WH3-13-2[x]	1 Sep	350	60	.17	Yes	R-G	6
WH3-13-7[X]	15 Aug	325	55	.17	Yes	R-G	7
WF3-16-2[x]	15 Aug	380	88	.23	Yes	Br	9
WF3-20-6[x]	1 Sep	338	77	.23	Yes	R-G	6
Teague	7 Aug	300	55	.18	Yes	G	5
Waldin	16 Aug	520	155	.30[W]	Yes	G	9
Yama 381	7 Aug	200	55	.18	Yes	G	3

[Z]Bl = black, Br = brown, G = green, R-G = russeted green.

[y]1 = least, 10 = greatest resistance in field and laboratory.

[x] First-generation seedling of Brooksville.

[w]Waldin' and 'Lula' have the largest seeds of Florida commercial cultivars. For comparison, the seed: fruit ratio of other cultivars is 0.15 for 'Booth 8' and 'Pollock'; 0.16 for 'Simmonds', and 0.17 for'Ruehle' (a 'Waldin' seedling).

Open pollination of the 'Brooksville' Mexican avocado (95 g) by the larger-fruited cultivars in the varietal block at Miami has produced F_1 seedlings that readily surpass the 300-g limit and may also have large seeds as would be expected of Mexican or West Indian cultivars (Table 2). Fruit randomly sampled from 17 different F_1 seedlings during the 1976 season averaged 242 g, with an average seed weight of 60 g. Actual fruit weights were 71-445 g, and seed weights 21-118 g. This demonstrates quite clearly that the larger-fruited cultivars in the germplasm collection have crossed with 'Brooksville' to produce most of the seedlings examined, although the smallest fruited trees may well result from selfing of 'Brooksville'. This probability is supported by the fact that, the trees with small fruits also have very thin-skinned, fungus-susceptible fruit (Mexican characters) and closely resemble 'Brooksville' in other respects, showing no definite West Indian or Guatemalan characters. The general run of F_1 seedlings varies considerably in skin thickness, disease resistance and fruit quality. Thus, seedlings outstanding for these characters may be selected from field populations.

Remarkable progress has resulted in California from breeding for small seed size to produce hardy avocados that combine Mexican and Guatemalan characters (4). The most outstanding selections from this work would be useful for back-crossing. Relatively small-seeded cultivars should also be used in the initial breeding work whenever possible.

The avocado selections that have been developed in California through self-pollination of commercial cultivars on the one hand and of extremely cold-hardy cultivars on the other, offer particularly exciting possibilities to the breeder (4). Presumably more homozygous (because of the limited inbreeding) than their parents, the selections in turn should be more reliable when used as parents. A greater proportion of useful seedlings are expected when inbred selections having desirable characteristics are crossed with one another.

Summary

We can reasonably say that commercial avocado production in the United States could be stabilized in those areas where the crop is currently grown and expanded into areas having winters too severe for currently important cultivars (provided the temperature goes no lower than -8°C) through development of new cultivars that combine the extreme hardiness of a few existing kinds with desirable fruit quality, disease resistance and productivity. Avocado production could be similarly expanded in many other parts of the world through development of such cultivars. Artificial chilling to determine leaf, twig or plant hardiness is useful in preliminary screening, but must be supplemented by field testing under natural conditions. Use of caging and isolation techniques can produce large quantities of seeds at relatively low cost.

Hardy Mexican-race avocados have been crossed with better quality avocados to produce a group that can withstand severe winter cold spells in California and Florida with minimal damage. In Florida, the hardiest seedlings are selected by artificial chilling, than planted by cooperators in cold areas to evaluate their performance in the field. No named varieties have resulted from this work to date, but hand-pollinations made in California in 1952 produced 2 new varieties of outstanding cold hardiness, 'Haston' and 'Teague'.

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