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THE POTENTIAL OF COLD-TOLERANT AVOCADO INTRODUCTIONS IN BREEDING FOR ENHANCED WINTER HARDINESS

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Abstract

Artificial chilling tests reported previously have been continued and indicate that the cold tolerance of a specific avocado seed parent (introduction M-18686) is inherited by an appreciable number of seedlings raised from open pollination. A minority of the second-generation seedlings from this population withstands artificial chilling tests as well as the original introduction, and the cold tolerance of the balance of the population varies from quite high to nil. Inasmuch as the second-generation populations appear to show genetic segregation for other phenotypic characters, research to date supports the feasibility of breeding for cold-tolerant cvs. of high horticultural quality**.**

Forty years ago, a prominent Florida horticulturist wrote, "the Redlands section in southern Bade County has thousands of acres of potential avocado land" (11). The passage of time and expanding urbanization are making that statement less acceptable every year. Some influential growers are still convinced that tree fruits will continue to be grown in southern Florida for the foreseeable future (2), but others believe that a move north and west of the present area of concentration, which is south and west of Miami, is inevitable (1). The cvs. of avocado (*Persea Americana* Mill.) now grown in south Dade County are of West Indian (Antillean), Guatemalan, or hybrid racial origin. They are reasonably well adapted to climatic conditions in this area, particularly since overhead irrigation can now be used to protect young trees, flowers, or late fruit from cold damage. For this region, the presently available varieties, especially those that ripen near the middle of the season, are of acceptable quality and productivity, and new varieties are not critically needed (5). However, the cvs. that perform well in southeastern Florida do not tolerate cold sufficiently to permit them to be planted elsewhere in this or other States.

Indians have been collecting and selecting avocados in Mexico for some 9,000 years, as archeological records gathered in caves show (9). Many of the compact-growing, shrubby, small-fruited ecotypes adjusted to Mexican environments tolerate or even prefer cooler and drier conditions than do the tall, large-fruited Antillean avocados that require warm tropical conditions to survive.

Mexican avocados have fruited for years in Gainesville, Florida, 300 miles north of the present zone of commercial culture (7). There they have sometimes withstood temps of 15°F (-9.4°C) without serious damage (4). For example, in recent years, the cvs. Gainesville and Mexicola have withstood cold at Gainesville and have fruited more regularly than any others, including 'Brogdon', 'Duke', and 'Topa Topa' (4).

The fruit quality of some Mexican cvs. is acceptably good as determined by flavor, texture, and oil content, but none of this group bears fruit sufficiently large, thick-skinned, and resistant to anthracnose disease (*Colletotrichum gloeosporioides* Penz.) to permit it to be planted for commercial sale in Florida. Therefore, the need exists for a new group of avocado cvs. of acceptable commercial quality that can withstand environmental conditions in central Florida and other areas that have similar climates.

No known barriers exist to interracial crossing in avocados, and many of the most successful Florida commercial cvs. Show mixed Guatemalan and Antillean characters. In addition, some individual plants in the Mexican race show the greatest tolerance of winter cold, and a group of Mexican seedlings tested artificially for cold tolerance scored the highest of seven seedling populations of disparate origins (6). We therefore undertook to grow seedling populations of 'Brooksville' (M18686), the hardiest avocado selection at the U. S. Department of Agriculture's Subtropical Horticulture Research Station (formerly Chapman Field) at Miami (3).

'Brooksville' is the only Mexican-race tree in its block, and thus its open-pollinated seedlings of necessity result from self-pollination or from crossing with the neighboring Antillean, Guatemalan, or Antillean-Guatemalan hybrid avocado introductions. Inasmuch as the avocado has a breeding system that promotes out-crossing (synchronous dichogamy, *i.e.*, A- or B-type blooming behavior), we expected most Brooksville seedlings to be interracial hybrids. Their appearance and fruiting performance have fulfilled that expectation. The first-generation seedlings, growing in blocks somewhat isolated from other avocados, have had opportunity to inter-cross through open pollination and produce a second generation of seedlings. These latter seedlings comprised what is essentially an F_2 generation from the initial crossing of Mexican X commercial cvs.

Materials and Methods

Over the past 8 years, we have planted 1,450 seedlings of first and second-generation Mexican origin, and this work is continuing. The trees are grown to first fruiting and evaluated for tree characteristics, fruit quality, and disease resistance. They are selected for further testing and consistent fruiting if they pass the initial observation. We determine the cold tolerance to the degree possible through artificial testing in a "cold room" designed for the purpose (6).

The cold room, previously described, is so designed that one can test whole plants in containers (a limited number) or many single-leaf or twig samples. The material to be tested is first conditioned by exposure for 24 hr in a 40°F (4.4°C) room and then placed in the cold room late in the afternoon of the day the test is to begin. A linkage of four thermostats and time clocks enables us to lower temps progressively through the night to duplicate as much as possible the effects of damaging freezes that result from radiation cooling in nature. A given setting of thermostats produces a reasonably duplicable set of conditions from night to night. We have found that a low of 18°F (-7.8°C) with 5 hr below 28°F (-2.2°C) produces responses in avocado material ranging from no damage, through severe injury, to death.

During the winter of 1973-74, we pursued three different courses of testing with avocados, each designed to bring to light genetic sources of cold tolerance. In the first series of tests, 66 seedlings each from two populations were compared by chilling entire container-grown plants. One group was composed of seedlings of 'Brooksville' (M-18686) open-pollinated (first-generation Mexican-race seedlings). The other was composed of open-pollinated seedlings of WB3-14-24, a first-generation seedling of M-18686 growing in a block of its own kind; thus these seedlings, though from open pollination, are considered second-generation Mexican seedlings. In a series of eleven overnight tests, a dozen paired seedlings, six each of M-18686 and WB3-14-25, were treated each time. An analysis of variance compared the results of this series of tests.

In the second group of tests, 10 Florida commercial cvs. Were compared with 'Brooksville' and 'Bacon', hardy cvs that originated in Florida and California, respectively. Five replicates consisting of a single leaf from each cv. were exposed in randomized blocks and afterward scored for damage to leaf blade and veins. The results were subjected to analysis of variance. The same material was exposed to the same conditions a second night and the results were analyzed as before.

The third and shortest series was made up of two tests of 19 reputedly cold-tolerant California cvs. and selections (scions of which were presented to USDA by Mr. L. H. Zill), plus 'Brooksville' and 'Collinson' (P.I. 55509), a Florida cv. of presumptive Guatemalan-Antillean origin. For this series, four single-leaf replicates were exposed in randomized blocks, and then scored for leaf blade and vein damage.

As a part of our over-all evaluation program, we are keeping records of the fruiting performance of avocados of interest. Particularly desirable is information about the fruit of cvs. That proves outstanding for cold tolerance. For that reason, a summary of pertinent information accumulated to date is included with this report.

Results and Discussion

Seedling tests. Statistical analysis of results with the first and second-generation Mexican seedlings indicated no significant difference between the two populations (Table 1). This result has positive implications for an avocado selection and breeding program because it indicates that a significant portion of an F_2 population inherits cold tolerance from a hardy parent. Distribution of the scores tends to oppose the idea of single-gene Mendelian inheritance of resistance to cold. Indeed, this distribution coincides with general experience in fruit breeding: most desirable characters depend on the interaction of more than one gene. Thus, they are inherited quantitatively, not in the neat proportions associated with one or two-gene patterns of segregation.

Table 1. Cold damage to two artificially tested avocado seedling populations; entire plant chilled overnight[z]

Population	None (%)	Slight (%)	Moderate (%)	Severe (%)	Killed (%)
M-18686 (First-generation)	4.5	15.2	42.4	27.3	10.6
WB3-14-24 (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.

None of the second-generation seedlings have fruited to date so important questions remain unanswered. The most important is whether the desired cold tolerance is closely linked with undesired qualities such as small fruit size, thin skin, and low resistance to anthracnose disease. A few cvs. Such *as* Bacon are cold tolerant, but bear fruit of good quality. Thus it should be possible to obtain fruit of high quality among the segregates in this F_2 hybrid population of part-Mexican origin. We hope to get additional pertinent information by raising the survivors of this test to fruiting age, then comparing fruit quality with response to cold. *Florida cultivars.* One can reasonably question whether results of machine testing can be extrapolated to predict response to field conditions of the material tested. The response of the 10 Florida commercial cvs. and the 2 hardier ones suggests that some confidence can be placed in the machine testing though one might wish the results more clear-cut (Table 2).

'Fuchs', which scored lowest both nights, is known to be one of the least hardy of the Florida cvs. (8). 'Brooksville' is a pure Mexican-race avocado that has withstood winter cold in north-central Florida. 'Bacon' is a frost-tolerant tree recommended for commercial planting in California in does not closely match the results obtained in machine testing. 'Taylor' has been reported among the most cold-hardy of Florida varieties, and 'Tonnage' among the next hardiest (8); yet neither withstood two cold nights well. 'Booth 7' has been classed as intermediate in hardiness, yet it did not withstand either night well.

Table 2. Response of 12 avocado cultivars to 2 nights of artificial chilling[z]

Cultivar	Injury first night[y]	Injury second night[y]
Brooksville (M-18686)	5.00 a	4.95 a
M-19853	4.80 a	4.60 ab
Bacon	4.70 ab	4.60 ab
Tonnage	4.40 ab	3.15 cd
Simmonds	4.30 ab	4.10 abc
Ruehle	3.90 abc	3.30 bcd
Waldin	3.70 abc	3.35 bcd
Booth 8	3.10 bcd	2.65 de
Taylor	3.10 bcd	2.80 cde
Brooks Late	2.50 cd	1.95 de
Booth 7	2.40 cd	2.05 de
Fuchs	1.70 d	1.50 e

[z]Score is the mean of scores for leaf blade and vein injuries, each rated as follows: 1, killed outright; 2, severe injury; 3, moderate injury; 4, slight injury; 5, no injury.

[y]Means are the average of five replicates. Those followed by the same letter do not differ at the 0.05 level of significance.

Exceptions to usual ranking are known to result from conditions of nutrition, age, vigor, and growth (8). Apparently such conditions affected the responses of our test material, despite our efforts to collect leaves as nearly alike as possible. We tested Florida cvs. to get data for comparison with the seedlings and selections tested. We do not base recommendations for commercial planting on the results of artificial testing to date. The data obtained in these tests are preliminary. We use them in selecting material for further work. Field testing in central and northern Florida and in other regions with a similar winter climate will determine whether a cold-tolerant avocado selection deserves to be introduced.

Cold-tolerant cultivare and selections. Tests of two different batches of the same material (19 cvs. and selections from California plus two from Florida) revealed no significant differences among the plants (Table 3).

In the first test, the mean reading obtained for the 21 cvs. after exposure for 5 hr to temp below 28°F (-2.2°C) was 4.63; that for the second test after 8 hr below 26°F (-3.3°C) was 4.43. ('Marsheline' was omitted from the second test because of a shortage of suitable leaf material.)

The material used in this third series—all selected for cold hardiness except 'Collinson'—was more uniform than the segregating seedling populations or the mixed batch of Florida cvs., therefore, one might expect a more uniform response from this material, and that is what we obtained. Results from the first test were so uniformly "good" that we made the second test more severe than usual. The average score for the second test was somewhat lower than that for the first, but the plants still responded better than any other plants observed this year. Most were above average in cold

tolerance, but some consistencies were nevertheless obvious; for example, 'Irwing 120' and 'Q8' scored highest in both tests and 'Al Boyce' (4-16) scored lowest. Thus all the material examined in the third test, except 'Al Boyce' and 'Collinson' (an old Florida cv.), merits trial in I central Florida, if its attributes other than cold tolerance are acceptable.

Table 3. Response of 21 avocado cultivars and selections to artificial overnight chilling[z]

Cultivar[y] or selection	Chilling injury score	
	First test[x]	Second test[w]
6836	5.00	4.63
Irwing 120	5.00	5.00
Q8	5.00	5.00
Yama 423	5.00	4.88
Bacon	4.88	4.88
Irwing 34	4.88	4.00
Yama 381	4.88	4.88
Fuerte	4.75	4.50
Irwing 65	4.75	4.63
Nabal Seedling	4.75	4.50
Brooksville (M-18686)	4.63	5.00
Irwing 78	4.63	4.13
Marsheline	4.63	--[v]
CRC 14/11	4.50	4.25
Irwing 59	4.50	4.25
Irwing 134	4.50	4.38
Creelman	4.38	5.00
Irwing 96	4.38	4.00
Yama 3	4.38	4.00
Collinson	4.13	3.50
Al Boyce (4-16)	3.63	3.25

[z] Scores are calculated as in Table 2, from four replicates of each tree tested. Analysis of variance gave no significant differences.

[y] All cultivars in this test, except Brooksville and Collinson, were supplied by L. H. Zill.

[x] Lowest temperature reached was 18°F; 5 hrs below 28°F.

[w] Lowest temperature reached was 18°F; 8 hrs below 26°F.

[v] Not tested.

Performance of cold tolerant material in southeastern Florida. Information on the fruiting behavior of the cold-tolerant cvs. listed in Table 3 is limited, because they have been in

the field at Miami for only 3 years, that is, since June 1971. Nevertheless, most of them have grown well. The precocity inherent in some lines of the Mexican material has enabled us to examine the fruit of several for two seasons and that of one (Yama 381) for three seasons.

Other reputedly cold-hardy cvs. or selections not yet artificially tested are fruiting at the Miami station. A few of these deserve to be tested elsewhere.

Table 4 lists the information gathered to date on the fruiting at Miami of accessions obtained from other regions and of seedlings selected at the station. From this information, we can make a few generalizations, all subject to emendation as more material accumulates. Certainly 'Bacon' deserves extensive trial in Florida in areas that are marginal for avocado culture. The fruit is somewhat small by Florida standards (but acceptable), and the seed is larger than ideal (but not so large, proportionally, as that of 'Lula')'Bacon's' flavor is excellent, and its overall quality is good. 'CRC 14/11' has not fruited as well as Bacon but the fruit is attractive and justifies further attention. Also, the possibility that the best individual plants in this group could serve as parents of new cold tolerant cvs. Should not be overlooked. We always consider this possibility during the evaluation.

Table 4. Fruit of several cold-tolerant avocados

Cultivar or Selection	Dates ripe	Fruit wt(g)	Seed wt(g)	Seed tightness in cavity	Coat adherence to seed or cavity	Skin color[z]	Anthracnose[y]	Firmness[y]	Flavor[y]
Bacon	15 Oct.	320	55	Yes	Both	G	7	8	8
CRC 14/11	7 Aug.	300	55	Yes	Seed	G	5	9	4
Irwing 96	1 Sept.	185	15	Yes	Seed	R-G	4	8	5
M-20536	7 Sept.	250	85	Yes	Both	R-G	7	7	6
WA-3-7-44	1 Aug.	375	80	Yes	Seed	R-G	7	6	5
WB-3-13-2	1 Sept.	350	60	Yes	Seed	R-G	6	7	5
WB-3-13-7	15 Aug.	325	55	Yes	Seed	R-G	7	7	6
Yama 3	1 Sept.	250	45	Yes	Seed	G	5	6	6
Yama 381	7 Aug.	200	35	Yes	Seed	G	3	8	6
Yama 423	25 Aug.	175	36	Yes	Both	G	6	8	6

[z] G = green, R-G = russeted green.

[y] 1 = Least desirable, 10 = most desirable score.

Conclusion

Artificial cold testing is useful for the initial selection of cold-tolerant seedling avocados. Other cvs. and selections can be screened by this method, which should then be supplemented by testing in the field. Results with the seedling populations examined to date indicate that an appreciable percentage of F_2 seedlings inherit a high degree of cold tolerance from the original seed parent.

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