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CONTRASTING EFFECTS OF ACID AND NONACID PUMMELOS ON THE ACIDITY OF HYBRID CITRUS PROGENIES

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CHANDLER—AN EARLY-RIPENING HYBRID PUMMELO DERIVED FROM A LOW-ACID PARENT

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**CONTRASTING EFFECTS OF ACID AND NONACID
PUMMELOS ON THE ACIDITY OF
HYBRID CITRUS PROGENIES¹****ROBERT K. SOOST² and JAMES W. CAMERON³****INTRODUCTION**

REPORTS on the levels of acid in hybrid progenies of fruit trees have been rather fragmentary. Most reports describe only the general behavior of progenies; when data on individual progenies are given, acid levels often cannot be separated from sugar levels or other factors of fruit quality. Bishop (1951)⁴ and Kimball (1930), in crosses of several apple varieties with Northern Spy and McIntosh, found that some parents gave a much higher percentage of acid individuals than did others. On the basis of organoleptic tests, Klein (1958) indicated that sweetness is recessive to acidity in apple progenies. Using chemical tests, Nybom (1959), whose report is more comprehensive than most others, concluded that sweetness is determined by a single recessive gene. In peach, Connors (1922) reported that Early Crawford transmitted acidity. Blake (1937) indicated association of blood-red flesh, astringency, and early ripening with acidity in progenies of the J. H. Hale peach with Dwarf Blood and Chinese Blood.

Although there are several reports (Harding and Fisher, 1945; Harding and Sunday, 1949; Harding and Wadley, 1945; Harding, Winston, and Fisher, 1940; Sinclair and Bartholomew, 1947) on the seasonal changes of acid levels in several varieties of citrus fruits in relation to their palatability, there seem to be no data concerning the behavior of acidity in progenies from parents of differing acid levels.

In the course of the citrus breeding program under way at the University of California Citrus Experiment Station, Riverside, fruiting populations of hybrids involving the pummelo (*Citrus grandis* Osbeck) as one parent have been under examination for the last seven years. The pummelos possess cer-

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⁴ See "Literature Cited" for citations, referred to in the text by author and date.

tain characters of possible value in breeding, including large size, and in some varieties a bland flavor with considerably less bitterness than the grapefruit. They have only sexually formed embryos, producing no nucellar (asexual) seedlings when used as seed parents. The use of one extremely low-acid variety has resulted in progenies with predominantly moderate (less than 1.5 per cent) average acid levels in January. In contrast, the progenies from the other pummelos used in our crossing have had high (over 2 per cent) average acid levels even in February or March. This difference in breeding behavior is the subject of this paper.

PARENTAGE

The hybrid progenies used in this study resulted from crosses made mostly in 1945 by Dr. H. B. Frost and Dr. J. W. Lesley. All hybrids were budded to sweet orange rootstock and planted in the orchard in 1949. Some of these trees began fruiting in 1953, but it was several years before they were fruiting in sufficient numbers for comparative evaluation.

Progenies were available from crosses of six pollen-parent varieties with one low-acid pummelo, Citrus Experiment Station (C.E.S.) Accession Number 2240. Progenies were also available from crosses of four of these same pollen parents with four relatively acid pummelos. The pollen parents crossed with both pummelo types were the Kara mandarin (Frost, 1935), Dweet tangor (Frost and Cameron, 1951), Trovita orange (Frost, 1935), and a pummelo labeled Kao Pan (C.E.S. 2241). The other two pollen parents were the hybrid mandarins Frua (Frost and Cameron, 1951) and Kinnow (Frost, 1935). The acid pummelos were the Pink (C.E.S. 2246), Karn Lau Yau (C.E.S. 2341), Deep Red (C.E.S. 2347), and Siamese (C.E.S. 2421). The pummelo parents were part of a variety collection introduced from the Orient through the United States Department of Agriculture, Bureau of Plant Introduction, about 1930. The names under which they were brought in are not always descriptive.

Frua and Trovita are early varieties, ripening at Riverside in January. Kinnow and Kara ripen in March, and Dweet in April or May. Pummelo 2241 is physically mature by February, but in most years it remains rather acid throughout the season. Among the seed parents, pummelo 2240 has always been extremely low in acid (about 0.1 per cent) at the earliest samplings in December. The other four pummelos, although physically mature by January or February, usually remain sour until March and often drop while still too high in acid to be palatable.

Sampling and Analysis. In this study, it is necessary to consider acid and soluble-solids levels of the fruit apart from maturity of physical characters. "Mature" will be used to indicate fruits that have essentially completed their physical development but do not necessarily have levels of soluble solids or acid acceptable for eating. "Ripe" will designate fruits that are mature and also have acceptable solids and acid levels. For a discussion of maturity, ripening, and the relation of soluble solids, acids, and other factors to ripening in citrus, see Harding *et al.* (1940, 1945, 1949) and Sinclair and Bartholomew (1947).

In 1957, 1958, and 1959, juice analyses were made on fruits of individual trees from six pollen parents, five pummelo seed parents, and ten progenies

involving these parents. Individual samples usually consisted of five fruits. Two sampling periods were established in each year. At the first sampling, in early January, the progenies involving low-acid pummelo 2240, and the pollen parents, some of which are early-ripening, were taken. At the second sampling, made in early February in 1957 and 1959 and in the third week of March in 1958, the acid-pummelo seed parents and the progenies involving them were taken. These sampling periods were chosen to demonstrate the difference between the average ripening period of the low-acid pummelo progenies and that of the acid-pummelo progenies. This sampling procedure does not take into account differences in maturity of the fruits among individual trees at the time of sampling. Some individuals, particularly in the acid-pummelo progenies, were not fully mature when sampled. Thus, absolute acid levels are confounded with maturity effects on acid. Only repeated samplings throughout the season would have clarified the relation of acidity to maturity. All progenies were sampled at least once each year; however, the individual trees sampled within a progeny were not entirely the same ones each year, because of occasional unavailability of fruit.

Total acid content was determined by titrating a known volume of juice with a standard sodium hydroxide solution, using phenolphthalein as an indicator. The free acid is expressed as per cent citric acid on a weight basis. The total soluble-solids content was determined with an Abbé refractometer and is also expressed as per cent of the juice.

RESULTS

Acidity. After the first few years of fruiting, it became apparent that in general the hybrids in the progenies from pummelo 2240 were palatable earlier in the season than those from the other pummelos. In fact, the fruits of many of the hybrids from the other pummelos dropped before becoming palatable. The first year's juice analysis demonstrated that the main difference between the two groups of progenies at the time of sampling was in their acid levels. The ranges and averages of acid levels of the progenies and their parents are presented in table 1. Note that seed parent pummelo 2240 has about 0.10 per cent acid, and thus has an extremely high solids : acid ratio.

The data taken in January are shown for the progenies of pummelo 2240, while the February-March data are given for the progenies of the acid seed-parent pummelos. This comparison gives the acid-pummelo progenies the advantage of an extra maturing and ripening period of a month or more. Despite this, in all three years the average acid levels of the progenies of 2240 are strikingly lower than the levels of those of the other pummelos. Comparison of the ranges of acidity between progenies of the two contrasting pummelo types which have a common pollen parent shows that there is only a small amount of overlap (e.g., 2240 \times Kara, 1.04–2.63 per cent acid; 2341 \times Kara, 2.15–3.50 per cent acid).

The data taken in January are shown (table 1) for the pollen parents. Comparison of the acid levels of progenies of pummelo 2240 with those of their pollen parents shows that where the medium-acid parents Kara, Dweet, 2241, and Kinnow were used, average acid levels of the hybrids are usually below those of the respective parents. It should be stated that these pollen

parents (Kara, Dweet, 2241, and Kinnow) are not fully ripe at the January sampling dates used in table 1. With the two less acid parents (Frua and Trovita), average acid levels of the progenies are similar to, or slightly above, the parental levels. In all progenies from pummelo 2240, the range of acid extends below the levels of the respective pollen parents.

TABLE 1
PERCENTAGES OF ACID AND SOLUBLE SOLIDS : ACID RATIOS IN
PUMMELO PROGENIES AND THEIR PARENTS, OVER A
THREE-YEAR PERIOD*

Parentage of progenies†	Total progeny trees sampled	1957			1958			1959		
		Percentage of acid		S : A ratio‡ av.	Percentage of acid		S : A ratio av.	Percentage of acid		S : A ratio av.
		Range	Av.		Range	Av.		Range	Av.	
2240 × Trovita.....	8	0.73-1.45	1.10	12.5*	0.72-1.76	1.21	10.5	0.99-1.11	1.05	12.1*
Kara.....	11	1.04-2.63	1.64	9.0*	1.13-2.25	1.64	8.0	0.91-1.57	1.16	11.4
Dweet.....	5	1.00-1.55	1.28	10.0	0.96-1.80	1.49	7.9	0.86-1.16	0.99	12.3
2241.....	6	1.14-1.57	1.39	9.2	0.92-2.09	1.56	8.0	0.78-1.31	1.13	10.9
Frua.....	10	0.82-1.54	1.06	12.9	0.66-1.54	0.99	12.8	0.62-1.03	0.79	16.1
Kinnow.....	8	1.23-1.73	1.56	8.5	0.91-2.34	1.57	8.6	1.04-1.61	1.23	9.9
2246 × Trovita.....	9	2.60-4.98	3.69	3.6	3.49-5.23	4.04	2.9	2.74-3.18	2.89	3.9
2341 × Kara.....	11	2.15-3.50	2.75	5.5	2.22-3.67	2.66	4.6	1.95-2.38	2.25	6.0
2347 × Dweet.....	17	2.43-4.13	3.24	4.4	1.68-3.45	2.66	4.2	2.29-3.51	2.82	4.5
2421 × 2241.....	3	1.85-2.43	2.14	5.9	1.87-2.75	2.22	5.5	1.36-2.24	1.85	7.0
<i>Seed parent varieties</i>										
2240.....	..	...	0.10	126.0	...	0.08	151.3	...	0.10	126.0
2246.....	..	...	1.93	6.2	...	...	...	...	1.67	7.0
2341.....	..	...	1.62	7.7	...	1.72	7.4	...	1.02	11.4
2347.....	..	...	1.66	7.7	...	1.80	7.3	...	1.46	8.2
2421.....	..	...	1.82	5.8	...	1.91	5.6	...	1.59	6.4
<i>Pollen parent varieties</i>										
Trovita.....	..	...	...	...	...	0.99	12.7	...	0.77	14.1
Kara.....	..	...	2.04	6.5	...	1.82	8.0	...	1.69	7.1
Dweet.....	..	...	2.15	5.2	...	1.96	5.8	...	1.90	5.9
2241.....	..	...	1.53	7.9	...	1.59	6.8	...	1.24	9.4
Frua.....	..	...	1.10	9.8	...	0.89	12.2	...	0.96	9.9
Kinnow.....	..	...	1.65	8.9	...	1.50	9.3	...	1.75	7.2

* Except for the asterisked samplings, data from progenies involving pummelo 2240 and data from the pollen parent varieties were obtained from the first sampling (January 5-13) each year. The asterisked data and data from the other progenies and from the seed parent varieties were obtained from the second (February-March) sampling.

† Each number entry indicates a pummelo variety carrying that Citrus Experiment Station Accession Number. See under "Parentage" in text for additional discussion of parent varieties.

‡ S : A means ratio of total soluble solids to acid.

In the progenies from the acid pummelos, the average acid levels are much above those of their respective seed parents. In fact, in many of the samplings the acid level of the lowest individual is higher than that of the seed parent. The average acid levels of the progenies are also much above the levels of the respective pollen parents, although the range sometimes extends below the parental level. All these comparisons indicate the effectiveness of pummelo 2240 in producing progenies with moderate acid levels early in the season, in contrast to the high levels produced by the other pummelos at the same date.

Total Soluble Solids. Total soluble solids were also determined on all samples in all years. The pollen parents ranged from a low of 9.5 per cent for Frua to a high of 14.3 per cent for Kinnow. The pummelo seed parents ranged from 10.2 to 13.2 per cent, with pummelo 2240 averaging 12.6 per cent. Among the progenies, there were a few consistent differences in the average levels of soluble solids, but they were relatively slight and were not related to the acid differences. For example, the average soluble-solids level of the progeny of $2240 \times \text{Frua}$ was always higher than the level of Frua itself. The average for 2240×2241 was higher than for the acid parent, 2241. The progeny of Kinnow was always slightly lower than the level of Kinnow itself. Except for the latter case, the systematic reduction in acid levels early in the season in progenies of pummelo 2240 was not accompanied by reductions in soluble solids. Between any two progenies with a common pollen parent, the average soluble-solids level at the sampling dates was essentially as high when low-acid pummelo 2240 was the seed parent as when the acid pummelos were seed parents.

Soluble Solids : Acid Ratios. Since there was little difference in the average levels of soluble solids between the progenies of the two pummelo types, differences in the solids : acid ratios are almost completely due to the differences in average acid levels. The resulting consistently higher ratios of the progenies of pummelo 2240 are evident in table 1. The ratios of these progenies are at or above the minimum legal ratio (8 : 1) for California oranges, while those of the progenies of the acid pummelos are mostly at or below the minimum legal ratio (5.5 : 1) for California grapefruit.

The ratios shown by these progenies also reflect some influence of the pollen parents. Thus, the average ratios of the progeny of pummelo $2240 \times \text{Trovita}$ were below those of Trovita, while the ratios of $2240 \times \text{Kara}$, Dweet, and pummelo 2241 were usually above those of the respective pollen parents. Since the progeny from Frua was consistently higher in soluble solids than Frua, the difference in ratio between the two is sometimes greater than the difference in acid levels. A consistently lower soluble-solids level in the Kinnow progeny resulted in ratios which are lower than those for Kinnow in two out of three years.

In the progenies from the acid-pummelo seed parents, soluble solids : acid ratios are all lower than the ratios of any of their respective parent varieties, except in the case of pummelo $2421 \times \text{pummelo } 2241$. In this progeny, ratios are similar to those of the seed parent.

DISCUSSION

In citrus fruits, the per cents of soluble solids and acid gradually change as the fruits mature and ripen. Because of this continued change, it is not possible to determine by single samplings whether individuals originally high in acid will eventually reach levels as low as or lower than those of low-acid individuals. One high-acid progeny ($2246 \times \text{Trovita}$) was sampled at both dates in 1958 and 1959. It had a maximum rate of decrease in per cent of acid per month of 0.22 in 1958 and 0.15 in 1959. If one assumes these same rates of decrease for a period of four months, then the lowest-acid individual in the progeny in each year would still be higher in acid in June than the highest individual in any of the low-acid progenies in January. If the other high-acid

progenies were declining at similar rates, some individuals would reach an acceptable acid level by May or June. However, organoleptic tests made throughout the tree life of the mature fruit indicate that most of the high-acid individuals never become low enough in acid to be palatable. Regardless of acid levels at later dates, the behavior of our progenies indicates that pummelo 2240 can be used in crosses with medium-acid varieties to obtain individuals with moderate or low-acid levels and favorable soluble solids : acid ratios early in the season. Conversely, few individuals with acceptable ratios early in the season can be expected when acid pummelos are involved in such crosses.

The behavior of the progenies of pummelo 2240 suggests that other extremely low-acid citrus varieties may also be of value in breeding early-ripening hybrids.

In apples, Klein (1958) indicates that in crosses of strongly subacid varieties with mild-flavored varieties, sweetness appears to be recessive to acidity. Nybom (1959) also reports that sweetness in apples is recessive, and that it is probably determined by a single gene. However, he found that the component actually affected was acid. This situation is comparable to that in our material, where high-acid and low-acid progenies were obtained, all of which had rather similar levels of soluble solids. In grapes (*Vitis vinifera*), Breider (1950) has also reported independent inheritance of soluble solids and acid.

SUMMARY

Among several pummelos used in a citrus breeding program, Accession Number 2240 is extremely low in acid, even at the earliest sampling dates, while five others are of medium or greater acid content until at least two months later. Progenies obtained by crossing pummelo 2240 with various medium-acid citrus varieties have consistently shown low to medium average acid levels early in the season. In each progeny, some hybrids have been lower in acid than their medium-acid parent, although none of those tested was as low as 2240. In contrast, crosses of the acid pummelos with some of the same medium-acid varieties have resulted in progenies with high average acid levels, even at later sampling dates. The ranges of acidity in the latter progenies were mainly above the levels of their respective pollen and seed parents. At the time of sampling, levels of total soluble solids were essentially as high in the progenies of pummelo 2240 as in the acid-pummelo progenies; as a result, solids : acid ratios average much higher in the progenies of 2240. Thus, by the use of this very low-acid pummelo as one parent, early-ripening hybrids with favorable soluble solids : acid ratios early in the season have been obtained. It is suggested that other low-acid citrus varieties might be used in a similar manner.

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