ROOTSTOCK EFFECTS ON FRUIT QUALITY

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The various parts of the tree maintain a high degree of autonomy in fruit crops. Different varieties grafted on the same tree often leaf out and bloom at different times, although they are supported by the same root system. It would not be realistic to expect a rootstock to induce radical changes in fruit quality; a 'Valencia' orange will always have the characteristics of this variety no matter on what rootstock it is grown. On the other hand, the roots are the absorbing organ for mineral elements and water and growth regulators are formed in them. The statement that compounds not normally found in the scion cannot be introduced by a rootstock is generally still true, although later work showed that organic compounds characteristic of the rootstock sometimes can be translocated into the top of the tree.

Rootstocks and scions interact in many ways including at least 14 fruit quality factors influenced by the rootstock. The magnitude of rootstock effects on fruit quality, e.g. increases of 22% in fruit circumference, 37% in rind thickness, 17% in juice content, and 28% in total soluble solids/acid ratio in grapefruit on 45 rootstocks in Texas, is substantial but does not approach the 230% yield increase observed. The importance to the grower of rootstock influences on fruit quality depends on how the fruit is sold. A high-quality variety, such as 'Valencia,' has adequate quality on any rootstock, but marginal varieties may not. Fruit destined for the fresh market must have good internal quality, but the appearance of the fruit (size, shape, peel color, peel thickness, interior color, seediness, and granulation) is also important. In fruit for processing, soluble solids production per acre is the most important criterion, but with the great number of 'Hamlin' orange trees now in production, juice color has become a concern of the processors and there is interest in improving the juice color of early orange varieties through rootstocks. Yield, soil adaptation, and disease resistance are still the key factors in selecting rootstocks, especially for fruit grown for processing. There are signs, however, that more attention will be given to solids content and juice color.

It is not clear how rootstocks exert their influence on fruit quality; some of the rootstock effects appear to be size-related (larger fruit have lower solids or based on nutritional effects (potassium increasing fruit size and acidity). It has to be kept in mind that rootstock effects sometimes vary from year to year, from area to area, and with cultural practices.

Fruit size and weight. Rootstock effects on fruit size are well documented. They are usually not dramatic, but can be readily seen without even taking measurements. Table 1 gives examples of variation in fruit size with rootstock. One of the best-known effects is small fruit size of 'Valencia' on trees budded to Cleopatra rootstock.

Table 1. Rootstock effects on fruit size and weight.

Rootstock	Diam. (cm)	Wt. (g)	Rootstock	Diam. (cm)	Wt. (g)
Marsh grapefruit (Florida) (Harding & Fisher, 1945)			Hamlin orange (Wutscher & Bistline, 1988)		
Rough lemon	11.8	553	Volkameriana	7.8	209
Sour orange	11.4	545	Rough lemon	7.7	201
Red grapefruit (Texas) (Wutscher, 1977)			Sour orange	7.2	181
			Troyer	7.1	178
Swingle	10.0	433	Swingle	7.1	177
Troyer	10.0	418	F 80-18	7.1	175
Carrizo	9.9	417	Valencia orange (Florida) (Harding et al., 1940)		
Sour orange	9.9	423			
Trifoliate or.	9.9	417	Cleopatra	8.2	264
Rough lemon	9.7	450	Rough lemon	8.1	275
Macrophylla	9.6	380	Grapefruit	8.1	271
Cleopatra	9.6	378	Sour orange	7.9	260
Sweet lime	9.5	385	Swt. or. sdlg.	7.5	206
Red grapefruit (Florida) (DPI, Winter Haven)			Sunburst mand. hyb. (Hearn, 1979)		
			Carrizo	6.8	-
Rough lemon	-	458	Rough lemon	6.7	-
Sweet lime	-	440	Sour orange	6.7	-
Sweet orange	-	419	Cleopatra	6.5	-
Rangpur	-	411	Murcott (Sidwell et al., 1962)		
Sour orange	-	407			
Cleopatra	-	396	Sour orange	-	161
Rough lemon	-	169	Sweet orange	-	160
Cleopatra	-	168			
Trifoliate or.	-	377			
Orlando tangelo (Krezdorn & Phillips, 1970)					
Sweet lime	-	187			
Rough lemon	-	179			
Sour orange	-	178			
Carrizo	-	174			
Cleopatra	-	162			

Rind color and rind thickness. Color and thickness of the peel have little importance in fruit grown for juice production, but they affect the value of fresh fruit. In general, vigorous rootstocks like rough lemon delay color break and induce thick rinds. Color can be rated by comparing fruit color with color charts or by means of a colorimeter. Ratings with color charts developed for Florida fruit are expressed in a letter code, starting with A for very green color and ending with K or L for very deep orange color. Hunter Lab Colorimeters give L, a, b values expressing a three-dimensional relationship among red, yellow and blue. Examples of rootstock effects on rind color are given in Table 2.

Table 2. Rootstock effects on rind color and rind thickness.

Rootstock	Rind color[z]	Rind thickness (mm)	Rootstock	Rind color[y]	Rind thickness (mm)
Marsh grapefruit (Harding & Fisher, 1945)			Valencia orange (Harding et al., 1953)		
Rough lemon	F[z]	0	Rough lemon	I	4
Sour orange	F	7.0	Seedling	L	4
Red grapefruit (Texas) (Wutscher, 1977)			Sour orange	J	3
			Cleopatra	J	3
Carrizo	G	6.2	Sweet orange	J	3
Col. sweet lime	G	6.1	Grapefruit	I	3
Sour orange	H	6.0	Hamlin orange (Wutscher & Bistline, 1988)		
Troyer	G	5.8			
Rough lemon	G	5.7	Volkameriana	H	6
Cleopatra	H	5.7	Rough lemon	I	5
Trifoliate or.	G	5.6	Sour orange	I	5
Swingle	G	5.5	Swingle	I	4
Sun Chu Sha Kat	G	5.5	Citrumelo F 80-18	I	4
Macrophylla	G	5.0	Citrumelo F 80-8	I	4
			Troyer	J	4
			Trifoliate or.	I	4
			Hyb. FF 1-131-20	J	4

[z]Color according to color table in Bull. 886 (Harding & Fisher, 1945) H is better than G.
[y]Color according to color table in Bull. 753 (Harding et al. 1940). L is better than J, better than I.

Juice content, total soluble solids and total acids. The range in differences in juice content (Table 3) can be very large; the 4-year averages from a large rootstock test in South Florida varied 88% between fruit on trees on citrumelo F 80-18 and rough lemon (Table 3). The differences in soluble solids (2-3% maximum) and in total acids (0.5% maximum) were much smaller, but they are important in meeting maturity standards and they affect earnings when they are based on pounds solids produced. Flavor and palatability of the fruit depend on the solids/acids balance. The Brix/acid ratio is the most important factor in determining maturity. Table 3 shows representative effects of rootstock on total soluble solids, total acids, and the Brix/acid ratio of grapefruit, oranges, and specialty fruit.

Table 3. Rootstock effects on juice content (%), total soluble solids (%), total acids (%), TSS/TA ratio and ascorbic acid (mg/100 ml).

Rootstock	Juice (%)	TSS (%)	TA (%)	TSS/TA	Ascorbic acid (mg/100 ml)
		Marsh grapefruit (Harding & Fisher, 1945)			
Sour orange	48	10.5	1.3	8.1	37
Rough lemon	47	9.4	1.4	7.4	38
		Ruby Red grapefruit (DPI, Winter Haven)			
Uvalde	58	9.6	1.25	7.7	-
Morton	42	9.4	1.23	7.6	-
Citrumelo F 80-9	51	9.1	1.12	8.1	-
Trifoliate or.	54	9.0	1.13	8.0	-
Smooth Flat Seville	50	9.0	1.10	8.2	-
Cleopatra	49	9.0	1.14	7.9	-
Troyer	52	8.9	1.12	8.0	-
Rusk	52	8.9	1.17	7.6	-
Citrumelo W-2	50	8.8	1.09	8.1	-
		Red grapefruit (DPI, Winter Haven)			
Trifoliate or.	49	9.5	1.12	8.5	-
Sour orange	50	9.5	1.16	8.2	-
Sweet orange	49	9.3	1.16	8.0	-
Rangpur	50	9.2	1.11	8.3	-
Cleopatra	49	9.1	1.15	7.9	-
Sweet lime	50	9.1	1.11	8.2	-
Rough lemon	51	8.2	1.06	7.7	-
		Hamlin orange (Wutscher & Bistline, 1988)			
Troyer	44	10.4	0.69	15.2	-
Citrumelo F 80-8	47	10.4	0.72	14.5	-
Sour orange	44	10.3	0.80	12.9	-
Citrumelo F 80-18	47	10.2	0.72	14.2	-
Trifoliate or.	46	10.2	0.63	16.4	-
Swingle	45	10.1	0.72	14.0	-
Hyb. FF 1-131-20	46	10.1	0.60	16.9	-
Rough lemon	25	8.3	0.60	13.8	-
Volkameriana	29	8.2	0.55	15.0	-
		Valencia orange (Harding et al., 1940)			
Sweet or. sdlg.	52	13.5	1.1	12.3	50
Sour orange	54	12.2	1.0	12.2	38
Cleopatra	52	12.0	0.9	13.3	38
Sweet orange	54	11.9	0.9	13.2	30
Grapefruit	54	11.7	0.9	13.0	35
		Hughes Nucellar Valencia (DPI, Winter Haven)			
Citrumelo F 80-8	64	12.3	0.95	13.0	-
Swingle	64	12.0	0.99	12.2	-
Smooth Flat Seville	63	11.5	0.90	12.7	-
Rangpur X Troyer	59	11.5	0.84	13.6	-
Carrizo	61	11.3	0.88	12.9	-
Rough lemon	58	10.3	0.81	12.7	-

Table 3. Continued.

		Murcott			
		(Sidwell et al., 1962)			
Sour orange	52	14.9	0.8	18.6	18
Sweet orange	59	14.8	0.7	21.1	19
Cleopatra	57	14.4	0.8	18.0	19
Rough lemon	54	12.8	0.7	18.3	18
		Orlando tangelo			
		(Krezdorn & Phillips, 1970)			
Sour orange	54	10.5	1.0	10.5	
Rubidoux trif.	55	10.5	1.1	9.5	
Christiansen trif.	55	10.5	1.1	9.5	
Troyer	54	10.4	1.1	9.5	
Eng. Small Fl. trif. or.	55	10.4	1.0	10.4	
Cleopatra	56	10.3	1.0	10.3	
Carrizo	55	10.3	1.0	10.3	
Sweet lime	56	9.5	1.0	9.5	
Rough lemon	54	9.0	0.8	11.3	
		Temple			
		(Harding & Sunday, 1953)			
Sour orange	59	13.7	1.1	12.5	55
Cleopatra	60	12.4	0.9	13.8	47
Sweet orange	60	12.3	1.0	12.3	49
Rough lemon	60	11.5	0.8	14.4	50
		Robinson tangerine hybrid			
		(Hearn & Hutchison, 1977)			
Morton	49	13.8	1.13	12.2	
Argentina trif.	47	13.5	1.08	10.9	
Carrizo	48	12.9	0.93	14.3	
Sun Chu Sha Kat	51	12.7	0.94	12.9	
Sour orange	49	12.4	0.98	12.0	
Cleopatra	49	12.0	0.83	10.3	
Volkameriana	50	11.6	0.81	17.7	
Rough lemon	50	11.5	0.82	15.4	
		Sunburst tangerine hybrid			
		(Hearn, 1979)			
Sour orange	-	11.9	1.03	11.6	
Carrizo	-	11.7	1.06	11.0	
Cleopatra	-	11.5	1.02	11.3	
Rough lemon	-	10.2	0.93	11.0	

Acid content influences juice pH; high acids lower the Brix/acids ratio. Relatively high acid levels have been reported in fruit from trees on Cleopatra, sour orange, Swingle citrumelo and trifoliate orange (Table 3); lemon rootstocks tend to induce low acid levels. Acids in citrus fruit consist primarily of citric and malic acid, but they also include ascorbic acid (Vitamin C). Citrus juice is relatively low in Vitamin C (30-60 mg/100 ml), and reports on rootstock effects have been contradictory. In general, the ascorbic acid (Vitamin C) content of oranges from trees on different rootstocks ranks as follows: grapefruit > Cleopatra > sour orange > rough lemon. Vitamin C in grapefruit from trees on sour orange is higher than from trees on rough lemon. High solids are usually

desirable, but low-solids fruit which is usually also low in acids, such as fruit from trees on rough lemon, passes maturity standards earlier than higher-acid fruit because of its higher Brix/acid ratio. A high ratio may indicate legal maturity but it is not always synonymous with superior quality.

Juice color. The ratio of 'Valencia' to 'Hamlin' trees in Florida groves has changed in the recent past; because of severe freezes, more 'Hamlins' were planted and there are as many 'Hamlin' as 'Valencia' trees now. The poor color of 'Hamlin' juice has created a problem because a color number of 36 is needed for classification of juice as Grade A. In the past, juice color was determined by comparing juice in a test tube with USDA OJ Standards (ranging from 1 to 6) in a light box. Hunter Lab #-45 Citrus Colorimeters are used now and the x,y,z values generated by the instrument are converted to color number by complicated formulas. 'Hamlin' juice commonly has a color number of 32-33, 'Valencia' juice 38. Juice from trees on trifoliate orange usually gives the highest color number, but the range between juice from fruit on different rootstocks is only 1 to 1.5 color numbers (Table 4). The numbers vary from year to year and harvesting the fruit late increases the color number (Table 4). 'Hamlin' juice color is not related to total soluble solids content. Fruit from trees on Macrophylla, which has a very low solids content, yields juice with relatively good color (Table 4). Work is under way to find out if the concentrating process improves the color number of low-Brix juice. The color number of raw juice sometimes varies from that of screened finished juice (Dr. W. S. Castle, personal communication). The interest in improving juice color by means of rootstock is recent because early work in the 1940's showed no difference in juice color between fruit from trees on sour orange and rough lemon and it was assumed that rootstocks had little influence on juice color. The low color number of juice from fruit of trees on sour orange was especially pronounced in 'Hamlin' juice, less so in 'Valencia' juice (Table 4).

Table 4. Rootstock influence on juice color number.

Rootstock	Harvest date 12/85	1/86	12/86	Mean
	Hamlin orange (Wutscher & Bistline, 1988)			
Trifoliate or.	34.4	35.5	33.0	34.3
Troyer	34.4	34.9	32.7	34.0
Macrophylla	34.1	34.7	33.3	34.0
Swingle	33.7	35.1	32.5	33.8
Sweet orange	33.8	34.5	32.8	33.7
Volkameriana	33.5	34.3	33.2	33.7
Rough lemon	33.6	33.9	32.2	33.2
Sour orange	32.7	34.6	31.4	32.9

Hughes Nucellar Valencia - St. Cloud
(Dr. W. S. Castle, CREC, Lake Alfred)

	Harvest 1986	1987
Eng. Small Fl. trifoliate or.		
Cleopatra	35.9	38.0
Swingle	36.2	37.8
Carrizo	36.0	37.7
Sour orange	35.8	37.6
Palestine sweet lime	35.0	37.4
Volkameriana	34.9	37.2

Hughes Nucellar Valencia - Avon Park
(Dr. W. S. Castle, CREC, Lake Alfred)

	Harvest 1988
Carrizo	38.6
Eng. Small Fl. trifoliate or.	38.4
Cleopatra	38.4
Swingle	38.3
Sour orange	38.3
Palestine sweet lime	38.1
Volkameriana	37.7
Rough lemon	37.6

Peel oil content. The rinds of 'Valencia' fruit on Savage citrange in California contained more peel oil than that on most of the common rootstocks, about twice as much as fruit on rough lemon. 'Valencias' in Florida had relatively high peel oil levels when grown on trifoliate orange, Sacaton citrumelo and Cleopatra mandarin; low levels were found in fruit from trees on the citranges Carrizo, Rusk, and Cunningham.

Bitterness. Juice bitterness is primarily a problem of grapefruit, but it is also found in oranges, especially navel oranges. Rootstock effects on bitterness of oranges have been ranked: trifoliate orange = grapefruit = Cleopatra < sweet orange < rough lemon. Grapefruit juice bitterness is affected in the order: trifoliate orange< sweet orange < rough lemon.

Fruit mineral content. The mineral content of all parts of the tree, including the fruit, is affected by rootstock. Citrus is an excellent source of potassium; together with calcium, K makes up the bulk of the ash of fruit. The ash content of fruit on different rootstocks varieties is as follows:

Orange

Peel	Sampson tangelo > Shaddock > rough lemon > Cleopatra
Pulp	Savage citrange > Sampson tangelo > Cleopatra > rough lemon
Juice	Trifoliate orange > Sampson tangelo > sour orange > rough lemon

Grapefruit

Peel	Sampson tangelo > grapefruit > sweet lime > rough lemon
Pulp	Sampson tangelo > grapefruit > Cleopatra > sour orange
Juice	Grapefruit > Sampson tangelo > sour orange > rough lemon

Rootstock effects on granulation. Granulation is affected more by scion variety, climate, and cultural practices than by rootstocks, but fruit from trees on lemon-type rootstocks has a greater tendency to granulate than fruit from trees on other rootstocks.

Rootstock effects on fatty acids in the fruit. Nordby reported that rootstocks affected fatty acids in 'Orlando' tangelo in this order: Milam = Orlando > Cleopatra > sour orange > Rusk citrange.

Postharvest effects of rootstocks. Red grapefruit from trees on 21 rootstocks was tested over three harvests in Texas by storing fruit from trees on different rootstocks for 9 weeks at 50°F (10°C) and then for 1 week at 70°F (21°C). The percentage of decay is shown in Table 5. Fruit from trees on Morton citrange and Changsha and Cleopatra mandarins had the highest decay incidence; fruit from trees on Macrophylla, Colombian sweet lime and Smooth Flat Seville (Australian sour orange) were the most decay resistant.

Table 5. Rootstock influence on postharvest decay of 'Red Blush' grapefruit in Texas (McDonald & Wutscher, 1974).

Stored 9 weeks at 50°F and 1 week at 70°F	
Rootstock	% Decay
Morton citrange	26.5
Changsha mandarin	25.3
Cleopatra mandarin	19.9
Sun Chu Sha Kat mandarin	17.9
Sunki mandarin	15.2
Rangpur	14.1
Bittersweet sour orange	12.1
Rich trifoliate orange	11.6
Carrizo citrange	11.0
Sour orange	10.5
Swingle citrumelo	8.6
Rough lemon	5.7
Macrophylla	5.5
Colombian sweet lime	4.0
Smooth Flat Seville	3.3

Discussion

There are always conflicting reports, but, in general, trees on sour orange can be expected to produce medium-sized to large fruit with high solids and acids, but relatively poor juice color. Fruit from trees on lemon rootstock is usually large; has thick, poorly colored

rinds, low solids and acids; and tends to granulate and dry out when left on the tree too long. Fruit of trees on citrange rootstock is large, with good solids and acid levels. On citrumelo rootstock, the fruit can be large, but in Florida it tends to be medium-sized (Table 1), with about the same acid levels as fruit from trees on sour orange, but with slightly less solids (0.2 - 0.3%). Fruit from trees on Cleopatra is often small, but there are conflicting reports. The solids content is high and the acids tend to be higher than on other rootstocks. Sweet orange rootstocks induce high Brix and acids and medium fruit size. Trees on trifoliate orange rootstock, in Florida as in most other areas, are known to produce small fruit of high quality, with exceptionally good juice color (Table 4). In Texas, grapefruit on trifoliate orange is relatively large, with low Brix and acids. Sweet lime rootstocks behave similarly to rough lemon; trees on these rootstocks produce fruit low in Brix and acids. Rangpur, which is a mandarin hybrid, induces medium-size fruit of fair quality, with Brix and acids higher than in those sweet lime and rough lemon. Grapefruit cuttings produced small fruit with relatively low total solids and acids in Texas.

Fruit quality effects will remain a secondary selection criterion when a rootstock is chosen, but they cannot be totally neglected, especially with varieties of marginal quality where rootstock can make the difference between salable and unsalable fruit.

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