PISTACHIO ROOTSTOCKS

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Choosing the rootstock is one of the most important decisions in orchard development. This chapter will present the current body of knowledge relating to pistachio rootstocks in California. In California, and other pistachio growing areas in the U.S., the nut producing species *Pistacia vera* is grown on seedling rootstocks of different *Pistacia* species or interspecific hybrids. There are five rootstocks which have been used by the California pistachio industry, three different *Pistacia* species and two interspecific hybrids. The rootstocks are *P. terebinthus, P. atlantica, P. integerrima* and two hybrids of *P. atlantica* pollinated by *P. integerrima*. The first two are referred top by their proper names, Terebinthus and Atlantica, and the latter three are known by their trade names or abbreviations thereof: Integerrima is Pioneer Gold I (PG I) and the hybrids are Pioneer Gold II (PG II) and UC Berkeley I (UCB I). All have characteristics which make them more or less suitable for specific planting situations. Understanding these differences will allow you to match the rootstock with your specific growing conditions.

During the early years of the pistachio industry in California, because *P. vera* cv. 'Kerman' had no resistance to nematodes or Phytophthora, Atlantica and Terebinthus were the rootstocks of choice. Atlantica was generally favored over Terebinthus due to greater ease of budding and uniformity. The bulk of pistachios were planted in the San Joaquin Valley where both rootstock species proved to be very susceptible to the soil-borne fungal disease, Verticillium wilt. A small test planting of Integerrima in Verticillium infested soil in the San Joaquin Valley was found to be tolerant of the disease. This discovery allowed planting of pistachios in Verticillium-infested soil. Since then, the commercial production Integerrima, PG I, has become the dominant rootstock of the California pistachio industry. Interest in increased vigor and early production, and research on the effects of rootstock on yield, Verticillium wilt and salinity tolerance led to the increased use the hybrid rootstock, UCB I. The other hybrid rootstocks, PG II is no longer commercially available having been demonstrated to have poor Verticillium tolerance.

The following discussion summarizes the specifics of these rootstocks and the recent research results

PISTACIA TEREBINTHUS

While *P. terebinthus* was commonly planted in the early days of the California pistachio industry, it has fallen out of favor because: 1) it is susceptible to Verticillium wilt; 2) it was generally perceived to be more difficult to bud than *P. atlantica* or *P. integerrima*; 3) its use often resulted in less uniformity than the other rootstocks; and 4) it is less vigorous than the other commonly used rootstocks. Currently, it is seldom used. *P. terebinthus* does have some characteristics which may make it useful in specific situations, and it may be valuable in future breeding programs. Of the five rootstocks, *P. terebinthus* is the most cold hardy. Pistachios growing on this rootstock have been reported to withstand temperatures as low as 15^{o}F with no damage. In nutritional studies where nutrient levels of 'Kerman' cultivar on different rootstocks were compared at seven locations throughout the state, *P. terebinthus* was never the lowest and often the highest. In these studies it was the most efficient for absorption of zinc and copper, micronutrients which are known to be deficient in soils of some California

pistachio orchards. Results of a rootstock trial in soil infested with Armillaria root rot in Yolo County have indicated that *P. terebinthus* is more resistant to this disease than are the other rootstocks.

PISTACIA ATLANTICA

Until *P. integerrima* was discovered to be tolerant of Verticillium, *P. atlantica* was the most common rootstock. *P. atlantica* is more cold hardy than *P. integerrima* and the two interspecific hybrids, but less cold hardy than *P. terebinthus*. It is susceptible to Verticillium wilt. It is less vigorous than *P. integerrima* and the two interspecific hybrids, and slightly slower to come into production. *P. atlantica* is more efficient at uptake of zinc than *P. integerrima* and UCB I, and has less copper uptake than *P. terebinthus* or PG II.

Because of greater cold tolerance than *P. integerrima* and the low incidence of Verticillium wilt in the Sacramento Valley, *P. atlantica* was the most common rootstock in this region. Since 1981 the desire for greater vigor has led to increased plantings of *P. integerrima*, and in the 1990s, the interspecific hybrid UCB I (*P. atlantica* x *P. integerrima*) in this region.

PISTACIA INTEGERRIMA

After *P. integerrima* was discovered to be tolerant of Verticillium wilt, it became the most widely planted rootstock in California. It is vigorous, buds easily and results in a uniform tree stand. It is the least cold tolerant of the commonly used rootstocks and can be damaged by winter freezes and early frosts, particularly if they occur when the tree is young. Results of the statewide rootstock trials terminated in 2002 indicated it has growth rates and early production superior to *P. atlantica* and 19.1% less than UCB I equal to or slightly less than the two interspecific hybrids.

Nutrient studies have shown *P. integerrima* to be less efficient than *P. atlantica* for boron, zinc and copper uptake.

INTERSPECIFIC HYBRIDS

Of the two interspecific hybrids, only one is currently available commercially. They are respectively Pioneer Gold II (PG II) and UCB I. PG II is the result of open pollination in an isolated situation with multiple *P. atlantica* trees as the female parent and multiple *P. integerrima* trees as the pollen parents. UCB I is the result of a closed pollination with a single tree of the same parents. (*P. integerrima* pollen is introduced into a closed greenhouse in which the *P. atlantica* tree is grown.) Thus, both are the same interspecific hybrid but are produced from different seedling parents and therefore both exhibit seedling variability. Both of the hybrid rootstocks have increased vigor compared to *P. atlantica*, and generally equal or greater vigor compared to *P. integerrima*. Ongoing statewide rootstock trials have demonstrated UCB I has the best yields through year 13 followed by PG I, PG II and *P. atlantica*.

Laboratory screening tests and early field studies indicate the two hybrids differ in resistance to Verticillium. *P. integerrima* appears to be the most tolerant, and *P. atlantica* the most susceptible; UCB I is tolerant to moderately tolerant; and PG II is moderately susceptible to susceptible.

Nutritional studies indicate PG II is relatively efficient in zinc uptake, compared to *P. terebinthus*; *P. atlantica* was intermediate; and UCB I and *P. integerrima* were the least efficient. PG II was slightly less efficient than *P. integerrima* and slightly more efficient than UCB I for uptake of boron. UCB I was similar to *P. atlantica* and *P. terebinthus* in terms of boron uptake. Preliminary results indicate PG II and *P. atlantica* are superior to Integerrima and UCB I for absorption of copper.

Some evidence of incompatibility with Kerman and UCB I has been observed in some locations in California and Arizona where 25 to 35% of the trees have shown incompatibility. It is believed that this incompatibility was related to a single maternal tree used in the early breeding program. It is also believed that the problem has been corrected and should not be seen in future plantings. Variability in vigor among UCB I rootstocks has also been observed. However, as nurseries continue to improve their seedbed rogueing this problem has dissipated.

CALIFORNIA PISTACHIO ROOTSTOCK TRIALS

Rootstock selection for most tree crops is generally a history of the limiting factors of producing a crop in a given location. Pistachios are no exception. The *Pistacia vera* cv. 'Kerman' female cultivar that is currently the sole nut producing cultivar in California is not grown on its own roots because it is susceptible to nematodes, Verticillium wilt, and the soil borne fungus Phytophthora. These susceptibilities are unfortunate, because on its own roots, it is more cold tolerant than most of our current rootstocks. Terebinthus and Atlantica, the industry's first rootstocks were replaced by Integerrima when the latter demonstrated superior tolerance to the soil borne fungus Verticillium. The Atlantica and Integerrima hybrids were developed for greater yield and vigor but are now demonstrating a salinity tolerance that would allow orchard establishment in marginal ground and use of marginal quality water.

From 1989 through 2002 in three long term field trials and, in 1999 a single greenhouse trial, we investigated the cold and salinity tolerance, Verticillium tolerance/resistance, and yield and alternate bearing behavior of trees grown on Atlantica, PG I and the two interspecific hybrids of Atlantica X Integerrima, UCB I and PG II. These 13 years of data collection and unexpected freezes have delineated the relative merits of the four rootstocks now used in California. The following tables detail these results and incorporate results from earlier trials and other researchers. The information will be presented in the order of most limiting factors first; sites limitation of cold, disease and salinity followed by horticultural effects, micronutrient uptake and effects on scion yield, quality and alternate bearing.

Cold Tolerance

Table 1 gives the relative cold tolerance of budded rootstocks less than two years of age. This data was obtained in the winter of 1989 – 1990 when the newly planted rootstock trials experienced freezing temperatures down to ranging from 4-12 º F for 11 nights. In our trials 41% of the trees on PG I rootstocks died. Trees on the other four rootstocks demonstrated the relative cold tolerances given in table 1. Trees on Terebinthus are more cold tolerant than trees grown on Atlantica, followed by trees on or UCB I and PG II. Scions on all rootstocks suffered freeze damage but recovered readily. Similar temperatures are not as damaging to a mature orchard as the rootstock is less exposed, and as the scion cultivar 'Kerman' is much more cold tolerant than these rootstocks.

Table 1. Relative cold tolerance of 2 year old budded rootstocks.

Rootstock	Cold Tolerance
P. terebinthus	*
P. atlantica	**
P. integerrima	****
PG II	***
UCB I	***

From Most * to Least ****

Soil Borne Fungal Disease Tolerance

Table 2 contains the relative soil borne fungal disease tolerance rankings of the current pistachio rootstocks. A recent long term Verticillium research trial demonstrated that while trees on both PG I and UCB I survived well in a heavily infested plot, the two rootstocks had different defense mechanisms. Trees on PG I rootstocks, while heavily infected with the pathogen, tolerated it well. Trees on UCB I rootstocks were much less likely to become infected, but, when infected, displayed decreased vigor. The fact that trees on PG I rootstocks are easily infected with Verticillium suggests that, as they age, they might have decreased vigor. Trees on both Atlantica and PG II rootstocks were easily infected by Verticillium, suffered marked declines in vigor and yield, and high mortality. Surprisingly, trees on PG II rootstocks were more susceptible than trees on Atlantica rootstocks. Verticillium infection was probably the reason for the poor performance of trees on PG II rootstocks when they were commercially released in the early 1990s. The trees were quickly infected with Verticillium.

Phytohpthora is currently not a problem except in saturated situations. However, as more rootstocks are planted in marginal ground and irrigated with saline water, Phytohpthora could become a problem. The results relative Phytophthora rankings given in Table 2. were produced by an Iranian colleague.

Armillaria has not proven to be a problem in pistachio production. However, if declining almond orchards are replaced with pistachios, Armillaria could become a problem.

Table 2. Relative disease tolerance of the five budded pistachio rootstocks.

Rootstock	Verticillium	Armillaria	Phytophthora
P. terebinthus		*	
P. atlantica	***	***	*
P. integerrima	*	***	***
PG II	****	***	
UCB I	*	*	*

From Most * to Least ****

Salinity Tolerance

Two trials, an eight year field trial started in 1994 and a one year greenhouse trial in 1999, were done to determine the relative and absolute salinity tolerance of the three commercial rootstocks. PG II was eliminated from the greenhouse trial as by 1999 it was no longer commercially available.

Table 3 integrates the results of these two trails. The greenhouse trial used 2 year old budded trees and the percentage decrease in scion growth relative to the control treatment was the measurement of salinity tolerance. In the 8 year field trial yield decrease as a function of irrigation water and root zone soil water salinity was the indicator of salinity tolerance. Trees on all three rootstocks tolerated 8 sequential seasons of irrigation with water adjusted to 8 dS/m, equivalent to 5120 PPM TDS. Above this, at 12 dS/m or 7680 PPM TDS, all four rootstocks had yield decreases, but UCB I appeared the most sensitive. However, in the companion greenhouse trial, trees on PG I rootstocks demonstrated the most sensitivity to salinity, losing a full 50% of their growth increase when root zone salinities reached 8 dS/m.

Salinity tolerance trials done in a greenhouse sand tank have two advantages over those done in an orchard. The well drained sand tanks eliminate the soil saturation that results as salinity increases, and, roots in the sand tank cannot avoid the salinity by proliferating outside the saline wetted treatment zone. For these reasons the results from the greenhouse trial are more reliable than the data from the field trial. However, results from both trials support the conclusion that all four pistachio rootstocks are tolerant of soil root zone salinity up to 8 dS/M, or 5120 PPM TDS.

Table 3. Relative salinity tolerance of pistachio rootstocks.

Rootstock	Salinity Tolerance
P. terebinthus	
P. atlantica	*
P. integerrima	****
PG II	
UCB I	**

From Most * to Least ****

Micronutrient Uptake Efficiency

Table 4 gives the relative micronutrient uptake of the five rootstocks. These results are a summarization of several trials and give only relative guidelines. Generally it demonstrates that trees on the two most commercially important rootstocks, PG I and UCB I, are prone to zinc and copper deficiencies and that the latter also is prone to boron deficiencies. In older orchards established with trees on Atlantica rootstocks replants with PG I or UCB I rootstocks can often be distinguished by the

later breaking foliage that characterizes a zinc deficiency.

Nutrient uptake efficiencies of sodium and chloride given below were generated in a sand tank trial. They demonstrated that trees on PG I rootstock had much higher uptake, and translocation to the scion, of sodium and chloride. Interestingly, in this trial only boron produced a specific ion toxicity in the form of an even marginal leaf burn. Both sodium and chloride partitioned equally into green and necrotic scion leaf tissue. This tendency for trees on PG I rootstocks to take up and translocate sodium and chloride to the scion could be deleterious in saline conditions. In the trial that produced the sodium and chloride data below trees on PG I rootstocks had significantly greater decreases in yield relative to trees on Atlantica and UCB I rootstocks at the same salinities. At 8 dS/m trees on PG I rootstocks had a 50% decrease in growth relative to no decrease in growth for trees on Atlantica and UCB I rootstocks.

Table 4. Relative micronutrient uptake efficiency of the five rootstocks.

Rootstock	Cl	Na	Zn	B	Cu
P. terebinthus			**	**	*
P. atlantica	**	**	***	***	**
P. integerrima	*	*	****	*	***
PG II			*	**	*
UCB I	***	****	****	****	***

From Most * to Least ****

Effect of Rootstock on Marketable Yield

Table 5 demonstrates the effect of rootstock on final marketable yield of 'Kerman' grown on the four different rootstocks. The data in this table was produced in three identical rootstock trials grown in three different microclimates from 1989 through 2001. To reduce cultivar effect all the trees in these three trials were budded with buds from the same male and female tree. The data in this table is based upon the first five producing years. The trees did not begin producing marketable crops until 1997. Alternate bearing commenced a very low crop in 1999, the third bearing year.

Trees on UCB I rootstocks produced significantly better yields than trees grown on the other three rootstocks in all locations and in all years. Averaged over all five years of crop production and all three trial locations trees on UCB I produced an average of 45.3% more marketable crop than trees on Atlantica rootstocks, 19.1% more than trees on PG I rootstocks, and 15.1% more than trees grown on PG II rootstocks. It must be remembered that this was only the first five years of economic production. Thus these results may only reflect the early bearing years. These trial orchards still exist. The only definitive way to demonstrate if this difference in effect of rootstock on 'Kerman' scion productivity persists through the trees' bearing life is to again measure yield and quality in these trials. There was no significant difference in the alternate bearing indexes among trees on the different rootstocks. On a scale of 0-1 with total alternate bearing being 1 and no alternate bearing 0 the alternate bearing indexes ranged from 0.66 to 0.68.

Within a crop year there were no consistent significant differences in nut size/weight among nuts produced from trees on the four different rootstocks. Similarly, within a crop year there were few consistent, significant differences in the percentage of blank and non-split nuts produced by trees on the four different rootstocks. Differences in nut weights, and the percentage of blanks and splits did differ among years, but in a similar fashion for 'Kerman' on all the rootstocks. For example,

on heavier crop years non-split percentages would rise in trees on all four rootstocks.

An analysis of the components of yield, clusters per tree, nuts per cluster and nut size, demonstrates UCB I yields better because it produces more clusters per tree than trees on the other rootstocks, not more or bigger nuts per cluster. This is reflected in the average relative trunk circumferences in trees grown on the different rootstocks. The more productive trees are generally larger trees.

The data demonstrates that rootstock affects the vigor of the 'Kerman' scion, producing a larger tree with more clusters. Rootstock obviously does not affect alternate bearing as the calculated alternate bearing indexes were approximately equal, and independent of absolute crop load among trees on the different rootstocks. This supports the view that alternate bearing is a function of the scion cultivar alone and that permanent elimination of this characteristic will come from rootstock breeding.

Table 5. Effect of rootstock on cumulative yield of marketable dry, inshell, split nuts*.

	County	UCB I	PG II	PG I	Atlantica
Average % increase in yield produced by trees on UCB I rootstocks			15.1	19.1	45.3
Alternate Bearing Index		.67	.66	.68	.67
Cumulative Yield 1989 through 2001	Fresno	11,095a	9,539b	9,442b	7,394c
(lbs/acre @ 112 ♀ trees/acre)	Kern	15,258a	13,301b	13,052b	11,418c
	Madera	7,170a	6,285b	5,643c	4,258d

*Values within a row followed by different letters are significantly different. Lack of letters indicates no significant differences within a row.

In summary, the results of the rootstock trials discussed indicate the following major conclusions. Atlantica is the most cold tolerant of the currently commercial rootstocks followed by UCB-I and PG I. PG I and UCB I are equivalent in their performance under Verticillium pressure but appear to have different mechanisms for coping with the disease. The PG I rootstock is tolerant whereas the UCB I rootstock is resistant. Both are significantly more tolerant of Verticillium than Atlantica or PG II, in that order. All four rootstocks tolerate salinity of up to 5120 PPM TDS or 8 dS/m in the root zone. Trees on PG I are the most saline sensitive, and have a tendency to take up and sequester sodium and chloride more readily than trees on UCB I or Atlantica rootstocks, in that order. Trees on UCB I produce the best yields among all the rootstocks, followed by PG II and PG I. All three produce better yields than trees on Atlantica rootstocks. Table 6 gives the final summary of rootstocks relative characteristics.

Table 6. Relative yield ranking of 'Kerman' female scion on four pistachio rootstocks.

Rootstock	Yield Ranking
P. terebinthus	
P. atlantica	****
P. integerrima	***
PG II	**
UCB I	*

From Most * to Least ****

Table 7. Tolerance ranking of pistachio rootstocks in San Joaquin Valley, 1989-2002, from best (1) to worst (4).

	Limiting Factor (1) best → worst (4)			
Rootstock	Frost	Yield	Salinity	Verticillium
P. integerrima	4	3	3	1
P. atlantica	1	4	1	3
PG II	3	2		4
UCB I	2	1	2	2