Nematode-resistant rootstocks released to nurseries

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Development of new rootstocks with broad and durable nematode resistance began in 1993/1994, with crosses made to enhance nematode resistance and improve rooting ability and shoot characteristics including internode length and the extent of lateral shoot production. Parents of these crosses included a number of grape species known to be highly resistant to both root-knot and dagger nematodes. They included several forms of *Vitis arizonica, V. candicans, V. champinii, V. cinerea, V. rufotomentosa*, and *Muscadinia rotundifolia*.*Vitis riparia* and *V. rupestris* were used in the crosses to improve rooting.

About 75 crosses were made, leading to establishment of more than 5,000 seedlings. In 1996, these plants were evaluated for shoot growth, internode length, and presence of laterals. One thousand selections were chosen, and they were later tested for their ability to root from dormant two-node cuttings. The best 100 were advanced to nematode testing.

In preparation for nematode-testing, soil samples with populations of root-knot nematodes capable of feeding on and damaging Harmony rootstock were obtained from Mike McKenry (University of California, Riverside). Peter Cousins (then a PhD student in the Walker lab), extracted nematodes from the soil samples and isolated two strains of root-knot nematode (RKN) that fed well on Harmony. These two strains were named Harm-A and Harm-C.

Kris Lowe (a recent PhD student in the Walker lab), characterized the Harm-A and Harm-C strains as *Meloidogyne arenaria* and *M. incognita*, respectively. A standard strain of *M. incognita* (termed R3), capable of damaging grapes, but not able to feed on Harmony or Freedom rootstocks was obtained from the Department of Nematology. *Xiphinema index* (the dag-

Table I. Parentage and nematode resistance of rootstock candidates that underwent certification testing at Foundation Plant Services. Combined testing involved the standard strain of *Meloidogyne incognita* (root-knot nematode), two aggressive Harmony/Freedom strains, and dagger nematode *Xiphinema index*.

8909-05 (UCD GRN-1™)	9363-16 (UCD GRN-2™)	9365-43 (UCD GRN-3™)	9365-85 (UCD GRN-4™)	9407-14 (UCD GRN-5™)
V. rupestris x *M. rotundifolia*	(*V. rufotomentosa* x (Dog Ridge x Riparia Gloire)) x Riparia Gloire	(*V. rufotomentosa* x (Dog Ridge x Riparia Gloire)) x *V. champinii* c9038 (probably *V. candicans* x *V. monticola*)	(*V. rufotomentosa* x (Dog Ridge x Riparia Gloire)) x*V. champinii* c9038 (probably *V. candicans* x *V. monticola*)	(Ramsey x Riparia Gloire) x *V. champinii* c9021 (probably *V. candicans* x *V. monticola*/*V. berlandieri*)
Characteristics: No galls in combined testing; resists citrus, lesion, and ring nematode. Less easy to medium propagation ability. Studies underway to determine fanleaf tolerance. Deep-rooting profile. Leaves are shiny and intermediate between *V. rupestris* and *M. rotundifolia*. Sterile flowers.	**Characteristics:** No galls in combined testing; resists lesion nematodes, has moderate resistance to citrus nematodes; susceptible to ring nematodes. Good mothervine with long canes and internodes, and limited lateral production. Shallow rooting depth. Mature leaves are three- to five-lobed and have some similarity to *V. aestivalis*. Male flowers.	**Characteristics:** No galls in combined testing; resists lesion and citrus has moderate vigor, but long canes with good internode length, moderate number of laterals. Moderately deep rooting depth. Mature leaves resemble *V. champinii.* Female flowers.	**Characteristics:** An average of less than one root gall in combined testing; moderate resistance to ring nematode. Good mothervine with long canes and internodes and few laterals. Moderately deep-rooting profile. Mature leaves resemble *V. riparia*. Male flowers.	**Characteristics:** No galls in combined testing; resists citrus and lesion nematode, moderate resistance to ring nematodes. Weak mothervine, but long internodes, good canes.Deep-rooting profile. Mature leaves resemble glossy *V. champinii*/*monticola.* Male flowers.
				

ger nematode vector of grapevine fanleaf virus) was extracted from several highly infested sites in Napa Valley. These nematodes were used in the first phases of nematode resistance evaluations, as single and then combined inoculum.

Initial work began by optimizing the nematode-screening procedures. Observing galls that form as a result of RKN feeding can be difficult. Peter Cousins modified an egg mass staining technique that was developed for RKN studies on tomato, and that technique was used to confirm that RKNs had penetrated, fed, and reproduced on the roots. As the nematode testing progressed, Liang Zheng (technician in the Nematology Department) became responsible for evaluating selections for resistance to various strains and combinations of nematodes.

Root-knot nematode resistance was evaluated by counting the number of stained egg masses produced on a root system after inoculation with 1,500 juvenile nematodes. Those without egg masses were judged to be resistant.

Dagger nematode resistance was determined by counting the number of galled roots after inoculation with 150 nematodes. Testing was also done for resistance against citrus nematode (*Tylenchulus semipenetrans*), lesion nematode (*Pratyclenchus vulnus*), and ring nematode (*Mesocriconema xenoplax*).

The first round of testing examined the ability of the 100 selections to resist the RKN R3 strain. Selections that resisted R3 feeding were then tested for resistance to the Harm-A and Harm-C strains, followed by testing for resistance to the dagger nematode. This round of screening identified 33 selections with strong resistance to each of the four nematode strains. These 33 selections were then tested against a combined inoculum using the four nematodes (R3, Harm-A, Harm-C, and dagger), which resulted in a group of 14 resistant selections. These 14 selections were also tested for resistance to citrus, lesion, and ring nematodes.

Durability of nematode resistance was tested by evaluating the selections to four nematode strains (R3, Harm-A, Harm-C, and dagger) at elevated temperatures. Resistance to RKN strains in tomatoes and other crops has been shown to break down when soil temperatures reach about 80ºF.

The 14 selections were then tested to determine whether their RKN resistance was based on a similar temperature-sensitive mechanism. The selections were tested at four temperatures: 75º, 80º, 86º, and 90ºF (24º, 27º, 30°, and 32ºC), using the cultivar French Colombard as the susceptible control and Harmony rootstock as the standard. At 80ºF, Harmony's moderate resistance to Harm-A was dramatically affected. It was as susceptible as French Colombard to RKN feeding.

These rootstock selections have been tested in large pots filled with vineyard soil from sites with severe nematode infestation to more closely approximate field conditions. The soils had high levels of RKN and ring nematodes, lesion nematodes, and *Xiphinema americanum*. Harmony rootstock was planted in 4-inch pots with one of these soils, as a control, and more than 100 RKN egg masses were recovered in seven weeks.

Five rootstocks released to nurseries for expansion

Five selections emerged from this screening and they have been released to nurseries to expand for commercial distribution.They have been patented and trademarked as UCD GRN-1™ through UCD GRN-5™.These trademarks were chosen to indicate the development was done at UC Davis and they are Grape Rootstocks for Nematode resistance.

It will take years to determine which vineyard sites these rootstocks are best suited to, but they have unparalleled levels of resistance to nematodes and should excel in sites with single and mixed nematode species infestations. They are all planted in field trials in sites with severe chronic nematode pressure.

Rooting angles of the released rootstocks have been evaluated using herbaceous and dormant cuttings as a rough approximation of rooting depth and ability to induce vigor. A wide range of rootstocks are also being examined to better establish the correlation between rooting angle from herbaceous and dormant cuttings, and known vigor levels in vineyard situations.

The most resistant of the releases is 8909-05 (UCD GRN-1™), it was highly resistant to all of the nematodes tested. This rootstock came from a group of 16 *V. rupestris* x *M. rotundifolia* seed populations that Harold Olmo made. Recently, it was discovered that almost all of these seedlings were not the result of the intended crosses, but instead were the result of pollen contamination from grape species that Dr. Olmo collected in Mexico.

Many of these selections have exceptional resistance to Pierce's disease and dagger nematodes. UCD GRN-1™ is a true *V. rupestris* x *M. rotundifolia* hybrid, and may possess the ability to tolerate fanleaf virus infection in a manner similar to the *V. vinifera* x *M. rotundifolia* rootstock O39-16. This tolerance is critical, since resistance to *X. index* feeding does not prevent the vectoring of, and infection by fanleaf virus.

Work is underway to determine whether UCD GRN-1™ is capable of preventing fanleaf disease. Cuttings of UCD GRN-1™ produce relatively few roots, and root at a slower rate, than other newly released rootstocks. These rooted cuttings have deep rooting angles, although not as deep as O39-16.

The 9363-16 (UCD GRN-2™) release is a cross of (*V. rufotomentosa* x [Dog Ridge x Riparia Gloire]) x Riparia Gloire that acquires its nematode resistance from *V. rufotomentosa* and *V. champinii* (Dog Ridge). It has lobed leaves similar to *V. rufotomentosa*, but they are relatively hairless, a trait acquired from *V. riparia*. UCD GRN-2™ propagates well, and produces roots with relatively shallow rooting angles. It is a good mother-vine and has excellent nematode resistance; although it is susceptible to ring nematodes.

9365-43 (UCD GRN-3™) is a cross of (*V. rufotomentosa* x [Dog Ridge x Riparia Gloire]) x *V. champinii* c9038 and has nematode resistance from *V. rufotomentosa, V. champinii* (Dog Ridge) and c9038 — a wild collection from Texas that appears to contain *V. monticola*, a *Vitis* species that grows on very dry limestone soils climbing on mesquite and juniper in west-central Texas.

UCD GRN-3™ looks like a form of *V. champinii* and produces moderately vigorous mother-vines with long canes and moderate lateral production. The cuttings root very well, and their rooting angles are intermediate in depth. It has excellent nematode resistance and has moderate resistance to ring nematodes.

9365-85 (UCD GRN-4™) is a sibling of UCD GRN-3™, but appears more like *V. riparia*. This may translate into reduced vigor, but the rooting angles of the two siblings are similar. Nematode resistance of UCD GRN-4™ is slightly less than UCD GRN-3™, but it is a more vigorous mother-vine.

The cross 9407-14 (UCD GRN-5™) of (Ramsey x Riparia Gloire) x *V. champinii* c9008 has strong and broad nematode-resistance from *V. champinii* (Ramsey) and c9021, a *V. champinii/monticola* selection from west-central Texas. However, it is susceptible to ring nematodes. The mother-vine resembles a glossy-leaved version of *V. champinii*. The canes are long, straight, and produce few laterals, but the mother-vine is relatively weak. Cuttings produce moderate-size roots with relatively deep rooting angles.

Summary

The lack of effective fallowing and crop rotation in vineyards are key factors leading to a nematode's potentially large negative impact on vineyard establishment and longevity.

These new rootstock selections were designed to durably resist a broad range of nematodes, enabling their use in infested sites without the use of nematicides and multi-year fallow periods. They also present a diverse range of nematode-resistance, providing more choices for rootstock rotation when vineyards are replanted. ■

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