Characterization of Grapevine Rugose Wood Disease Sources from Italy

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ABSTRACT

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A collection of 27 sources of grapevine rugose wood (RW) disease from a viticultural region in northern Italy was analyzed by graft-inoculating vines of three selective *Vitis* indicators (*V. rupestris* cv. St. George, *V. berlandieri* × *V. riparia* cv. Kober 5BB, and hybrid cv. LN 33). On the basis of stem reactivity, different groups were identified among the selected RW inoculum sources: nine isolates induced pitting only on cv. St. George, whereas four induced grooving only on cv. Kober 5BB. These two groups were classified as isolates of *rupestris* stem pitting and Kober stem grooving. Three of the remaining isolates induced wood abnormalities on cvs. LN 33 and Kober 5BB, seven induced wood abnormalities on cvs. St. George and Kober 5BB, and four induced symptoms on all three indicators. These groups may represent RW sources with various disease combinations. RW-affected grapevine clones used as inoculum sources also were tested for virus infections by enzyme-linked immunosorbent assay (ELISA). ELISA revealed the presence of grapevine fleck virus, grapevine leafroll-associated closterovirus 1 and 3, and grapevine trichovirus A. These viruses infected most of the selected RW sources. However, eight of the latter were ELISA-negative. The findings are discussed, and the biological and etiological complexity of the RW phenomena in grapevine is confirmed.

Viruses and virus-like pathogenic agents, transmitted and perpetuated by vegetative propagation, cause economically serious diseases in grapevines. One of the most important of these diseases is rugose wood (RW), which occurs worldwide and is especially common in Italy. RW is a generic term adopted to designate a group of distinct disorders, mainly characterized by the development of pitting and grooving in the woody cylinder. The diseases generally are found on *Vitis vinifera* L. cultivars in a latent state, and symptoms usually do not appear until bud scions from diseased donor vines are grafted onto certain American rootstocks, when they adversely affect growth and yield (16,20).

On the basis of the latest information, four RW syndromes may be identified by graft-inoculation of healthy indicator vines (13,15,16,19): *rupestris* stem pitting (RSP), with distinctive symptoms on *V. rupestris* Sheele 'St. George'; Kober stem grooving (KSG), so termed because of the reaction on rootstock cv. Kober 5BB (*V. berlandieri* Planch. × *V. riparia* Michx.); LN 33 stem grooving (LNSG), which only induces symptoms on indicator hybrid cv. LN 33 (Couderc 1613 × Thompson Seedless); and corky bark (CB), which is expressed in *V. rupestris* and cv. LN 33. The RW etiology

has not been established, but flexuous filamentous viral particles have been found in vines with wood deformities (1,6,7,10,14–18).

During a sanitary selection program in northern Italy, several candidate clones of *V. vinifera* cultivars carrying infectious agents that induce RW phenomena were found (12; R. Credi, unpublished data). Appropriate biological indexing tests were carried out on the diseased material available to better characterize the wood abnormalities. Some preliminary results with graft-transmissions were reported previously (11). This paper describes results that reveal the diversity and heterogeneity of indicator responses, which can be used to differentiate between the RW sources and as a basis for their classification.

MATERIALS AND METHODS

RW sources. The RW-affected grapevine materials used as inoculum sources were obtained from a foundation vineyard set up by the Dipartimento di Colture Arboree, University of Bologna, Italy. The vineyard was established over time by collecting several clones from a single mother vine selection from most of the local *V. vinifera* cultivars grown in Emilia Romagna. All original mother vines and daughter clones were inspected repeatedly in the field for symptoms of virus and virus-like diseases. Most of them also had undergone standard indexing procedures (12; R. Credi, unpublished data). Over time, many clones were affected by RW and, therefore, were selected for the current differential indexing trials (Table 1).

Graft-inoculation on RW indicators. The selected RW-affected clones were used

as budwood to graft-inoculate healthy indicator cvs. St. George, LN 33, and Kober 5BB, originally obtained from A. C. Goheen, University of California, Davis. Buds from a virus-free, heat-treated clone that was negative for RW and other infectious diseases were used as controls. Trials were carried out from 1988 onward. Dormant canes of indicator vines were collected during the winter, and three bud cuttings (30 to 40 cm long) were inoculated with RW donor vines, using the chip-budding technique (16). Graft combinations were stratified in sawdust in boxes and callused in a heated room (approximately 30°C for the first 4 to 5 days and 25 to 27°C for an additional 15 days) at 80 to 90% relative humidity. Subsequently, the callusing boxes were placed in an unheated room (approximately 15 to 20°C) for another 10 days, and after waxing, the indicator plants were potted and maintained in a glasshouse at temperatures ranging from 15 to 27°C until the following fall. During this period, the growing inoculated buds were periodically pruned back to prevent subsequent growth. Finally, during the following winter, successfully rooted and grafted vines were transplanted to a field nursery in rows with 50 cm between each plant and an interrow spacing of 200 cm, using standard cultivation practices.

Indicator vines subsequently were evaluated for virus and virus-like diseases during the growing season. Final inspections of surviving vines for RW symptoms were made 3 or 4 years after grafting. During the spring, individual vines were uprooted and examined for alterations of the woody cylinder after removing the stem bark. Symptom severity was classed as weak (+), moderate (++), and strong (+++).

Virus testing. All selected RW sources were assayed serologically for the presence of the following phloem-limited viruses: grapevine leafroll-associated closteroviruses 1, 2, 3, and 5 (GLRaV-1, 2, 3, and 5) (4); grapevine trichovirus A (GVA) (2,10); and grapevine fleck virus (GFKV) (3,5). Grapevine fanleaf (GFLV) and arabis mosaic nepovirus (ArMV) tests also were performed. A conventional double-antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) (9) was used for GLRaV-1, GLRaV-3, GFLV, and ArMV, with coating and conjugate antibody preparations purchased from Sanofi Diagnostics Pasteur (Marnes-La-Coquette, France), Bioreba Ag (Basel, Switzerland), and Agritest (Valenzano, Italy). Biotin DAS-ELISA was used for GLRaV-2 and 5, using kits also prepared by Sanofi Diagnostics. The presence of GVA and GFKV

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in grapevine samples was assayed with polyclonal and enzyme-conjugated monoclonal antibodies from Agritest. The antibody-trapped antigen forms of ELISA were used, following protocols developed by Boscia et al. (2,3). All the ELISA tests were performed following the manufacturer's instructions, with a few modifications. Duplicate samples were collected from each RW donor vine for at least two consecutive years. Samples of bark scrapings of dormant canes were prepared, frozen in liquid nitrogen, ground with a pestle and mortar, mixed in extraction buffer (0.2 M Tris-HCl, pH 8.2, containing 0.8% NaCl, 2% polyvinylpyrrolidone, and 0.05% Tween 20) with a ratio of 1:10 to 1:15 (wt/vol), and ground again. The extracts were filtered and incubated (0.2 ml per well) in duplicate wells on micro-ELISA plates (Dynatech Co. Inc., Alexandria, VA). Samples of virus-free grapevine tissues were added to each plate as negative controls. Optical absorbance at 405 nm was measured with an ELISA reader (Dynatech). Values three times higher than the mean of the healthy controls (0.03) and equal to or greater than 0.10 were considered positive. Samples with absorbance values close to the positive-negative threshold were tested again.

RESULTS

The results of the differential indexing trials and ELISA carried out with 27 RW-affected clonal selections are summarized in Tables 2 through 6.

Reaction of indicator vines. All the selected RW inoculum sources induced stem pitting or grooving when graft-inoculated onto *Vitis* indicators. In contrast, no wood abnormalities were observed on control vines. Graft-transmission efficiency varied from 30 to 100%. On the basis of indicator reactivity, individual RW sources were classified into diverse host-range groups. Nine RW-affected clones caused symptoms exclusively on cv. St. George (Table 2). The stem reaction associated with clones BL11A, CNO9, CNO15, RSS6, and TRCV1 varied in severity from weak to strong and consisted of a row of pits that developed downward from the point of inoculation (Fig. 1A). The other clones (BL1, LS3, PGD2, and TRCV4) induced similar symptoms. Pittings, however, were distributed wherever the trunk was exposed. Four clones (ALZ1A, BL13, MS6, and MS7) induced wood symptoms only on cv. Kober 5BB indicator plants (Table 3). Stem reactions on graft-inoculated vines generally had a mixed expression, ranging from moderate to strong, of pitting and grooving, systematically distributed in the woody cylinder (Fig. 1B). More than one indicator cultivar reacted positively with the rest of the RW inoculum sources. Three affected clones (AL19, TR12, and TSC1) induced symptoms on vines of cvs. LN 33 and Kober 5BB (Table 4). Most of the inoculated vines showed strong stem

grooving (Fig. 1C), but the bark appeared normal. Seven clones (BR17C, CG18, LGR4A, LGR9, LO9, LS12G, and LSB4) induced a positive RW reaction, of moderate to strong severity, on cvs. St. George and Kober 5BB (Table 5; Fig. 1D). Of these, LSB4, BR17C, and LGR9 also caused suberification of the stem cortex of cv. Kober 5BB vines. Finally, four clones (LGR4B, LGR5, LGR7, and LGR30G) induced RW in vines of all three indicators (Table 6). Recipient cv. LN 33 vines also expressed abnormally thick and corky stem bark (Fig. 1E and F).

Virus detection in RW inoculum sources. The results of ELISA indicated

that the RW-affected clones used as inoculum sources were free of GFLV, ArMV, GLRaV-2, and GLRaV-5. In contrast, most of them (19 of 27 tested) contained infections of GLRaV-1 and 3, GVA, and GFkV. The exceptions were five clones (BL1, LS3, PGD2, RSS6, and TRCV1) that only induced stem pitting on cv. St. George indicator plants (Table 2) and three clones (LO9, LS12G, and LSB4) that caused stem grooving on cv. St. George and Kober 5BB indicator plants (Table 5); these cultivars were virus-free. Multiple virus infections usually were found, the most prevalent being that of GLRaV-1 in combination with GVA.

Table 1. Selected clones of *Vitis vinifera* cultivars used as rugose wood (RW) disease inoculum sources in graft-transmission trials and their complete infectious disease status

Cultivar	Clone	Sanitary status ^a
Albana	AL19	RW + LR + VN + FK
Alionza	ALZ1A	RW + LR + VN
Biancale	BL1	RW + VM
Biancale	BL11A	RW + VN + FK
Biancale	BL13	RW + LR + VM + FK
Brugnola	BR17C	RW + LR
Canino	CNO9	RW + LR + VN + FK
Canino	CNO15	RW + LR + VN
Cargarello	CG18	RW + LR + VN
Lambrusco	LS3	RW + VN + VM
Lambrusco	LGR4A	RW + LR + VM
Lambrusco	LGR9	RW + LR + VM
Lambrusco	LO9	RW + VN + VM
Lambrusco	LS12G	RW + VN + VM
Lambrusco	LSB4	RW + VN + VM
Lambrusco	LGR4B	RW + LR + VM
Lambrusco	LGR5	RW + LR + VM
Lambrusco	LGR7	RW + LR + VM
Lambrusco	LGR30G	RW + LR + VN+FK
Moscato	MS6	RW + LR + FK
Moscato	MS7	RW + LR + VN
Pagadebit	PGD2	RW + VN + VM
Rossola	RSS6	RW + VM
Tosca	TSC1	RW + LR + VN + VM
Trebbiano	TR12	RW + LR + VN + VM
Trebbiano	TRCV1	RW + VN
Trebbiano	TRCV4	RW + LR + VN + VM

^a Grapevine virus and virus-like diseases according to previous biological indexing and field observations: RW = rugose wood, LR = leafroll, VN = vein necrosis, VM = vein mosaic, and FK = fleck.

Table 2. Response of *Vitis* indicators to graft-inoculation with affected clones that induced rugose wood (RW) disease stem symptoms only on cv. St. George, which, therefore, were classifiable as isolates of rupestris stem pitting disease, and their enzyme-linked immunosorbent assay (ELISA) reactivity

RW inoculum source clone	ELISA reactivity ^a	Indicator vine ^b		
		St. George	LN 33	Kober 5BB
BL1	—	++ (5/5)	— (0/9)	— (0/33)
BL11A	GLRaV-1, GFkV	++ (13/17)	— (0/16)	— (0/35)
CNO9	GLRaV-3, GFkV	++ (20/26)	— (0/9)	— (0/30)
CNO15	GLRaV-1, GLRaV-3	++ (6/13)	— (0/10)	— (0/5)
LS3	—	+++ (20/31)	— (0/18)	— (0/34)
PGD2	—	++ (4/12)	— (0/2)	— (0/3)
RSS6	—	+++ (7/14)	— (0/21)	— (0/25)
TRCV1	—	++ (13/17)	— (0/31)	— (0/26)
TRCV4	GLRaV-1	++ (4/10)	— (0/19)	— (0/10)

^a Virus infections: GLRaV-1 and 3 = grapevine leafroll-associated virus 1 and 3 and GFkV = grapevine fleck virus; — indicates the clone was rated negative for virus.

^b Average rating of stem symptom severity: +, ++, and +++ indicate vines showing mild, medium, and strong symptoms, respectively; — indicates no symptoms observed. The number of vines with positive stem reactions per number of graft-inoculated vines are shown in parentheses.

DISCUSSION

The results obtained with the current graft-transmission trials support previous findings on the possibility of distinguishing single disease components of the grapevine RW complex (13,15,16,19). Five host-range groups based on the RW inoculum sources used in the study were identified by indexing on the proper differential *Vitis* indicators. Some of RW-affected clones induced symptoms on all three indicator cultivars and the others on only one or two cultivars. A number of the isolates from selected RW sources caused stem pitting exclusively on *V. rupestris* cv. St. George (Table 2). These appear to correspond with the RSP syndrome (15,16). The symptomatic expression of RSP is reported to have a basipetal localized distribution in the woody cylin-

der when indicator vines are inoculated by chip-budding. However, about half of these isolates produced pits all over the stem. One possible explanation is the existence in nature of different RSP pathotypes. Moreover, the investigation clearly indicated that some of the selected RW inoculum sources should be classified as KSG (16,19), inducing stem grooving only on cv. Kober 5BB (Table 3). None of the inocula were definitely shown to contain the single presence of LNSG (13,16). However, the majority of the RW-affected clones tested showed different probable combinations of these three single RW diseases.

Based on the indexing results, the RW sources grouped in Table 4 may have been affected by both LNSG and KSG. The inoculum sources grouped in Table 5 may

have contained a combination of RSP and KSG, whereas those in Table 6 may have contained a combination of RSP, LNSG, and KSG. These last two groups of isolates, however, induced a reaction characterized by strong grooving, systemically distributed, in cv. St. George stems that was not typical of the RSP disease. A possible synergistic effect of various causal pathogenic agents can be suggested. CB disease, another component of the grapevine RW complex, also is reported to induce severe stem grooving and pitting in cvs. St. George and LN 33 (15,16). However, this host-range pattern (Table 6) was not accompanied by the typical leaf and cane symptoms usually associated with CB on cv. LN 33. Indicator vines only showed rolling and reddening of leaves, which is characteristic of leafroll disease (16). Consequently, the occurrence of CB disease has not been demonstrated.

Generally speaking, the interpretation given for the RW phenomena described here are very tentative due to the numerous complex factors involved. For instance, the causal agents for the individual RW syndromes are still unidentified. The possible influence on their expression of associated virus and virus-like infections (Table 1) also is still unknown. Moreover, woody indexing tests may not be completely reliable, because results can be affected by various elements. For example, a possible latency of these wood disorders must be considered, as has been suggested previously (20). This also would explain the low graft-transmission efficiency in some groups of inoculated indicator vines.

The results of the ELISA tests indicated the virological status of the inoculum sources and made it possible to analyze the relationship between the presence of GLRaV-1 and 3, GVA, and GFkV and the RW symptoms found. However, other grapevine leafroll-associated closterovirus infections may have been present. For example, the possible occurrence of GLRaV-4, 6 (4), and 7 (8) was not investigated. GLRaV-1 and 3 are considered the most important etiological agents of grapevine leafroll disease (4,16). GFkV is the causal agent of fleck disease (3,5). The presence of these viruses usually was consistent with the infectious disease status of the selected RW-affected clones, previously ascertained by traditional indexing procedures and field observations (Table 1) or determined during these trials. GVA infection reportedly is linked to the KSG wood disorder (7,14). The present investigation seems to confirm these findings. GVA was not found among RSP isolates (Table 2), whereas all the KSG isolates contained this virus (Table 3). GVA also was detected in almost all the remaining RW sources, possibly containing the multiple presence of KSG with other RW single components. The exception was represented by three isolates that did not have any virus infection (Table 5). These, along with the

Table 3. Response of *Vitis* indicators to graft-inoculation with affected clones that induced rugose wood (RW) disease stem symptoms only on cv. Kober 5BB, which, therefore, were classifiable as isolates of Kober stem grooving disease, and their enzyme-linked immunosorbent assay (ELISA) reactivity

RW inoculum source clone	ELISA reactivity ^a	Indicator vine ^b		
		St. George	LN 33	Kober 5BB
ALZ1A	GLRaV-3, GVA	– (0/18)	– (0/15)	+++ (34/35)
BL13	GLRaV-1, GVA, GFkV	– (0/10)	– (0/15)	++ (12/15)
MS6	GLRaV-1, GVA, GFkV	– (0/12)	– (0/3)	++ (2/5)
MS7	GLRaV-1, GVA	– (0/8)	– (0/7)	+++ (8/9)

^a Virus infections: GLRaV-1 and 3 = grapevine leafroll-associated virus 1 and 3, GVA = grapevine trichovirus A, and GFkV = grapevine fleck virus.

^b Average rating of stem symptom severity: ++ and +++ indicate vines showing medium and strong symptoms, respectively; – indicates no symptoms observed. The number of vines with positive stem reactions per number of graft-inoculated vines are shown in parentheses.

Table 4. Response of *Vitis* indicators to graft-inoculation with affected clones that induced rugose wood (RW) disease stem symptoms on cvs. LN 33 and Kober 5BB and their enzyme-linked immunosorbent assay (ELISA) reactivity

RW inoculum source clone	ELISA reactivity ^a	Indicator vine ^b		
		St. George	LN 33	Kober 5BB
AL19	GLRaV-1, GVA, GFkV	– (0/15)	++ (11/21)	+++ (16/16)
TR12	GLRaV-1, GVA	– (0/17)	+++ (9/12)	+++ (21/29)
TSC1	GLRaV-1, GVA	– (0/10)	+++ (3/10)	+++ (9/11)

^a Virus infections: GLRaV-1 = grapevine leafroll-associated virus 1, GVA = grapevine trichovirus A, and GFkV = grapevine fleck virus.

^b Average rating of stem symptom severity: ++ and +++ indicate vines showing medium and strong symptoms, respectively; – indicates no symptoms observed. The number of vines with positive stem reactions per number of graft-inoculated vines are shown in parentheses.

Table 5. Response of *Vitis* indicators to graft-inoculation with affected clones that induced rugose wood (RW) disease stem symptoms on cvs. St. George and Kober 5BB and their enzyme-linked immunosorbent assay (ELISA) reactivity

RW inoculum source clone	ELISA reactivity ^a	Indicator vine ^b		
		St. George	LN 33	Kober 5BB
BR17C	GLRaV-1, GLRaV-3, GVA	++ (3/6)	– (0/7)	+++ (13/16)
CG18	GLRaV-3, GVA	++ (17/28)	– (0/23)	++ (24/35)
LGR4A	GLRaV-1, GVA	+++ (11/13)	– (0/8)	+++ (6/6)
LGR9	GLRaV-1, GVA	++ (12/18)	– (0/5)	+++ (12/14)
LO9	–	+++ (19/21)	– (0/23)	+++ (21/37)
LS12G	–	+++ (19/19)	– (0/5)	+++ (5/11)
LSB4	–	+++ (4/8)	– (0/11)	++ (32/37)

^a Virus infections: GLRaV-1 and 3 = grapevine leafroll-associated virus 1 and 3 and GVA = grapevine trichovirus A; – indicates the clone was rated negative for viruses.

^b Average rating of stem symptom severity: ++ and +++ indicate vines showing medium and strong symptoms, respectively; – indicates no symptoms observed. The number of vines with positive stem reactions per number of graft-inoculated vines are shown in parentheses.

RSP isolates also rated ELISA-negative (Table 2), could be potential pure disease sources. The data confirmed the etiological complexity of the RW phenomena occurring in grapevine. In an attempt to elucidate the phenomena, the possible occur-

rence of grapevine trichovirus B, reported by Boscia et al. (6), which is thought to play a key role in the CB syndrome, grapevine trichovirus C, reported by Monette and James (18), and grapevine trichovirus D, recently isolated by Abou-Ghanem et

al. (1), must be investigated further. The possible existence of other filamentous virus particles, distinct from those previously described (17), also should be considered.

In conclusion, the collection of grapevine RW isolates, representing the diversity of types occurring naturally in a typical viticultural region, is an important resource and will be invaluable in future fundamental etiological studies.

Table 6. Response of *Vitis* indicators to graft-inoculation with affected clones that induced rugose wood (RW) disease stem symptoms on cvs. St. George, LN 33, and Kober 5BB and their enzyme-linked immunosorbent assay (ELISA) reactivity

RW inoculum source clone	ELISA reactivity ^a	Indicator vine ^b		
		St. George	LN 33	Kober 5BB
LGR4B	GLRaV-1, GVA	+++ (21/24)	++ (14/27)	+++ (17/21)
LGR5	GLRaV-1, GVA	++ (14/25)	+++ (18/21)	+++ (24/28)
LGR7	GLRaV-1, GVA	+++ (15/19)	++ (1/1)	+++ (2/2)
LGR30G	GLRaV-1, GVA	++ (8/25)	++ (9/9)	+++ (32/32)

^a Virus infections: GLRaV-1 = grapevine leafroll-associated virus 1 and GVA = grapevine trichovirus A.

^b Average rating of stem symptom severity: ++ and +++ indicate vines showing medium and strong symptoms, respectively. The number of vines with positive stem reactions per number of graft-inoculated vines are shown in parentheses.

Fig. 1. Differential stem reaction of *Vitis* indicator plants to graft-inoculation with affected clones from selected grapevine rugose wood (RW) disease sources. (A) Symptoms of rupestris stem pitting (RSP) on cv. St. George induced by clone CN09. (B) Symptoms of Kober stem grooving (KSG) on cv. Kober 5BB induced by clone ALZ1A. (C) Symptoms on indicator cv. LN 33 induced by clone TR12, with a possible association of LN 33 stem grooving (LNSG) and KSG. (D) Symptoms on indicator cv. St. George induced by clone LGR4A, with a possible association of RSP and KSG. (E) Trunk of indicator cv. LN 33 showing corky bark and (F) after exposure, grooving of the woody cylinder induced by clone LGR30G, with a possible association of RSP, LNSG, and KSG diseases.

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