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Comparison of resistance to powdery mildew and downy mildew in Chinese wild grapes

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Summary

This research was performed under natural conditions in an effort to compare resistance within Chinese *Vitis* germplasm to powdery mildew and downy mildew. Sixty-six genotypes of 13 Chinese wild *Vitis* species were selected to evaluate disease resistance. Seven among these 13 species, *V. amurensis*, *V. romanetii*, *V. piazezkii*, *V. davidii*, *V. davidii* var. *cyanocarpa*, *V. liubanensis*, and *V. bashanica* showed resistance to powdery mildew. Three species, *V. yeshanensis*, *V. davidii* var. *cyanocarpa*, and *V. pseudoreticulata* exhibited resistance to downy mildew. Among 66 genotypes, 46 were resistant to powdery mildew, 28 were resistant to downy mildew and 19 genotypes had resistance to both diseases. Although more than half of the genotypes exhibited resistance to powdery mildew and a lesser number expressed resistance to downy mildew, resistance to both diseases in Chinese *Vitis* were significantly related (r = 0.395, df = 64, $r_{0.01}$ = 0.325). Also, there is resistance variation regarding both diseases between the species and also, to a lesser degree, among the genotypes. The variation is not related to the geographic distribution of the germplasm. These variations should be considered when researchers collect the gemplasm on location, making every effort to obtain extensive genotypes for the breeding program.

K e y w o r d s : Grapevine, Chinese grapes, wild germplasm, disease resistance, powdery mildew, downy mildew.

Introduction

Powdery mildew [*Erysiphe necator* Schwein. (syn. *Uncinula necator* (Schw.) (Burr.)] and downy mildew [*Plasmopara viticola* (Berk. and Curtis) Berl. and de Toni] are the two most important diseases that devastate grapes worldwide (POOL *et al.* 1984, HE 1994, 1999, GADOURY 1996, REISCH and PRATT 1996; BROWN *et al.* 1999 a, b, c). Symptoms of powdery mildew appear as irregular chlorosis of gray-white with white powder on the leaf surface, and as black net lines with white powder on berry, stalk and tendril surface (REISCH and PRATT 1996, HE 1999). Symptoms of downy mildew appear as yellowish, oily lesions on leaf surface (HE 1999, BROWN *et al.* 1999 a, b; EMMELT *et al.* 1999). Powdery mildew retards the development of berries and causes berry crack, resulting in loss of berry quality and grape production (HE 1999, REISCH and PRATT 1996). Downy mildew causes leaf abscission, resulting in overall vigor reduction, winter injury or even death of susceptible vines (HE 1999, BROWN *et al.* 1999 a and b).

Given the economic importance of powdery mildew and downy mildew, grape breeders have screened germplasm materials to breed resistant cultivars (SPRAGUE 1980, PATIL 1989, LENNE and WOOD 1991, THIND 1996). Germplasms with resistance to powdery mildew include: *V. rotundifolia*, *V. munsoniana*, *V. yenshanensis*, *V. riparia*, *V. vulpine*, *V. thunbergii*, *V. champinii*, *V. cinerea helei*, *V. cinera*, *V. flexuosa*, *V. aestivalis*, *V. argentifolia*, *V. cordata* and *V. mustangensis* (STAUDT 1997). Germplasms with resistance to downy mildew include: *V. munsoniana*, *V. rotundifolia*, *V. candicanus*, *V. piasezkii*, *V. doaniana*, *V. tiliaefolia*, *V. palmate*, and *V. shuttle worthi* (STAUDT and KASSEMEYER 1995, BROWN *et al.* 1999 b).

China is one of the principal centers of origin of *Vitis* species (WANG *et al.* 1998, HE 1999). More than 35 species among approximately 70 known species all over the world originated in China. Chinese *Vitis* species have extremely high resistance to *Elsinoë ampelina* (de Barry) Shear. (WANG *et al.* 1998) and high resistance to *Coniothyrium diplodilla* (Speq.), Sacc. and *Glomerella cingulata* (Ston.) Spauld et Schrenk (HE 1999). In addition, the berries of Chinese *Vitis* do not have "foxy" flavor, which commonly exists in the berries of *Vitis* that originate in North America (ALLEWELDT and POSSINGHAM 1988, HE 1999). Chinese *Vitis* species can be easily crossed with *V. vinifera*, and incorporating the disease resistance from Chinese *Vitis* species into *V. vinifera* has proven to be a useful way to improve the disease resistance of the major European grapes (HE1999, WANG *et al.* 1998). These desirable characteristics of Chinese wild *Vitis* have captured grape breeders' attention (WANG *et al.* 1998, HE 1999, LUO and HE 2004, LIN *et al.* 2006).

Grape production in China has dramatically increased in the past 20 years (LÜ 2000). The cultivated area for grapes in China was 29,200 ha in 1978, and has now increased to 407,900 ha (LÜ 2000). However, grape production in certain areas of China has greatly decreased because its continental climate has allowed an epidemic of powdery and downy mildew to arise. In China, the annual average production loss caused by powdery and downy mildew is

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estimated to range between 8.7-23.6 % and 11.2-21.9 % respectively (HE 1999). Therefore, to exploit the germplasm in an effort to breed resistant cultivars or to improve the disease resistance of the major cultivars grown in China is a pressing issue facing the Chinese grape breeders.

This study was to compare the resistance of Chinese wild *Vitis* to powdery mildew and downy mildew, and to identify some resistant materials for the breeding program.

Material and Methods

Germplasm was obtained from the grape germplasm and breeding program of Northwest A&F University at Yangling, Shaanxi Province, China. Sixty-six genotypes of 13 Chinese wild *Vitis* were selected; control materials obtained from 'Campbell Early' of *V. labrusca*, 'Beaumont' of *V. riparia* and from 3 cultivars of *V. vinifera* L., which were all evaluated from 2001 to 2003.

In Yangling, the rainy season spans from May to October with an annual rainfall of approximately 800 mm. Under natural conditions, grape powdery mildew appears in June and peaks in the middle of August, while downy mildew appears in May and peaks in late September and early October. For this reason, evaluation of resistance to powdery mildew and downy mildew was conducted in the middle of August and from late September to early October, respectively, when the symptoms of these two diseases are fully developed.

150 leaves of each genotype or cultivar were selected arbitrarily for evaluation of resistance to each disease. The symptoms on each leaf were rated from 0 to 7, based on the estimated percentage of lesion over the whole leaf as follows (HE 1994 and WANG *et al.* 1998): Grade 0 = no symptoms, 1 = 0.1-5.0 %, 2 = 5.1-15.0 %, 3 = 15.1-30.0 %, 4 = 30.1- 45.0 %, 5 = 45.1-65.0 %, 6 = 65.1-85.0 %, 7 = 85.1-100.0 %. The grades were then converted into a susceptibility index (SI),

$$SI = \frac{\text{Sum of (grade value} \times \text{no. of leaves in that grade)} \times 100}{\text{Total of leaf number} \times \text{the highest grade value}}$$

The resistance level of each genotype was rated in five categories based on its SI value: extremely resistant (ER), SI = 0.0; highly resistant (HR), SI = 0.1-5.0; resistant (R), SI = 5.1-25.0; susceptible (S), SI = 25.1-50.0; highly susceptible (HS), SI = 50.1-100.0.

Variance analysis and correlation coefficients of susceptibility indices between powdery mildew and downy mildew, and correlation coefficients of susceptibility indices between years, for genotypes of Chinese *Vitis* were calculated (SNEDECOR and COCHRAN 1989).

Results and Discussion

Among the 13 Chinese wild *Vitis* species, 7 species, *V. amurensis*, *V. romanetii*, *V. piazezkii*, *V. davidii*, *V. davidii* var. *cyanocarpa*, *V. liubanensis*, and *V. bashanica* were resistant to powdery mildew and *V. qinguangularis* had variable resistance. 3 species, *V. yeshanensis*, *V. davidii* var. *cyanocarpa*, and *V. pseudoreticulata* proved resistant to downy mildew and *V. romanetii* had variable resistance. Among the control species, the 3 cultivars of *V. vinifera* were highly susceptible to powdery mildew and downy mildew, while *V. labrusca* was resistant and *V. riparia* was highly resistant to both diseases (Tab. 1).

Among 66 genotypes of Chinese wild *Vitis*, 46 genotypes were resistant to powdery mildew, 28 genotypes were resistant to downy mildew, and 19 of those genotypes were resistant to both diseases. The number of species/genotypes in Chinese wild *Vitis* resistant to powdery mildew is more than those resistant to downy mildew. And there are species/genotypes in Chinese wild *Vitis* that boast resistance to both fungal diseases (Tab. 1). It would be important to disease resistance breeding to take advantage of Chinese wild *Vitis* species/genotypes that exhibit multiple resistance to diseases.

Regarding both diseases, variance analysis showed that susceptibility indices of genotypes within 6 species, *V. amurensis*, *V. quinquangularis*, *V. romanetii*, *V. piazezkii*, *V. pseudoreticulata* and *V. davidii*, and all 66 genotypes of Chinese wild grapes presented significant variation (Tab. 2). Though the correlation coefficients (r) of susceptibility indices between three years' data are significant (r (for powdery mildew) = 0.9005, r (for powdery mildew) = 0.9001, df = 64, $r_{0.01}$ = 0.325), the mean square variance of susceptibility indices between three years' are also significant (F (for powdery mildew) = 1462.816, F (for powdery mildew) = 179.1259, df = 65, $F_{0.01}$ = 4.08). This indicates that data of multiple years' collection is prerequisite to the efficient identification and evaluation of disease resistance in germplasm.

The analysis of correlation coefficients (r) of average susceptibility indices between powdery mildew and downy mildew for genotypes of 6 of the 13 Chinese *Vitis* species selected, and for 66 total genotypes of Chinese *Vitis* (Tab. 3) shows that the r-value of the three species of *V. amurensis*, *V. quinquangularis* and *V. romanetii* are significant, the r-value of the other three species are insignificant, but the r-value of all 66 genotypes is significant (r = 0.395, df = 64, $r_{0.01}$ = 0.325) (Tab. 3), which indicates that resistance to both diseases in Chinese wild *Vitis* is complex.

The host may co-evolve in cooperation with the pathogen, which means if the host and the pathogen originated in the same place, the host may obtain resistance to the pathogen; if not, the host may not obtain the resistance (BURDON 1987, MITCHELL-OLDS and BERGELSON 2000, RICHTER and RONALD 2000). *E. necator* and *P. viticola* originated in North America, which may be the reason that most *Vitis* species originating here such as *V. riparia*, *V. vulpine*, *V. thunbergii*, *V. champinii*, *V. cinerea hellei*, *V. cimera*, *V. flexuosa*, *V. aestivalis*, *V. argentifolia*, *V. cordata*, and *V. mustangensis* have resistance to these two fungal diseases, while *V. vinifera* is susceptible to these diseases (STAUDT and KASSEMEYER 1995, STAUDT 1997). The susceptibility indices of both powdery and downy mildew for most genotypes of Chinese wild *Vitis* were higher (infe-

Table 1

Susceptibilty indices and level of resistance rating to powdery mildew and downy mildew for genotypes of Chinese *Vitis* under natural conditions in 2001-2003

Genotypes or cultivars	Powdery mildew					Downy mildew				
	Susceptibility index				RL[x]	Susceptibility index				L R
	2001	2002	2003	Aver.[y]		2001	2002	2003	Aver.	
V. amurensis Rupr.										
Shuangyou	31.17	25.46	26.13	27.59	S	41.05	53.54	56.47	50.35	HS
Tonghua No.3	17.65	13.38	18.16	16.4	R	32.52	44.69	42.36	39.86	S
Zuoshan No.1	15.03	14.32	17.32	15.56	R	36.11	45.02	48.33	43.15	S
Zuoshan No.2	16.16	11.00	19.17	15.44	R	36.32	47.00	53.68	45.67	S
Zuoshan 75097	17.55	11.08	16.22	14.95	R	37.56	44.90	51.25	44.57	S
Zuoshan74-1-326	14.14	12.00	13.09	13.08	R	37.26	44.67	45.17	42.37	S
Heilongjiang-♂	13.52	10.00	14.87	12.80	R	18.82	28.08	27.61	24.83	R
Taishan-11	12.10	10.00	19.36	13.82	R	25.77	30.74	38.65	31.72	S
Huaxian-47	5.08	1.56	4.32	3.32	HR	19.82	25.50	24.54	23.28	R
V. quinquangularis Rehd.										
Nanzheng-1	15.33	9.55	18.26	14.38	R	32.55	36.70	40.16	36.47	S
83-4-96-♂	13.17	5.95	17.76	12.29	R	21.38	23.90	26.32	23.87	R
83-4-96-♀	20.33	14.02	22.16	18.84	R	16.85	24.21	30.16	23.74	R
Danfeng-2	15.67	9.08	16.92	13.89	R	36.77	40.55	38.67	38.66	S
83-4-49-♀	22.36	16.14	20.86	19.79	R	22.03	26.72	22.16	23.64	R
83-4-94-♂	35.54	25.17	40.16	33.62	S	42.08	50.94	56.23	49.75	S
83-4-94-♀	38.81	28.29	38.17	35.09	S	63.72	72.85	65.44	67.34	HS
83-4-67	30.07	27.23	32.66	29.99	S	43.55	53.05	64.32	53.64	HS
Shangnan-24	15.10	10.00	18.51	14.54	R	29.32	35.02	40.16	34.83	S
Taishan-12	8.12	4.02	12.16	8.10	R	42.86	52.23	49.53	48.21	S
Weinan-3	15.61	9.27	20.32	15.07	R	21.92	23.06	26.37	23.78	R
V. romanetii Roman.										
Pingli-2	18.26	13.08	19.05	16.80	R	7.74	13.14	18.32	13.07	R
Jiangxi-1-♀	20.17	12.33	18.67	17.06	R	25.27	31.87	30.54	29.23	S
Jiangxi-2-♂	16.07	8.68	8.66	14.47	R	9.05	14.05	17.64	13.58	R
Jiangxi-2-♀	15.49	11.25	16.57	14.44	R	8.36	12.15	15.67	12.06	R
Baihe-22	21.36	15.94	19.36	18.89	R	15.51	20.93	21.23	19.22	R
Liuba-1	22.17	14.71	21.02	19.30	R	26.01	34.63	36.23	32.29	S
Pingli-7	19.31	14.01	18.55	17.29	R	24.18	30.45	33.85	29.49	S
V. piazezkii Maxim.										
Liuba-6	8.08	4.06	12.32	8.15	R	27.65	34.09	38.63	33.36	S
Liuba-7	11.51	5.12	15.86	10.83	R	32.64	37.85	41.05	37.18	S
Liuba -8	11.25	4.84	16.23	10.77	R	4.38	4.34	5.06	4.56	HR
Liuba-9	6.54	0.00	6.32	4.29	HR	3.31	5.32	6.08	4.90	HR
Nanzheng-2	20.65	15.68	21.67	19.33	R	20.25	25.07	27.12	24.15	R
Huaxian-1	19.24	13.64	19.36	17.41	R	26.64	30.07	36.33	31.01	S
Baishui-40	17.32	9.2	15.23	13.92	R	22.23	26.11	27.06	25.13	S
Meixian-6	19.65	13.22	19.17	17.35	R	22.36	26.28	24.86	24.50	R
Gansu-91	37.23	23.85	28.26	29.78	S	24.65	30.10	36.33	30.36	S
V. pseudoreticulata W. T. Wang										
Hunan-1	33.86	26.58	30.27	30.24	S	12.36	24.08	30.67	22.37	R
Baihe-35-1	8.14	—[a]	9.17	8.66	R	8.81	15.35	24.32	16.16	R
Baihe-35-2	30.03	26.86	28.16	28.35	S	10.35	15.86	21.32	15.84	R
Guangxi-1	28.11	25.07	29.54	27.57	S	12.17	16.89	20.37	16.48	R
Guangxi-2	31.55	24.74	30.28	28.86	S	14.65	18.04	23.37	18.69	R
Baihe-13	37.27	28.41	34.23	33.30	S	13.27	17.59	21.54	17.47	R
Baihe-13-1	28.87	26.42	27.36	27.55	S	19.36	25.18	30.28	24.91	R
Shangnan-1	30.16	24.53	31.65	28.78	S	17.54	20.80	26.32	21.55	R
Shangnan-2	33.23	24.19	34.78	30.73	S	16.31	24.40	31.15	23.95	R
V. davidii (Roman.) Foëx.										
Tangwei	5.26	0.00	4.09	3.12	HR	29.26	35.10	38.66	34.34	S
Fujian-4	7.48	4.98	6.83	6.43	R	24.32	28.22	31.52	28.02	S
Lueyang-4	24.31	16.04	18.32	19.56	R	27.55	32.91	34.32	31.59	S
Ningqiang-6	18.54	13.99	19.05	17.19	R	28.36	32.13	38.26	32.92	S
Xuefeng	8.32	4.02	6.07	6.14	R	28.62	33.71	36.17	32.83	S

Tab. 1 continued

Genotypes or cultivars	Powdery mildew					Downy mildew				
	Susceptibility index				RL[x]	Susceptibility index				L R
	2001	2002	2003	Aver.[y]		2001	2002	2003	Aver.	
V. adstricta Hance.										
Anlin-1-♂	48.57	36.09	43.92	42.86	S	40.17	54.87	65.37	53.47	HS
Anlin-2-♀	42.05	32.39	41.55	38.66	S	37.21	44.53	48.32	48.35	S
Taishan-1-♂	46.97	36.17	45.38	42.84	S	51.77	60.69	67.54	60.00	HS
Taishan-2-♀	44.39	32.84	42.08	39.77	S	43.82	50.52	48.16	47.50	S
V. hancockii Hance.										
Lingye	45.11	31.25	40.66	39.01	S	30.52	40.81	45.03	38.85	S
Jiangxi-3	33.24	27.45	32.87	31.19	S	27.74	33.58	36.17	32.50	S
V. davidii var. cyanocarpa (Gagn.) Sarg										
Zhen'an-3	20.15	16.36	18.67	18.39	R	8.29	14.43	12.68	11.80	R
Lan'ao-5	15.32	9.20	14.17	12.90	R	7.35	12.98	13.26	11.20	R
V. liubanensis L. X. Niu										
Liuba-10	14.26	8.27	15.03	12.52	R	19.66	24.68	22.32	22.22	R
Lan'ao-2	18.36	12.98	17.67	16.34	R	25.42	31.85	33.86	30.38	S
V. qinlingensis P. C. He										
Pingli-5	26.66	21.97	25.86	24.83	R	33.92	38.64	35.17	35.91	S
Lueyang-4	34.32	26.02	30.92	30.42	S	39.27	45.42	42.36	42.35	S
V. bashanica P. C. He										
Baihe-41	16.35	13.08	17.21	15.55	R	31.84	40.50	38.62	36.99	S
Baihe-42	11.07	5.27	13.08	9.81	R	20.32	30.01	32.19	27.51	S
V. yeshanensis J. X. Chen										
Yanshan-1	33.05	25.00	30.66	29.57	S	20.62	26.72	26.08	24.47	R
Yanshan-2	27.32	18.78	24.26	23.45	R	21.27	25.79	24.32	23.79	R
V. vinifera L. (CK[b])										
Red Globe	40.28	32.22	38.07	36.86	S	50.32	58.44	61.37	56.71	HS
Ruby Seedless	64.30	50.16	53.26	55.91	HS	64.30	50.16	86.32	66.93	HS
Blush Seedless	70.64	51.81	67.88	63.44	HS	70.64	51.81	78.36	66.94	HS
V. labrusca L.(CK)										
Campbell Early	9.65	4.27	15.32	9.75	R	6.32	8.17	5.43	6.64	R
V. riparia Michx.(CK)										
Beaumont	3.27	0.00	4.32	2.53	HR	0.00	0.87	1.54	0.80	HR

a: the genotype grapevines were inoculated with powdery mildew spores by other researchers in 2002;
b = control; x = resistance level; HR = highly resistant; R = resistant; S = susceptible;
HS = highly susceptible; y = average susceptibility index of 2001, 2002 and 2003.

Table 2

Variance analysis of susceptibility indices of powdery mildew and downy mildew for genotypes of Chinese *Vitis*

	V. amurensis	*V. quinquangularis*	*V. romanetii*	*V. piazezkii*	*V. pseudoreticulata*	*V. davidii*	Total
df	8	10	6	8	8	4	65
SS^p	897.745	2510.318	142.59	1336.568	1570.647	650.821	19560.21
MS^p	112.218	251.032	23.765	167.071	196.331	162.705	300.926
F^p	28.199 **	83.032 **	9.428 **	31.914 **	54.753 **	77.162 **	69.326 **
SS^d	2193.601	6505.864	1403.447	3286.735	299.759	68.995	32764.72
MS^d	274.2	650.586	233.908	410.842	37.47	17.249	504.0711
F^d	44.871 **	49.825 **	117.497 **	91.735 **	9.561 **	17.639 **	66.2003 **
$F_{0.01}$	3.89	3.368	4.821	3.89	3.89	7.006	1.59

P: Variance analysis for powdery mildew; D: Variance analysis for downy mildew

rior resistance) to those of *V. labrusca* and *V. riparia*, and lower (superior resistance) to those of *V. vinifera* (Tab. 1). However, the reason that some Chinese wild *Vitis* possess resistance to powdery mildew and downy mildew needs to be further investigated.

Chinese wild *Vitis* expressed variation of resistance to both diseases, not only among the species but also, to some degree, among the genotypes. The variation of resistance, even within the same species, is not related to the geographic distribution. For example, all four types, 'Liu-

Table 3

Correlation coefficients of average susceptibility indices between powdery mildew and downy mildew for genotypes of Chinese *Vitis*

	V. amurensis	*V. quinquangularis*	*V. romanetii*	*V. piazezkii*	*V. pseudoreticulata*	*V. davidii*	Total
df	7	9	5	7	7	3	64
r	0.770	0.639	0.682	0.399	0.360	-0.0319	0.395
$r_{0.05}$	0.666	0.602	0.754	0.666	0.666	0.878	0.250
$r_{0.01}$	0.798	0.735	0.847	0.798	0.798	0.959	0.325

ba-6', 'Liuba-7', 'Liuba-8', and 'Liuba-9' of *V. piazezkii* were collected from the Liuba County of Shaanxi Province, but 'Liuba-6' and 'Liuba-7' presented susceptibility to grape downy mildew, and 'Liuba-8' and 'Liuba-9' showed high resistance to downy mildew. When we exploit the germplasm of Chinese wild grapes for disease resistance breeding, we should investigate these variations amongst the species and the genotypes. We should also make an effort to methodically incorporate the selections which express multiple resistance to diseases into the breeding program.

Our research results over the last 25 years recognize that Chinese wild *Vitis* is a vital germplasm for contributing disease resistance genes into the cultivars of *V. vinifera*. In the past 18 years, we have conducted 25 interspecific crosses between European grapes and Chinese wild grapes. We found in certain crosses that Chinese wild grapes had high inheritance of disease resistance in their F1 generation. From these F1 groups, we have selected 6 superior hybrids with high disease resistance and good quality berries for adaptability testing. We expect that we will release at least 2 wine cultivars from these superior hybrids in the near future. Therefore, we conclude that Chinese wild *Vitis* are an essential germplasm resource for disease resistance breeding, and contain especially useful breeding material for improving the disease resistance of European grapes.

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