

葡萄种质资源对晚霜冻害的抗性表现

张剑侠

(西北农林科技大学园艺学院·旱区作物逆境生物学国家重点实验室·
农业部西北园艺植物种质资源利用重点开放实验室,陕西杨凌 712100)

摘要:【目的】了解葡萄种质资源的抗晚霜表现,为育种利用提供参考依据。【方法】晚霜发生后3 d,对中国野生葡萄17种或变种的56个株系、美国野生葡萄6种的8个株系及17个栽培品种(系)共81份葡萄种质资源抗晚霜冻害表现进行自然鉴定。【结果】中国野生葡萄中,毛葡萄、桑叶葡萄、瘤枝葡萄、华东葡萄表现为避霜;燕山葡萄、麦黄葡萄、麦黄复叶葡萄高抗;藜蔓葡萄高抗或抗;陕西葡萄、小复叶葡萄、菱叶葡萄抗;山葡萄、秋葡萄、复叶葡萄、刺葡萄、秦岭葡萄种内存在抗性差异,既有高抗或抗的株系,也有不抗或极不抗的株系;裂叶刺葡萄‘宁强-6’极不抗。美国野生葡萄中,冬葡萄为避霜;美洲葡萄、甜冬葡萄高抗;河岸葡萄、峡谷葡萄和沙地葡萄抗。栽培品种中,欧亚种品种‘无核白’高抗,‘早玫瑰’‘早金香’‘绯红’抗,‘无核紫’‘新郁’‘京秀’不抗;欧美杂种‘巨峰’高抗,‘藤稔’‘早生高墨’‘京优’‘木星’和‘海王星’抗;欧山杂种‘00-1-10’为避霜,‘00-1-5’高抗,‘北醇’和‘左优红’不抗。【结论】中国野生葡萄、栽培品种抗晚霜表现具丰富多样性,美国野生葡萄表现出较强的抗性。葡萄种质资源对晚霜抗性表现与冬季抗寒性表现不完全一致。

关键词:葡萄;种质资源;晚霜;冻害;抗性

中图分类号:S663.1

文献标志码:A

文章编号:1009-9980(2019)02-0137-06

The resistance of grape germplasm resources to late frost damage

ZHANG Jianxia

(College of Horticulture, Northwest A & F University / State Key Laboratory of Crop Stress Biology in Arid Areas / Key laboratory of Horticultural Plant Utilization in Northwest China, Ministry of Agriculture, the People's Republic of China, Yangling 712100, Shaanxi, China)

Abstract:【Objective】Late frost is a natural disaster leading to extensive crop losses for fruit producers in the world. Although grapevine (*Vitis vinifera* L.) has a wide environmental adaptability, the late frost is a serious threat to grape production in frost-prone viticultural regions. Selection of grape cultivars with strong resistance is a reliable method for avoiding late frost damage. The objective of this study was to understand the resistance of different grape germplasm resources to late frost and to provide a reference for breeding resistant variety and rootstock.【Methods】A severe late frost occurred on 6 and 7 April, 2018, causing damage to young shoots and swollen buds of grapevine in a large area of Northwest China. During the cold wave, the daily minimum temperature fell to 0 degrees C in Yangling district of Shaanxi province which is located in the western part of Guanzhong plain. The occurrence of the late frost provided an opportunity for us to evaluate the resistant performance of grape germplasm resources to late frost. The field natural identification was employed to evaluate the resistance of grape germplasm resources to late frost injury. The third day after late frost (9 April), we carried out a identification of the late frost-resistance for 81 grape germplasm resources under field natural condition, including 56 accessions of 17 Chinese wild *Vitis* species or varieties and 8 accessions of 6 American wild *Vitis* species as well as 17 cultivars. All plants are above 5 years-old and are grown in the grape repository of Northwest A & F University, Yangling, Shaanxi, China. Three plants of each grape var. or acc. were in-

收稿日期:2018-09-06 接受日期:2018-11-19

基金项目:陕西省重点项目-农业(2017ZDXM-NY-026);国家科技支撑计划子课题(2013BAD02B04-06)

作者简介:张剑侠,男,教授,研究方向:葡萄种质资源与生物技术。Tel:18700812259, E-mail:zhangjx666@126.com

vestigated. According to the proportion of damaged tender shoots and swollen buds to total germinated buds, the injury severity of each vine was recorded, and then the average injury severity of three vines of the same var. or acc. was calculated. Finally, according to the average injury severity of each grape var. or acc., the resistant level of the tested grape germplasm resources to late frost damage was divided into four classes: high resistance, resistance, susceptibility and high susceptibility.【Results】As a result of late frost damage, lots of tender shoots of some grapevines showed varying degrees of water stain, wilting, browning and even blackness, but other grapevines had no changes or no sprouting, implying that the different grape germplasm resources had different resistance performance to the late frost. Among the Chinese wild *Vitis* species, *V. quinquangularis*, *V. ficifolia*, *V. davidii* var. *cyanocarpa*, and *V. pseudoreticulata* were frost-avoiding; *V. yenshanensis*, *V. hancockii*, and *V. bashanica* showed high resistance; *V. thunbergii* was highly resistant or resistant; *V. shensiensis*, *V. liubaensis*, and *V. hancockii* were resistant; There were resistance variation in intraspecies of *V. amurensis*, *V. romanetii*, *V. piasezkii*, *V. davidii*, and *V. qinlingensis*, in which the phenotypes were from highly resistant to highly susceptible; *V. davidii* var. *ningqiangensis* was highly susceptible. For the American wild *Vitis* species, *V. berlandieri* was frost-avoiding; *V. labrusca* and *V. cinerea* were highly resistant; *V. riparia*, *V. orizonica* and *V. rupestris* showed resistance. For the *V. vinifera* cvs., ‘Thompson Seedless’ had high resistance; ‘Zaomeigui’, ‘Zaojinxiang’, and ‘Cardinal’ presented resistance; ‘Monukka’ ‘Xinyu’ and ‘Jingxiu’ showed susceptibility. For the Euro-America hybrids, ‘Kyoho’ was highly resistant, ‘Fujiminori’ ‘Wase Takansumi’ ‘Jingyou’ ‘Jupiter’ and ‘Neptune’ were resistant. For the hybrids of *V. vinifera* × *V. amurensis*, 00-1-10 was frost-avoiding, 00-1-5 was highly resistant, ‘Beichun’ and ‘Zuoyouhong’ were susceptible. 【Conclusion】The resistance of Chinese wild *Vitis* and cultivars to late frost was complex. There were not only highly resistant and resistant types, but also susceptible and highly susceptible types, while the American wild *Vitis* species were highly resistant or resistant types. Among of them, *V. quinquangularis*, *V. ficifolia*, *V. davidii* var. *cyanocarpa*, *V. pseudoreticulata*, *Vitis amurensis* acc. Zuoshan-1, *V. yenshanensis*, *V. bashanica*, *V. baihensis*, *V. thunbergii*, *V. romanetii* acc. Meixian-6, *V. piasezkii* acc. Guansu-91, Liuba-8 and Liuba-6, *V. davidii* acc. Tangwei and Xuefeng, *V. berlandieri*, *V. labrusca*, *V. cinerea* as well as cultivars (or acc.) ‘Thompson Seedless’, ‘Kyoho’, 00-1-10, 00-1-5 were the important resistant germplasm resources to late frost damage. The resistance of grape germplasm resources to late frost was not completely consistent with the tolerance to winter cold.

Key words: Grape; Germplasm resource; Late frost; Cold damage; Resistance

晚霜冻害是一种重要的自然灾害,是果树在生长期夜晚土壤和植株表面温度短时降至0℃或0℃以下,引起果树幼嫩部分遭受伤害的现象^[1]。葡萄作为全球广泛栽培的果树,尽管适应性强,但在葡萄产区晚霜是葡萄生产的重要风险^[2-3]。关于晚霜对葡萄的危害,许多国家如法国^[2]、美国^[4-6]、澳大利亚^[7]、巴西^[8-9]等都有研究报道,国内亦有不少报道^[10-15],特别是我国最重要的葡萄产区——西北地区,由于属于大陆性气候,温变剧烈,晚霜冻害频繁,常造成较大的经济损失^[11-12,14-15]。随着全球气候变暖,春季气温升高,葡萄萌芽提前,晚霜冻害的风险增加^[3,10,14,16-17]。针对晚霜危害,研究者们提出了一些预

防措施及补救办法,如建立防护林^[15]、延迟葡萄冬季修剪^[16]、喷保护剂^[18]、灌水推迟发芽^[12-13,15]、葡萄园喷水^[4-5,15]、应用植物生长调节剂^[9,15]、熏烟^[12,15]、延迟春季出土^[14]等,这些栽培措施在一定程度上可减轻晚霜危害和损失,但从根本上还是要培育避霜或抗霜性强的品种和砧木。有研究发现,葡萄品种萌芽越早,生长量越大,冻害越重^[12],选择萌芽迟的品种依然是避免晚霜危害更为可靠的方法^[18]。关于葡萄受晚霜冻害的程度,一些研究者以芽或新梢的受冻率作为评价指标^[11-12,14],未有具体的分级,所研究的葡萄材料也均为生产上栽培的鲜食和酿酒品种,未见有对葡萄种质资源进行抗晚霜冻害的系统评价。

2018年4月6—7日陕北和关中发生了严重的晚霜冻害,其中位于关中西部的杨凌区6日最低气温2℃,最高气温17℃,7日最低气温0℃,最高气温19℃,8日气温回升至9~25℃。4月9日笔者对杨凌西北农林科技大学葡萄种质资源圃中保存的81份葡萄种质资源遭受晚霜危害情况进行了田间自然鉴定,通过评价它们的抗晚霜冻害表现,以期为利用避霜和抗霜种质资源选育抗性品种和砧木提供参考依据。

1 材料和方法

1.1 材料

西北农林科技大学葡萄种质资源圃中生长的中国野生葡萄、美国野生葡萄、栽培品种(系)共81份资源,均为5 a(年)生以上成龄树,管理同生产园相同。

1.2 方法

在晚霜发生后3 d(4月9日),田间自然鉴定81份葡萄种质资源的抗晚霜表现。每株系或品种调查3株。调查每株树萌发的全部新梢数(包括绒球期的芽)、受害新梢数(包括绒球期的芽),计算受害率。受害率/%=受害新梢数/全部新梢数。每株系或品种的受害率取3株树的平均值。参照罗国提等^[19]对马铃薯霜冻害的分级方法,略加改动,按照受害率大小将葡萄受害程度分为4级:1级,受害率为0,极抗(high resistance, HR);2级,受害率≤25%,抗(resistance, R);3级,受害率>25%和≤50%,不抗(susceptibility, S);4级,受害率>50%,极不抗(high susceptibility, HS)。

2 结果与分析

2.1 野生葡萄资源的抗晚霜表现

2.1.1 中国野生葡萄资源的抗晚霜表现 对中国野生葡萄17个种或变种的56个株系抗晚霜表现鉴定结果(表1)表明,毛葡萄、桑叶葡萄、瘤枝葡萄、华东葡萄4个种的所有株系均属于萌芽迟的避霜类型,特别是瘤枝葡萄、华东葡萄的芽眼尚未萌动,刚萌芽的毛葡萄和桑叶葡萄未受到伤害。燕山葡萄、麦黄葡萄、麦黄复叶葡萄表现高抗,蔓茎葡萄高抗或抗,陕西葡萄、小复叶葡萄、菱叶葡萄抗。山葡萄9个品种(株系)中,‘左山-1’萌芽迟,表现为避霜,‘黑龙江实生’‘通化-3’‘华县-47’表现为抗,其余5个品种

(株系)不抗,特别是‘双优’极不抗,说明了山葡萄种内不同株系抗性差异较大。萌芽最早的秋葡萄种,1个株系‘眉县-6’高抗,1个株系‘留坝-1’抗,其余3个株系不抗,也表现出种内株系间明显的抗性差异。复叶葡萄中既有高抗的‘甘肃-91’‘留坝-8’‘留坝-6’,也有抗的‘华县-1’‘留坝-9’‘白水-40’,还有极不抗的‘南郑-2’,表现出种内的差异性。刺葡萄中,‘塘尾’和‘雪峰’高抗,‘略阳-4’不抗。裂叶刺葡萄‘宁强-6’极不抗。秦岭葡萄中,‘略阳-4’抗,而‘平利-5’极不抗。这表明中国野生葡萄资源对晚霜的抗性具有丰富多样性。

2.1.2 美国野生葡萄资源的抗晚霜表现 在鉴定的美国野生葡萄6个种(表1)中,冬葡萄尚未萌芽,表现为避霜;美洲葡萄、甜冬葡萄高抗,河岸葡萄、峡谷葡萄和沙地葡萄抗。这表明原产美国的野生葡萄是重要的抗晚霜种质资源。

2.2 葡萄栽培品种(系)的抗晚霜表现

对3个不同类型栽培品种(系)的鉴定结果(表2)表明,7个欧亚种葡萄品种的抗性不同,‘无核白’表现高抗,‘早玫瑰’‘早金香’‘绯红’抗,而‘无核紫’‘新郁’‘京秀’不抗。6个欧美杂种中,‘巨峰’高抗,其余5个品种抗。4个欧山杂种中,‘00-1-10’萌芽迟,表现为避霜,‘00-1-5’高抗,‘北醇’和‘左优红’不抗。

3 讨 论

关于葡萄对低温胁迫的抗性,以冬季抗寒性研究报道较多^[20-24],对葡萄种质资源抗晚霜能力的评价尚未见系统的报道,仅见有栽培品种的受害程度、预防与补救措施的报道^[10-15],也未有具体的分级标准。从本研究结果可以看出,一是葡萄种质资源抗晚霜能力存在较大差异,不仅表现在种间,也表现在种内;二是葡萄种质资源抗晚霜能力与冬季抗寒能力并不完全一致,冬季抗寒性强的葡萄种质资源不代表其一定抗晚霜,比如抗寒性极强的山葡萄株系‘双优’‘泰山-11’等^[23],它们却不抗晚霜。推测其原因,冬季抗寒性是葡萄经过秋季和初冬较长时间的低温驯化过程,植株处于停止生长状态,对低温有了较强的抵抗能力,而春季晚霜发生时葡萄已萌动的芽或新梢突然遭受低温,处于细胞旺盛分裂和新梢迅速生长阶段,幼嫩的细胞和组织易受到低温的伤害。再者,推测葡萄冬季抗寒与春季抗晚霜的分子机制

表 1 野生葡萄资源的抗晚霜表现

Table 1 The resistance of wild grape resources to late frost

种 Species	株系 Accession	新梢受害率 Sprout injury rate/%	抗晚霜表现 Resistance to late frost	种 Species	株系 Accession	新梢受害率 Sprout injury rate/%	抗晚霜表现 Resistance to late frost
山葡萄 <i>V. amurensis</i>	双优 Shuangyou	53.2	HS	小复叶葡萄 <i>V. liubaensis</i>	留坝-10 Liuba-10	1.6	R
	黑龙江实生				嵐皋-2 Langao-2	15.1	R
	Heilongjiang seedling	16.6	R	刺葡萄 <i>V. davidii</i>	雪峰 Xuefeng	0.0	HR
	泰山-11 Taishan-11	42.9	S		塘尾 Tangwei	0.0	HR
	通化-3 Tonghua-3	6.3	R		略阳-4 Lueyang-4	49.2	S
	左山-1 Zuoshan-1	0.0	HR ¹	裂叶刺葡萄 <i>V. davidii var. ningqianguensis</i>	宁强-6 Ningqiang-6	60.0	HS
	左山-2 Zuoshan-2	41.7	S				
	左山 75097	31.5	S	桑叶葡萄 <i>V. ficifolia</i>	山东(♂)Shandong	0.0	HR ¹
	Zuoshan 75097				渭南-3 Weinan-3	0.0	HR ¹
	左山 74-1-326	29.2	S	瘤枝葡萄 <i>V. davidii var. cyanocarpa</i>	镇安-3 Zhen'an-3	0.0	HR ¹
秋葡萄 <i>V. romanetii</i>	华县-47 Huaxian-47	14.3	R				
	江西-1 Jiangxi-1	38.9	S	秦岭葡萄 <i>V. qinlingensis</i>	平利-5 Pingli-5	83.3	HS
	江西-2 Jiangxi-2	35.7	S		略阳-4 Lueyang-4	24.0	R
	平利-7 Pingli-7	30.0	S	菱叶葡萄 <i>V. hancockii</i>	江西-3 Jiangxi-3	1.7	R
	留坝-1 Liuba-1	4.0	R	麦黄葡萄 <i>V. bashanica</i>	旬阳-8 Xunyang-8	0.0	HR
毛葡萄 <i>V. quinquangularis</i>	眉县-6 Meixian-6	0.0	HR		白河-41 Baihe-41	0.0	HR
	83-4-49(♂)	0.0	HR ¹	麦黄复叶葡萄 <i>V. baihensis</i>	白河-40 Baihe-40	0.0	HR
	南郑-1 Nanzheng-1	0.0	HR ¹				
	83-4-96(♀)	0.0	HR ¹	华东葡萄 <i>V. pseudoreticulata</i>	白河-35-1 Baihe-35-1	0.0	HR ¹
	83-4-96(♂)	0.0	HR ¹		白河-35-2 Baihe-35-2	0.0	HR ¹
	商南-24 Shangan-24	0.0	HR ¹		湖南-1 Hunan-1	0.0	HR ¹
	泰山-12 Taishan-12	0.0	HR ¹		广西-1 Guangxi-1	0.0	HR ¹
	83-4-67	0.0	HR ¹		广西-2 Guangxi-2	0.0	HR ¹
	83-4-94(♀)	0.0	HR ¹		白河-13 Baihe-13	0.0	HR ¹
	83-4-94(♂)	0.0	HR ¹		白河-13-1 Baihe-13-1	0.0	HR ¹
蔓葡萄 <i>V. thunbergii</i>	丹凤-2 Danfeng-2	0.0	HR ¹		商南-1 Shangan-1	0.0	HR ¹
	泰山-1 Taishan-1	0.0	HR		商南-2 Shangan-2	0.0	HR ¹
	泰山-2 Taishan-2	0.0	HR				
燕山葡萄 <i>V. yenshanensis</i>	安林-2 Anlin-2	2.6	R	河岸葡萄 <i>V. riparia</i>	河岸(♀) He'an	8.0	R
	燕山-1 Yanshan-1	0.0	HR		河岸-2 Mcadams	6.5	R
复叶葡萄 <i>V. piasezkii</i>	甘肃-91 Gansu-91	0.0	HR		河岸-3 Beaumont	14.3	R
	华县-1 Huaxian-1	7.0	R	美洲葡萄 <i>V. labrusca</i>	Y157	0.0	HR
	留坝-8 Liuba-8	0.0	HR				
	南郑-2 Nanzheng-2	66.7	HS	甜冬葡萄 <i>V. cinerea</i>		0.0	HR
	留坝-9 Liuba-9	1.4	R				
	留坝-6 Liuba-6	0.0	HR	冬葡萄 <i>V. berlandieri</i>		0.0	HR ¹
	白水-40 Baishui-40	6.8	R	峡谷葡萄 <i>V. orizonica</i>		2.0	R
陕西葡萄 <i>V. shenxiensis</i>	平利-2 Pingli-2	13.2	R	沙地葡萄 <i>V. rupestris</i>	Constantia	10.0	R

注:HR¹表示萌芽迟,表现为避霜。下同。

Note: HR¹ means late-sprouting and presents frost-avoiding. The same below.

可能不一样。Kovacs 等^[5]研究了 7 个山葡萄杂种对晚霜的抗性,结果表明,山葡萄杂种比酿酒品种‘Viognoles’更不抗晚霜危害,从而指出由于北美大陆冬季温度波动大而春季晚霜常见,山葡萄作为抗(避)霜冻遗传资源的价值有限。这一结果也印证了本研究中中国野生山葡萄抗晚霜表现存在种内较大差异的结果。

一般认为,霜冻的危害程度与植物的耐寒能力、低温程度、低温持续时间有关。何维勋等^[27]通过对植物霜冻害与冻结温度、结冰进程和解冻速率之间的关系研究,将植物分为不耐霜冻植物、中度耐霜冻

植物和耐霜冻植物 3 类。早期的“解冻伤害”学说认为,对植物起致死作用的并不是冰冻,而是冰冻之后的解冻,如果缓慢解冻则细胞可以恢复;反之,迅速解冻则易引起死亡。这一学说被农业气象工作者普遍接受,并用于指导防霜作业^[26]。

上世纪 80 年代以来的研究^[27-29]还发现,某些微生物能加重植物的霜冻。这些微生物分泌特定的蛋白质,为冰晶的形成提供必要的凝结核(冰核),使组织中的水在较高的低温条件下发生胞内或胞外结冰,从而加重低温伤害^[30],其中以冰核细菌分布最为广泛,对植物的影响也最显著^[29]。目前已在

表2 栽培品种(系)的抗晚霜表现

Table 2 The resistance of grape cultivars or accessions to late frost

种 Species	品种或株系 Cultivar or accession	新梢受害率 Sprout injury rate/%	抗晚霜表现 Resistance to late frost
欧洲葡萄 <i>V. vinifera</i>	无核白 Thompson Seedless	0.0	HR
	无核紫 Monukka	25.5	S
	新郁 Xinyu	45.4	S
	京秀 Jingxiu	33.5	S
	早玫瑰 Zaomeigui	8.3	R
	早金香 Zaojinxiang	21.4	R
	绯红 Cardinal	12.5	R
欧美杂种 <i>V. vinifera</i> × <i>V. labrusca</i>	巨峰 Kyoho	0.0	HR
	藤稔 Fujiminori	8.5	R
	早生高墨 Wase Takasumi	7.5	R
	京优 Jingyou	20.0	R
	木星 Jupiter	7.3	R
	海王星 Neptune	14.3	R
	北醇 Beichun	26.3	S
<i>V. vinifera</i> × <i>V. amurensis</i>	左优红 Zuoyouhong	46.8	S
	00-1-5	0.0	HR
	00-1-10	0.0	HR ¹

葡萄上分离出了冰晶细菌^[30]。因此,冰晶细菌数量多少也影响到葡萄新梢遭受霜冻危害的轻重程度。

本研究的81份葡萄种质资源生长在同一种质资源圃中,在不考虑冰核细菌影响的情况下,自然鉴定它们遭受晚霜危害的程度,能够客观、真实地反映各株系或品种的抗性水平。在所鉴定的资源中,一些资源萌芽迟,如毛葡萄、桑叶葡萄、瘤枝葡萄、华东葡萄、山葡萄‘左山-1’、冬葡萄及欧山杂种‘00-1-10’,表现为避霜;一些资源尽管新梢已萌发和生长,但具有极强的抵抗力,如燕山葡萄,麦黄葡萄,麦黄复叶葡萄,碧霞葡萄,秋葡萄‘眉县-6’,复叶葡萄‘甘肃-91’‘留坝-8’‘留坝-6’,刺葡萄‘塘尾’‘雪峰’,美洲葡萄,甜冬葡萄以及栽培品种(系)‘无核白’‘巨峰’、欧山杂种‘00-1-5’。对于野生资源而言,这是长期自然选择和进化过程中形成的一种对晚霜逆境的适应性。在今后的育种利用中,选择亲本时不仅要考虑其冬季抗寒性,还应考虑春季避霜特性或抗晚霜特性,通过种间杂交或种内杂交,选育抗寒、抗霜冻葡萄新品种或砧木新品种。

4 结 论

中国野生葡萄、栽培品种抗晚霜表现具丰富多样性,美国野生葡萄表现出较强的抗性。葡萄种质资源对晚霜抗性表现与冬季抗寒性表现不完全一致。

参考文献 References:

- [1] 鄒荣庭. 果树栽培学总论[M]. 3版. 北京:农业出版社,1997: 303.
XI Rongting. Pomology overview [M]. 3rd ed. Beijing: Agriculture Press, 1997: 303.
- [2] SGUBIN G, SWINGEDOUW D, DAYON G, de CORTAZAR-ATAURI I G, OLLAT N, PAGE C, VAN LEEUWEN C. The risk of tardive frost damage in French vineyards in a changing climate[J]. Agricultural and Forest Meteorology, 2018, 250: 226-242.
- [3] MOLITOR D, CAFFARRA A, SINIGOJ P, PERTOT I, HOFFMANN L, JUNK J. Late frost damage risk for viticulture under future climate conditions: a case study for the Luxembourgish winegrowing region[J]. Australian Journal of Grape and Wine Research, 2014, 20(1): 160-168.
- [4] LIPE W N, BAUMHARDT L, WENDT C W, RAYBURN D J. Differential thermal-analysis of deacclimating chardonnay and Cabernet Sauvignon grape buds as affected by evaporative cooling[J]. American Journal of Enology and Viticulture, 1992, 43(4): 355-361.
- [5] KOVACS L G, BYERS P L, KAPS M L, SAENZ J. Dormancy, cold hardiness, and spring frost hazard in *Vitis amurensis* hybrids under continental climatic conditions[J]. American Journal of Enology and Viticulture, 2003, 54(1): 8-14.
- [6] WARMUND M R, GUINAN P, FEMANDEZ G. Temperatures and cold damage to small fruit crops across the eastern United States associated with the April 2007 freeze[J]. Hortscience, 2008, 43(6): 1643-1647.
- [7] JONES J E, WILSON S J, LEE G, SMITH A M. Effect of frost damage and pruning on current crop and return crop of Pinot Noir[J]. New Zealand Journal of Crop and Horticultural Science, 2010, 38(3): 209-216.
- [8] MARCON J L, ALLEBRANDT R, DE BEM B, MUDREI P I, MACEDO T A, SCHLEMPER C, LERIN S, OUTEMANE M, KRETZSCHMAR A A, RUFATO L. Damage to ‘Cabernet Sauvignon’ after late frost in the southern Brazilian highlands [C]// XXIX International Horticultural Congress on Horticulture. Sustaining Lives, Livelihoods and Landscapes (IHC2014): IV International Symposium on Tropical Wines and International Symposium on Grape and Wine Production in Diverse Regions. Brisbane, Australia: Acta Horticulturae, 2016: 211-216.
- [9] MEYER G D, TALAMINI J, BUENO M E, RUFATO L, KRETZSCHMAR A A, RUFATO A D. Gradual release of growth regulators for a delay in budding and growth of ‘Chardonnay’ and ‘Pinot Gris’ in Southern Brazil[C]//XXIX International Horticultural Congress on Horticulture. Sustaining Lives, Livelihoods and Landscapes (IHC2014): IV International Symposium on Tropical Wines and International Symposium on Grape and Wine Production in Diverse Regions. Brisbane, Australia: Acta Horticulturae, 2016: 237-241.
- [10] CHEN W, ZHANG Z W, DONG X P. Discussion on characteristics of abnormal late frost and defensive measures of wine grape in Manasi county, Xinjiang[C]//Proceedings of the seventh International Symposium on Viticulture and Enology. 7th

- International Symposium on Viticulture and Enology. Yangling: Northwest A & F University, 2011: 142-147.
- [11] 郝燕,王玉安,张辉元. 2010年甘肃天水葡萄晚霜冻害调查[J]. 中国果树,2011(3):66-68.
HAO Yan, WANG Yu'an, ZHANG Huiyuan. Investigation on frost damage of grape in Tianshui region of Gansu province in 2010[J]. China Fruits, 2011(3): 66-68.
- [12] 王正平,刘榆,刘效义,彭治铭,蒋廉勤. 宁夏地区葡萄晚霜冻害调查报告[J]. 中外葡萄与葡萄酒,2004(6):29-31.
WANG Zhengping, LIU Yu, LIU Xiaoyi, PENG Zhiming, JIANG Lianqin. Investigation report of grape late frost damage in Ningxia region[J]. Sino-Overseas Grapevine & Wine, 2004(6): 29-31.
- [13] 剡传化,刘三军,孙桂香,于巧利,陈勇朋,孙传珍,刘崇怀. 黄河中下游地区葡萄晚霜冻害的发生与防治[J]. 中外葡萄与葡萄酒,2010(4):45-47.
KUAI Chuanhua, LIU Sanjun, SUN Guixiang, YU Qiaoli, CHEN Yongpeng, SUN Chuanzhen, LIU Chonghuai. The occurrence and prevention of grape late frost damage in middle and lower reaches of the Yellow River[J]. Sino-Overseas Grapevine & Wine, 2010(4): 45-47.
- [14] 张振文,陈武. 终霜冻对新疆北疆地区酿酒葡萄冻害和产量的影响[J]. 西北农业学报,2011,20(9):123-128.
ZHANG Zhenwen, CHEN Wu. Influence of late frost damage on wine grape and yield in Northern Xinjiang[J]. Acta Agriculturae Boreali-occidentalis Sinica, 2011, 20(9):123-128.
- [15] 杨江山. 甘肃河西走廊地区葡萄晚霜冻害预防与补救措施[J]. 中外葡萄与葡萄酒,2016(6):46-47.
YANG Jiangshan. Prevention and remedial measures of grape late frost injury in the Hexi corridor area of Gansu province [J]. Sino-Overseas Grapevine & Wine, 2016(6): 46-47.
- [16] BRIGHENTI A F, ALLEBRANDT R, CIPRIANI R, MALLINOVSKI L I, DE BEM B P, FELDBERG N P, SILVA A L. Using delayed winter pruning to prevent spring frost damage in 'Chardonnay' cultivar[C]/IX International Symposium on Grapevine Physiology and Biotechnology. La Serena, Chile: Acta Horticultae, 2017: 389-392.
- [17] MOSEDALE J R, WILSON R J, MACLEAN I M D. Climate change and crop exposure to adverse weather: Changes to frost risk and grapevine flowering conditions[J]. PLoS One, 2015, 10 (10): e0141218.
- [18] CENTINARI M, GARDNER D M, SMITH D E, SMITH M S. Impact of amigo oil and KDL on grapevine postbudburst freeze damage, yield components, and fruit and wine composition[J]. American Journal of Enology and Viticulture, 2018, 69(1): 77-88.
- [19] 罗国提,丘少欢,黄耀波. 关于马铃薯霜冻害标准制定及防霜冻技术措施[J]. 广东农业科学,2010,37(2):11-12.
LUO Guoti, QIU Shaohuan, HUANG Yaobo. Standards for frost damage of potatoes and technical measures for frost prevention [J]. Guangdong Agricultural Sciences, 2010, 37(2): 11-12.
- [20] 贺普超,牛立新. 我国葡萄属野生种抗寒性的研究[J]. 园艺学报,1989,16(2):81-88.
HE Puchao, NIU Lixin. Study of cold hardiness in the wild *Vitis* native to China[J]. Acta Horticulturae Sinica, 1989, 16(2): 81-88.
- [21] 王丽雪,李荣富,张福仁. 葡萄枝条中蛋白质、过氧化物酶活性变化与抗寒性的关系[J]. 内蒙古农牧学院学报,1996,17(1): 45-50.
WANG Lixue, LI Rongfu, ZHANG Furen. The relationship between the changes of protein and peroxidase activity and the cold resistance in grape shoot[J]. Journal of Inner Mongolia Institute of Agriculture & Animal Husbandry, 1996, 17(1): 45-50.
- [22] JONES K S, PAROSCHY J, MCKERSIE B D, BOWLEY S R. Carbohydrate composition and freezing tolerance of canes and buds in *Vitis vinifera*[J]. Journal of Plant Physiology, 1999, 155 (1):101-106.
- [23] ZHANG J X, WU X C, NIU R X, LIU Y, LIU N, XU W R, WANG Y J. Cold-resistance evaluation in 25 wild grape species [J]. Vitis, 2012, 51(4): 153-160.
- [24] 付晓伟,张倩,刘崇怀,樊秀彩,姜建福,郭大龙,曹亚平. 评价葡萄根系抗寒性指标的确定[J]. 果树学报,2014,31(1):52-59.
FU Xiaowei, ZHANG Qian, LIU Chonghuai, FAN Xiucai, JIANG Jianfu, GUO Dalong, CAO Yaping. Index for the evaluation of grape root cold-resistance[J]. Journal of Fruit Science, 2014, 31(1): 52-59.
- [25] 何维勋,冯玉香,夏满强. 解冻速率对作物霜冻害的影响[J]. 应用气象学报,1993,4(4):440-445.
HE Weixun, FENG Yuxiang, XIA Manqiang. Effects of thawing rate on frost injury of crops[J]. Quarterly Journal of Applied Meteorology, 1993, 4(4): 440-445.
- [26] 杨建民,周怀军,王文凤. 果树霜冻害研究进展[J]. 河北农业大学学报,2000,23(3):54-58.
YANG Jianmin, ZHOU Huajun, WANG Wenfeng. The advance in frost injury research of fruit trees[J]. Journal of Agricultural University of Hebei, 2000, 23(3):54-58.
- [27] LINDOW S E, AMY D C, UPPER C D. Bacterial ice nucleation: a factor in frost injury to plants[J]. Plant Physiology, 1982, 70(4): 1084-1089.
- [28] 孙福在,朱红,何礼远,张永祥. 我国植物上冰核活性细菌种类鉴定[J]. 自然科学进展-国家重点实验室通讯,1994,4(4): 449-456.
SUN Fuzai, ZHU Hong, HE Liyuan, ZHANG Yongxiang. Species identification of ice nucleated active bacteria on plant in China[J]. National Key Laboratory Communication: Advances in Natural Science, 1994, 4(4): 449-456.
- [29] 孙福在,赵廷昌. 冰核细菌生物学特性及其诱发植物霜冻机理与防霜应用[J]. 生态学报,2003,23(2):336-345.
SUN Fuzai, ZHAO Tingchang. Biological characteristics and frost-inciting mechanisms of ice nucleated active (INA) bacteria and the research in frost control[J]. Acta Ecologica Sinica, 2003, 23(2):336-345.
- [30] 孙鲁龙,宋伟,翟衡. 葡萄叶片上冰核细菌的分离鉴定[J]. 中外葡萄与葡萄酒,2016(4):6-9.
SUN Lulong, SONG Wei, ZHAI Heng. Isolation and identification of ice nucleic bacteria on grape leaves[J]. Sino- Overseas Grapevine & Wine, 2016(4): 6-9.