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Impact of spring freeze on yield, vine performance and fruit quality of *Vitis* interspecific hybrid Marquette

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ABSTRACT

In viticultural regions with spring freeze events, early budburst increases the risk of vine damages compromising industry long-term sustainability. Marquette is a cold hardy hybrid with *Vitis riparia* in its parentage, a source of cold hardiness and rapid budburst characteristics. In 2012 and 2013, the capacity of Marquette to rebound from significant bud mortality from a series of spring freeze events was quantified and the capacity of recovering the damages the following year, measuring vine yield and the effect on fruit quality. The compound bud on grapevine is actually three buds in one, with primary, secondary, and tertiary all present. Spring freeze events in 2012 killed over 80% of the shoots arising from primary buds (SPB) while secondary buds (SSB) were almost unaffected. By tracking the performance SPB and SSB, we were able to quantify vine response to spring freeze events. A comparative analysis of phenological and fruit quality characteristics of the SPB and SSB clusters showed different development and ripening of those of SBS. However, the differences disappeared at harvest, with no significant impact on yield or only partially on fruit composition. The results suggest that Marquette has the potential to generate significant yield from SSB with desirable fruit quality and could offer a solution to spring freeze losses. In 2013, year characterized by no spring freeze events, vines recovered full productivity, yielding 61% more fruit, due to an increased number of cluster per vine (+60%) with also better fruit quality at harvest.

1. Introduction

The development of a sustainable wine industry in a cool-cold climate is a challenge. An array of problematic environmental conditions confront growers, and climate change is expected to exacerbate them (Sabbatini and Howell, 2011; Schultze et al., 2014). In Michigan, where the nascent wine industry is committed to the cultivation of *Vitis vinifera*, losses from weather related events have been severe and that has driven the need to seek varieties to mitigate that risk. A key attribute guiding grower decisions is a cultivar's cold hardiness, as defined by its sensitivity to below freezing temperatures (Dami et al., 2016).While growing season phenomena, like low heat accumulation, excessive vigor, or high disease pressure can negatively affect the crop, once budburst occurs (Howell, 2001), spring frost poses the greatest threat (Trought et al., 1999; Schultze et al., 2016). Probable outcomes range from low levels of bud and shoot damage to 100% primary bud necrosis, depending on maximum low temperature, event duration, bud development stage, and vine health. Fortunately, the *Vitis* genus is characterized by a compound bud that includes a primary, secondary, and tertiary bud generating in the spring shoots arising from primary bud (SPB), from secondary bud (SSB) and rarely from tertiary bud (STB), with the potential for additional crop when these conditions appear (Mullins et al., 1992; Keller, 2010).

Spring's warming temperatures cause buds to lose their cold hardiness via two critical physiological processes: the rehydration of the meristematic tissues, which occurs with the movement of water into intercellular spaces, and concurrently, the degradation

Abbreviations: SPB, shoot originated from the primary bud of a compound bud; SSB, shoot originated from the secondary bud of a compound bud; STB, shoot originated from the tertiary bud of a compound bud; HTRC, Michigan State University Horticulture Teaching and Research Centre; T_{max}, maximum temperature; T_{min}, minimum temperature; T_{mean}, mean temperature; TA, titratable acidity.

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of sugars and protein complexes that bind water and act as cryoprotectants (Keller, 2010). Previous studies have documented this process and the relationships between bud water content, stage of development, and tissue temperature tolerance (Gardea, 1987; Trought et al., 1999). Under normal spring conditions, a new shoot begins its development arising from the primary bud of the compound bud (SPB), while the secondary (SSB) and tertiary buds (STB) typically remain undeveloped (Mullins et al., 1992). When spring primary bud shoot necrosis or injury is prevalent, grapevines react inducing the growth of new shoots from the secondary buds of the compound buds (Mullins et al., 1992; Keller, 2010; Friend et al., 2011). Friend et al. (2011) also observed that the number of shoots developing from these secondary buds after a spring freeze is positively related to the number of primary shoots injured or killed.

Marquette is a cold-hardy hybrid (Ravat 262 × MN1094) red wine grape released from the University of Minnesota in 2006 (Hemstad and Luby, 2008). Its parentage is complex and includes *V. riparia* and *V. vinifera*, with Pinot noir among others cultivars (Hemstad and Luby, 2008). Marquette inherits the deep winter cold hardiness, rich fruitfulness, rapid budburst, disease resistance and early ripening traits of *V. riparia*, but its enological properties more closely resemble those of *V. vinifera* (Hemstad and Luby, 2000; Manns et al., 2013; Pedneault et al., 2013; Slegers et al., 2015; Read and Gamet, 2016). Wines from Marquette have been judged tobe of superior quality when compared to the non-*V. vinifera* wines with high potential for excellent color, complex aromatics and no undesirable sensory attributes (Hemstad and Luby, 2008; Manns et al., 2013; Pedneault et al., 2013; Slegers et al., 2015). In growing regions wanting to compete more favorably with *V. vinifera* producers, Marquette is a unique and appealing cultivar, and it is for this reason that growers in the challenging climate regions of the Midwest and Eastern U.S. have shown great interest in it (Manns et al., 2013; Read and Gamet, 2016). However, reports of its early budburst and consequent spring frost susceptibility with potential crop loss (Reisch et al., 1993; Londo and Johnson, 2014; Schultze et al., 2016) are tempering the cultivar's popularity, but little is known about its ability to recover from spring freeze damage; investment in Marquette across the East of US would increase if the early season cold damage risk could be reduced.

When spring frost damages shoots derived from primary buds (SPB) of *V. vinifera*'s compound bud, shoots arising from secondary buds (SSB) have very low fruitfulness and yields are considered unacceptable and qualitatively unsatisfying (Trought et al., 1999; Keller, 2010; Friend et al., 2011). In contrast, *V. riparia* is characterized by higher fruitfulness on shoots from these secondary buds, which often carry clusters similar to those of primary shoots. They are even known to ripen fully under favorable environmental conditions (Gerrath and Posluszny, 1988a, 1988b; Mullins et al., 1992).

In March 2012, an anomalous and record-breaking warm weather system settled over Michigan presenting a set of conditions that allowed the field study of Marquette's ability to recover lost primary bud yield (due to freeze damage) from the production of shoots arising from the secondary buds (SSB) of the vines' compound buds. The premature warm temperatures, with highs staying above 20 °C for three weeks duration, triggered the rapid budburst of Marquette (28 Mar, approx. 50% of primary buds showing green leaf tissue), more than a month earlier than the historical average. When April low temperatures dropped well below 0 °C, most of the shoots were killed, so that in May secondary buds of the compound buds were induced to develop. These events provided the opportunity to systematically track, describe, and compare the vegetative and reproductive characteristics of shoots arising from primary buds (SPB) and from secondary buds (SSB) sourced in the compound bud of Marquette grapevines after the occurrence of several spring freeze events. Specifically, the objectives of this study included the measurement of canopy growth, berry development, and fruit quality from budburst through harvest in 2012. In 2013, the study focused on evaluating the recovery of the vines after the 2012 damaging events to understand the cultivar's potential to reliably produce an economically-viable yield with good fruit quality in a climate where spring freeze events routinely threaten damage to early budburst varieties.

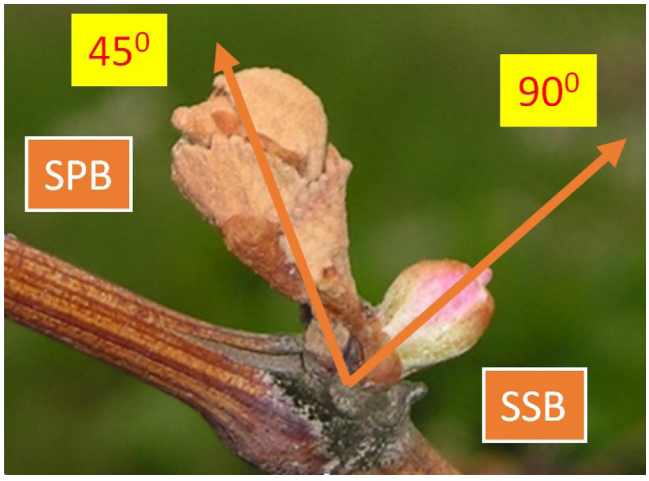

Fig. 1. Detail of a shoot from primary bud (SPB), grown with an angle of projection from the cane of 45° and killed by spring freeze events, and a shoot from secondary bud (SSB), growing with a angle of projection of from the cane of 90° and not damaged by spring freeze events.

2. Materials and methods

2.1. Site, plant material and experimental design

The experiment was conducted in 2012 and 2013 at the Michigan State University Horticulture Teaching and Research Center (HTRC) in Holt, Michigan (lat. 42°40′24″N; long. 84°29′13″W; elev. 264 m) on five year-old vines of the interspecific hybrid (MN 1094 × Ravat 262) cv. Marquette. The vines were own-rooted, planted in Marlette fine sandy loam soil (US Department of Agriculture, Soil Conservation Service 1957) at a spacing of 2.4 × 3.1 m (vine × row) in north-south rows and trained to a high-wire cordon system. The vineyard was not irrigated and standard cultural and pest control practices for hybrids grown commercially in the region were applied.

The experiment was a complete randomized block design of 27 vines organized in three blocks with two treatments: (1) shoots arising from primary buds (SPB), and (2) shoots arising from secondary buds (SSB) of a compound bud. During the first week of May 2012, after the threat of freeze events had ceased, all vines within the experimental plot were evaluated for bud damage. All surviving SPB were flagged. On 15 May 2012, each vine was again evaluated with any secondary buds developing new shoots counted and flagged. Shoot origin (SPB or SSB) was determined by the angle of projection from the cane. In detail, all the survived shoots with an angle of projection of about 45° were flagged as SPB and all the shoots growing with an angle of projection of 90°, in correspondence of a dead or alive SPB at 45°, were instead flagged as SSB (Fig. 1). STB were also present, but being small in number and not fruitful, they were identified, but not included in the study. All the shoots of each experimental vine were therefore flagged as SPB, SSB or STB (unflagged) and followed throughout the experiment. Three SPB and SSB per vine, fruitful and actively growing were randomly selected to serve as modal shoots and tagged with white laminated paper tags and numbered 1 through 3 for follow-up measurements. This resulted in three SPB and three SSB per vine (81