How can grafting affect yield and wine from hybrid grapevines under climatic conditions of Quebec, Canada?

C. Provost and A. Campbell

Centre de recherche agroalimentaire de Mirabel, 9850 rue Belle-Rivière, Québec, Canada. J7N2X8.

Abstract

Grapevine production is relatively recent in Quebec, Canada, and several challenges restrict quality grape production. Quebec's rigorous climate and short growing season are just a couple of limiting factors in grape production and varietal selection. Rootstocks adapted to growing conditions allow producers to plant varieties that are better adapted and more efficient in specific soil and climatic conditions. Selected scion/rootstock combinations could be better suited to growing conditions found in Quebec vineyards, thereby homogenizing vegetative growth for all vines, reducing costs associated with management and help to reach maturity and optimum berry quality. The main objective of this project was to evaluate the use of grafting as a technique to adapt hybrid vines to the cold climate growing conditions found in Quebec, Canada. Several combinations were produced using Frontenac, Frontenac blanc and Marquette cultivars along with 4 rootstocks (101-14 MGT, 3309 R, Riparia Gloire de Montpellier, SO4), as well as own-rooted vines. The experimental plot was implanted in 2013 in gravelly-loam soil. Several parameters were observed, such as yield, berry chemistry and wine sensory analysis. Rootstock effect showed little impact on yield, but a significant impact on berry chemistry, mainly on total soluble solids and on titratable acidity. Moreover, a significant effect on wine appreciation was noticed, where use of rootstock generally increased wine quality. In Quebec, grafting hybrid cultivars is not a common practice, but it could be profitable to the producer to select rootstocks adapted to their soil and climate conditions to improve profitability.

Keywords: cold-hardy hybrid, rootstock effect, cold climate, Frontenac, Marquette

INTRODUCTION

Growing grapes in cold climates has several challenges to overcome. Cold injury to grapevines, short growing seasons and soil conditions that are often too fertile and poorly drained are just a few examples of factors that affect grapevine production and limit the choice of grape variety when establishing a vineyard(Zabadal et al., 2007). While genetics determines the ultimate degree of cold hardiness expression, the environment, as well as cultural practices and pest management, affect that expression. Cold injury and disease resistance studies have helped lead breeding programs in eastern North America and have led to the development of several hybrid cultivars with high cold hardiness (Reynolds, 2015).

Rootstocks may be used to enhance vine development in limited growing conditions. Rootstocks allow growers to plant varieties that become better adapted and more efficient in specific soil and climatic conditions. Improving the scion/rootstock combination optimizes the adaptation of grape varieties to specific (climate and soil) conditions. Grafting is not a common practice for hybrid cultivars as rootstocks are typically used for *Vitis vinifera*. However, in recent years, some studies have been carried out in British Columbia (Canada), Ontario (Canada), New York and Missouri to assess the benefits of using rootstocks for hybrid grape varieties grown in cold climates (Bates et al., 2015; Harris, 2013; Hoover et al., 2002; McCraw et al., 2005; Reynolds and Wardle, 2001).

Several rootstocks are available for grafting to hybrids, and each has its own set of characteristics(Cousins, 2005; Wolpert, 2005). Some rootstocks increase physiological development of the vine and can ensure optimal ripening of the grafted grape variety (Bates, 2005; McCraw et al., 2005; Reynolds and Wardle, 2001). Thus rootstocks may have an impact on yield and berry quality. The effects of grafting hybrids on yields and berry chemistry were not consistent between studies. Some studies show that there is a significant interaction between grape varieties and rootstocks related to yield, the accumulation of sugars in berries, the chemical composition of the berries and the aromas (Harris, 2013; Krstic et al., 2005; McCraw et al., 2005; Reynolds and Wardle, 2001). However, others show more variable results and grafted plants are often similar to those that are own-rooted (Reynolds and Wardle, 2001).

Under specific soil and climate conditions, grapevine grafting may influence grape production, and specifically in an emergent grapevine production region such as Quebec, Canada. This project evaluated the effects of grafting on yield, berry chemistry and wine appreciation of grafted cold-hardy hybrids. These results can be used by growers, stakeholders, nurseries and researchers for the development of the wine industry in eastern Canada.

MATERIALS AND METHODS

All trials were done at the experimental vineyard of the Centre de recherche agroalimentaire de Mirabel (CRAM) located in the municipality of Oka, Quebec, Canada (45°30'N, 74°4.2'W). Climate is characterized by cold winters with temperatures reaching as low as -30°C, short growing seasons (155 to 200 days without frost), and hot summers that accumulate 1295-1450 growing degree days (base 10). The climate is also humid, with mean annual precipitation of 790 mm of rain during growing season (snow excluded).

Grafted vines were planted in June 2013. The experimental design is composed of four replicates (plots) for each of the scion/rootstock combinations (3 grape varieties, 5 root systems). Three cold-hardy hybrid varieties were used: Frontenac, Frontenac blanc and Marquette and five root systems were evaluated: Couderc 3309 (3309C), Sélection Oppenheim 4 (SO4), Riparia Gloire (RP), Millardet et de Grasset 101-14 (101-14), and own-rooted. Each plot included ten grapevines, for a total of 40 vines per combination. The four blocks containing the combinations were implanted according to a complete random distribution. Rows are oriented North-South, and the vines were planted to 1.20 m x 2.44 m spacing within and between the rows, respectively. Grapevines were trained to a bilateral cordon and vertical shoot positioning system. For this study, data were collected from April 2016 to November 2018. An initial pruning was done during the month of April and the final pruning completed in May, after the risk of spring frost had passed to leave 16 nodes per vine.

Viticultural parameters

Data were collected throughout the growing season and measured on the six central plants of each plot. Several parameters were monitored but for this study only parameters at harvest were considered, namely yield (as kilograms per vine), clusters per vine and berry weight (calculated from random sampling of 100 berries within the sampled vines). Cluster weight was determined from these data. Chemical composition of fruit at harvest was analyzed using a random sampling of 200-300 berries. All chemical analyses were done on fresh juice by using a wine titrator for titratable acidity (Hanna, model HI 84102), a refractometer for soluble solids (Hanna, model HI96811) and a pH-meter (Hanna, model HI9124).

Data related to harvest components and fruit composition were analyzed using two-way ANOVA with rootstock, year and interaction as fixed parameters. The analyses were performed on R (R Core Team 2017) using the functions of the *lme4* library.

Wine production

Wines were produced for each combination separately according to standard winemaking protocols established for the two types of wine, white and red. The yeast strains used for vinification were SO Flavour for red wine (Martin Vialatte©) and L'Éclatante for white wine (OenoFrance©). Chemical analyses were carried out: 1) on the must, 2) at the end of the alcoholic fermentation, and 3) at the end of the malolactic fermentation. At the end of the winemaking process, the wine was bottled. Experts and consumers carried out annual blind tastings to assess the wines produced. A group of 5 to 8 people characterized the wine for each of the 15 combinations according to these parameters: color, flavor, aromas, intensity, tannin, balance, acidity, and general appreciation.

RESULTS

Growing season affected yield components and fruit composition for all three grape varieties (Table 1-3). The highest yields were obtained during 2016, whereas yield during 2017 and 2018 were intermediate, except for Marquette in 2018 where the lowest yield was noted. We do not have a constant trend between years for the number of clusters, cluster weight and berry weight. The number of clusters range from 24 to 37 clusters, the lowest number of clusters was observed during 2018 for all varieties. The lowest cluster weight was observed during the 2017 season for Frontenac and Frontenac blanc and in 2018 for Marquette. The heaviest berries were noted during the 2016 growing season. Lastly, berry chemistry was also affected by growing season. For Frontenac and Frontenac blanc, berries maturity was optimal during 2016 and 2018, where a higher sugar content, a lower pH and a lower total acidity were observed. Berries from Marquette showed a higher sugar content during 2016, followed by 2017 and 2018.

Frontenac

Rootstocks affected some yield components and fruit composition parameters for Frontenac (Table 1). Results showed that the rootstocks affect cluster weight, berry weight, soluble solids, pH and acidity. Vines grafted on 3309C produced the heaviest clusters, followed by Riparia gloire, and own-rooted while the lightest clusters were produced on vines grafted to SO4. Significant differences for berry weight were noted between rootstocks, the lowest berry weights were for vines grafted on 101-14 and 3309C, and the highest for own-rooted vines. The number of clusters and yield were not significantly affected by rootstocks. Rootstocks affected fruit composition for soluble solids, pH and titratable acidity. Higher levels of soluble solids and pH, and a lower total acidity were seen for vines grafted on 101-14, 3309C and Riparia Gloire compared to own-rooted vines.

The qualitative assessment of the wine shows different characteristics depending on the rootstock. For Frontenac, the wines produced for the three vintages are mainly characterized by black fruits and red fruits aroma though the aromas of cocoa, spices, herbaceousness, blackberry, and cherry was also noted (Table 2). The properties are somewhat different from one year to another. However, globally, we note that the wines from vines grafted on rootstocks 101-14, 3309C and sometimes Riparia Gloire, have more structure, tannins, complexity and are well balanced. In general, these wines have higher overall appreciation scores than wines from own-rooted vines.

Table 1: Effect of rootstock on yield quantity and fruit composition of grapevine 'Frontenac'

	Rootstock	Average number of cluster (pcs)	Cluster weight (g)	Berry weight (g)	Yield (kg·vine-1)	Extract (°Brix)	pH	Total acidity (g·L-1 tar. ac.)
Rootstock	101-14	31,25	96.41 ab	1.13 a	2,96	24.45 a	3.22 a	12.39 a
	3309C	30,47	103.33 a	1.18 ab	3,11	24.15 a	3.19 ab	12.54 a
	own-rooted	29,54	99.42 ab	1.30 c	2,95	21.89 c	3.13 c	13.64 b
	Riparia gloire	29,79	100.01 ab	1.21 b	3,04	23.70 ab	3.18 ab	13.06 ab
	SO4	29,44	90.22 b	1.21 b	2,68	22.43 bc	3.14 bc	13.78 b
Year	2016	35.97 a	106.41 a	1.27 a	3.77 a	24.73 a	3.20 a	13.21 a
	2017	29.75 b	80.92 b	1.13 b	2.42 b	21.53 b	3.12 b	12.14 b
	2018	24.64 c	106.36 a	1.23 a	2.66 b	23.73 a	3.20 a	13.91 c
p-value	Rootstock	0.8315	0.0160	<0.0001	0.2887	<0.0001	<0.0001	<0.0001
	Year	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Roostock x Year	0.7802	0.6487	0.5646	0.7077	0.8736	0.7802	0.3466

Table 2: Wine appreciation according to rootstocks for 'Frontenac'

		101-14	**3309**	**Own-rooted**	**Riparia Gloire**	**SO4**
2016	**Aromas**	black fruit, cocoa	black fruit, red fruit, cocoa	herbaceousness, candied fruit	red fruit, black fruit, coffee	herbaceousness, candied fruit
	Mouthfeel	complexity rich flexible	pleasant tannins, beautiful structure	less balanced astringency thinner	good length good balance tannins astringency	vegetal good length bitterness light tannins
	Note (/5)	3,4	2,8	1,9	2,8	2,4
2017	**Aromas**	black fruit	dark fruit, cherry, light spice	herbaceousness	dark fruit, light spice herbaceousness	herbaceousness
	Mouthfeel	light tannins less balanced	light tannins nice acidity less balanced	hardiness high acidity	light tannins nice balance lively	lively more vegetal high acidity
	Note (/5)	2,7	3	1,8	2,5	1,9
2018	**Aromas**	black fruit, herbaceousness, blackberry	red fruits, cherry, black fruits	black fruit, cherry, blackberry,	red fruits, herbaceousness, blackberry	black fruit, cherry, herbaceousness
	Mouthfeel	clean attack supple tannins full structure balanced	clean attack balanced supple tannins	clean attack harsh tannins thin structure unbalanced	clean attack supple tannins thin finish	frank attack narrow texture harsh tannins unbalanced
	Note (/5)	3,5	3,25	2,5	2,87	2

Frontenac blanc

Rootstocks had a greater impact on Frontenac blanc than on the Frontenac variety. We observed a significant effect of the rootstocks on all the studied parameters except for average number of clusters (Table 3). The vines grafted on SO4 had significantly lighter clusters than those grafted on Riparia Gloire, 3309C, 101-14 and own-rooted vines. The heaviest clusters were observed on own-rooted vines. Statistical analyses showed significantly higher berry weight for own-rooted vines and vines grafted on Riparia Gloire compared to rootstocks 3309C, 101-14 and SO4. Yield ranged from 2.76 kg to 3.56 kg per vine and was highest for own-rooted vines while vines grafted on 101-14 and SO4 recorded the lowest yields. Fruit composition was related to grape maturity where the lowest grape maturity was observed for own-rooted vines with low soluble solid concentration and high titratable acidity. All vines grafted on the four rootstocks showed similar fruit composition at harvest.

The white wines produced from Frontenac blanc mainly present aromas of peach, pear and floral aromas. In 2016, almond aromas were also noted, while in 2017, there were notes of quince and lychee, then in 2018, aromas of apricot, lemon and exotic fruits were noted. The wines produced from grapes from vines grafted on 3309C rootstocks were the most appreciated for their length on the palate, frank attack, richness and volume. The wines made from grapes from the own-rooted vines were the least popular.

Table 3: Effect of rootstock on yield quantity and fruit composition of grapevine 'Frontenac blanc'

	Rootstock	Average number of cluster (pcs)	Cluster weight (g)	Berry weight (g)	Yield (kg·vine-1)	Extract (°Brix)	pH	Total acidity (g·L-1 tar. ac.)
Rootstock	101-14	29.57	98.11 a	1.11 a	2.84 ab	23.51 a	3.12 a	12.94 a
	3309C	33.59	102.39 a	1.12 a	3.4 bc	24.13 a	3.12 a	12.74 a
	own-rooted	32.85	106.69 a	1.25 b	3.56 c	20.89 b	3.05 b	14.59 b
	Riparia gloire	31.54	97.73 a	1.23 b	3.09 abc	22.84 a	3.10 ab	13.55 a
	SO4	33.58	83.55 b	1.13 a	2.76 a	23.32 a	3.11 a	13.35 a
Year	2016	36.58 a	103.62 a	1.27 a	3.75 a	23.48 a	3.06 a	14.85 a
	2017	34.53 a	84.53 b	1.09 b	2.93 b	21.97 b	3.10 a	11.45 b
	2018	25.55 b	106.78 a	1.16 c	2.73 b	23.48 a	3.14 b	14.09 c
p-value	Rootstock	0.1756	<0.0001	<0.0001	0.0007	0.0005	0.0104	<0.0001
	Year	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001
	Roostock x Year	0.0307	0.8599	0.2175	0.1376	0.3627	0.9169	0.9620

Table 4: Wine appreciation according to rootstocks for 'Frontenac blanc'

		101-14	**3309**	**own-rooted**	**Riparia Gloire**	**SO4**
2016	**Aromas**	peach, floral, almond	peach, floral	pear, floral	peach, floral	herbaceousness, floral, almond
	Mouthfeel	poor balance bitterness less material	nice length good attack good balance rich, volume	little length skinny aggressive	nice length harmonious volume interesting	little complex little volume
	Note (/5)	2,4	3,5	2,2	3	3
2017	**Aromas**	pear, quince	floral, lychee, pear	pear	pear, floral	floral
	Mouthfeel	lack of balance less character bitterness	nice length and nice attack warm	freshness aggressive hardiness	lack of balance high bitterness unpleasant	medium intensity lack of balance
	Note (/5)	2,5	3,4	2	2,4	2
2018	**Aromas**	apricot, lemon, quince, exotic fruits, white flower, floral	pear, apple, quince, exotic fruits, white flower, floral	quince, lemon, pear, white flower, acacia	quince, lemon	quince, peach, almond, white flower, floral
	Mouthfeel	dry lively balanced	dry lively aggressive	dry lively good intensity	dry expressive medium finish	dry biting expressive
	Note (/5)	3,62	3,25	2,75	3,12	2,37

Marquette

Of the studied varietals, Marquette is the most affected by grafting and growing season (Table 5). Statistical analyses demonstrated that the greatest yield was observed on own-rooted vines and those grafted on Riparia Gloire and 3309C. Yield per vine was directly related to the number of clusters that were higher for the same rootstocks. Cluster weight from vines grafted on 101-14 and SO4 was lower than vines grafted on Riparia Gloire and 3309C. Berry weight varied from 1.21 g to 1.40 g with the heaviest berries on own-rooted vines; the lightest berries were noted on the rootstock 101-14. Rootstocks also affected Marquette fruit composition at harvest. Soluble solids content was higher for own-rooted vines and vines grafted on rootstocks 3309C, 101-14 and Riparia Gloire compared to rootstock SO4. Titratable acidity was then linked to sugars as we observed lower levels of titratable acidity on vines grafted to 3309C, 101-14, Riparia Gloire as well as own-rooted vines, compared to rootstock SO4.

The wines produced for the Marquette grape variety show primary aromas of red fruits, black fruits and cocoa. Vegetable aromas were noted in 2016, while the 2017 wines had aromas of spices and ripe fruit, and in 2018 aromas of blackcurrant, pepper and blackberry were noticed. The wine produced with the grapes from vines grafted on rootstock 101-14 was the most appreciated in 2016 and 2018, while the best wine in 2017 was from the Riparia Gloire rootstock.

Table 5: Effect of rootstock on yield quantity and fruit composition of grapevine 'Maquette'

	Rootstock	Average number of cluster (pcs)	Cluster weight (g)	Berry weight (g)	Yield (kg·vine-1)	Extract (°Brix)	pH	Total acidity (g·L-1 tar. ac.)
Rootstock	101-14	29.48 ab	57.42 a	1.21 a	1.69 a	24.41 a	3.23 ab	10.98 a
	3309C	32.64 a	66.06 b	1.31 b	2.19 b	25.09 a	3.24 a	10.59 a
	own-rooted	32.06 a	64.98 ab	1.40 c	2.10 b	24.81 a	3.23 a	11.24 a
	Riparia gloire	32.14 a	71.25 b	1.37 bc	2.29 b	25.05 a	3.18 b	11.09 a
	SO4	25.61 b	58.97 a	1.34 bc	1.68 a	23.15 b	3.20 ab	12.07 b
Year	2016	36.63 a	68.95 a	1.44 a	2.53 a	25.42 a	3.16 a	12.03 a
	2017	33.97 a	65.02 a	1.27 b	2.22 b	24.39 b	3.43 b	9.01 b
	2018	20.05 b	58.25 b	1.28 b	1.26 c	23.72 c	3.07 c	12.58 c
p-value	Rootstock	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0041	<0.0001
	Year	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Roostock x Year	<0.0001	<0.0001	0.9850	<0.0001	0.0930	0.0874	0.0429

Table 6: Wine appreciation according to rootstocks for 'Marquette'

		101-14	**3309**	**own-rooted**	**Riparia Gloire**	**SO4**
2016	**Aromas**	red fruit, cocoa, prune	cocoa, black fruit	black fruit, pepper ,herbaceousness	herbaceousness, red fruit	black fruit, herbaceousness
	Mouthfeel	complexity, bitterness, pleasant tannins	astringency, slight bitterness, tannins	bitterness, slight astringency, more vegetal	nice length, beautiful material, pleasant	nice balance, astringency, tannins
	Note (/5)	3,5	1,9	2,6	2,8	2,2
2017	**Aromas**	red fruit, vegetal, spice	black fruit, cocoa, spice	ripe fruit	ripe fruit, black fruit	spice
	Mouthfeel	hardiness tannins	fruity nice balance hardiness	coarser neutral unbalanced	fruity nice balance bitterness tannins	fruity more diluted hardiness
	Note (/5)	2,9	3,1	2,5	3,4	2,9
2018	**Aromas**	red fruits, black fruits, blackcurrant, prune, cocoa, blackberry,	black fruits, prune, blackcurrant, cocoa, pepper	red fruits, cocoa, black fruits, pepper	cocoa, black fruits, blackcurrant, blackberry, pepper, cloves	red fruits, black fruits, blackcurrant, blackberry
	Mouthfeel	clean attack, balanced, supple tannins	balanced, full structure, supple tannins	clean attack, supple tannins, structure, fleshy, balanced	balanced, narrow body, full structure, supple tannins	clean attack, lack of substance, supple tannins, thin structure
	Note (/5)	3,5	3,37	2,62	3,25	2,12

DISCUSSION

Results related to yield components showed that there are significant differences between rootstocks and own-rooted vines. Frontenac was the less affected grape variety compared to Frontenac blanc and Marquette, only cluster weight and berry weight were impacted. Other studies observed an effect of rootstocks on yield components for hybrid varieties (Harris, 2013; Hoover et al., 2002; Kaplan et al., 2018; Reynolds and Wardle, 2001; Sabbatini and Howell, 2013; Striegler and Howell, 1991). Hoover et al. (2002) have demonstrated that there were few significant difference in yield and fruit composition among the scion/rootstock combinations for St-Pepin. However, Kaplan et al (2018), Harris (2013) and Striegler and Howell (1991) have shown a significant impact of rootstock on yield for Regent, Norton and Seyval grape varieties, where higher yields were produced by vines grafted on Kober 5BB, 125AA and 110R, respectively. Reynolds and Wardle (2001) evaluated the effect of four rootstocks (compared to own-rooted vine) for nine hybrid varieties in British Columbia and the northwestern United States. For all scion/rootstock combinations, the results demonstrated weak to moderate effects of the rootstocks on yield.

Overall, we observe for the two Frontenac grape varieties, a low soluble solids content, low pH and a high titratable acidity for fruits on own-rooted vines compare to grafted vines on rootstocks 101-14 and 3309C. Grafting affected differently fruit composition for Marquette where the lowest grape maturity was observed for fruits on vines grafted on SO4. Soluble solids and titratable acidity are significant indicators of grape ripening and fruit quality. Obtaining higher soluble solids content on grafted vines was also observed by Reynolds and Wardle (2001) for Okanagan Riesling, Seyval blanc and Chardonnay on rootstocks 5BB, SO4 and 3309C. However, in several cases, grafting has no influence on the sugar content in juice at harvest, and this for several grape varieties (Hoover et al., 2002; McCraw et al., 2005; Reynolds and Wardle, 2001). Similar results have also been noted by other authors where grafting has little or variable effects on the pH and titratable acidity of musts at harvest (Hoover et al., 2002; McCraw et al., 2005; Reynolds and Wardle, 2001).

The appreciation of wines with grafted vines compared to own-rooted vines was higher for the two Frontenac grape varieties, but there was less difference for Marquette. Rootstock 101-14 and 3309C produced the most appreciated wines for both Frontenac and Frontenac blanc, while wines with 101-14 and Riparia Gloire obtain the higher score for Marquette. No studies have evaluated the effect of rootstocks on wine characteristics and appreciation for hybrid grapevines. Other studies with *Vitis vinifera* showed an effect of rootstock on chemical characteristics of wine, such as higher polyphenol and anthocyanin content with some rootstocks (Krstic et al., 2005; Mantilla et al., 2018; Mijowska et al., 2017; Ollat et al., 2001; Suriano et al., 2016). However, Suriano et al.(2016) have observed that the differences in term of flavanols due to rootstocks were lost after winemaking.

CONCLUSION

Though, several studies have demonstrated the impact of rootstocks in improving vine performance and fruit composition, mainly for *V. vinifera*, the number of studies looking into their impact on hybrids grape varieties remains very limited. This study has demonstrated that rootstocks may affect cold-hardy hybrids in different ways and some of them showed higher potential than others for use under eastern North American conditions. The study of cold-hardy hybrids in eastern Canada is still relatively recent and more work needs to be done to improve knowledge about these grape varieties under specific growing condition. Further research into the matter should test new and novel rootstocks that were developed specifically for and from North American hybrid cultivars.

ACKNOWLEDGMENTS
Funding of this project has been provided in part through the AgriScience program-cluster on behalf of Agriculture and Agri-Food Canada. We also thank Richard Kamal, Stefano Campagnaro and Pascale Boulay for their technical support.

Literature Cited

Bates, T. (2005). Grapevine root biology and rootstock selection in Eastern US. Grapevine Rootstocks Curr. Use Res. Appl. 8.

Bates, T.R., English-Loeb, G., Dunst, R.M., Taft, T., and Lakso, A. (2015). The interaction of phylloxera infection, rootstock, and irrigation on young Concord grapevine growth. VITIS-J. Grapevine Res. *40*, 225.

Cousins, P. (2005). Evolution, genetics, and breeding: viticultural applications of the origins of our rootstocks. Grapevine Rootstocks Curr. Use Res. Appl. 1.

Harris, J.L. (2013). Effect of rootstock on vegetative growth, yield, and fruit composition of Norton grapevines. M.S. University of Missouri--Columbia.

Hoover, E.E., Hemstad, P., Larson, D., MacKenzie, J., Zambreno, K., and Propsom, F. (2002). Rootstock Influence on Scion Vigor, Hardiness, Yield, and Fruit Composition of St. Pepin Grape. In XXVI International Horticultural Congress: Viticulture-Living with Limitations 640, pp. 201–206.

Kaplan, M., Klimek, K., Borowy, A., and Najda, A. (2018). Effect of rootstock on yield quantity and quality of grapevine 'Regent'in South-Eastern Poland. Acta Sci. Pol.-Hortorum Cultus *17*, 117–127.

Krstic, M., Kelly, G., Hannah, R., and Clingeleffer, P. (2005). Manipulating grape composition and wine quality through the use of rootstocks. Grapevine Rootstocks Curr. Use Res. Appl. 34.

Mantilla, S.M.O., Collins, C., Iland, P.G., Kidman, C.M., Ristic, R., Boss, P.K., Jordans, C., and Bastian, S.E.P. (2018). Shiraz (Vitis vinifera L.) Berry and Wine Sensory Profiles and Composition Are Modulated by Rootstocks. Am. J. Enol. Vitic. *69*, 32–44.

McCraw, B.D., McGlynn, W.G., and Striegler, R.K. (2005). Effect of rootstock on growth, yield and juice quality of vinifera, American and hybrid wine grapes in Oklahoma. Grapevine Rootstocks Curr. Use Res. Appl. 61.

Mijowska, K., Ochmian, I., and Oszmiański, J. (2017). Rootstock effects on polyphenol content in grapes of 'Regent'cultivated under cool climate condition. J Appl Bot Food Qual *90*, 159–164.

Ollat, N., Tandonnet, J.P., Lafontaine, M., and Schultz, H.R. (2001). Short and long term effects of three rootstocks on Cabernet Sauvignon vine behaviour and wine quality. In Workshop on Rootstocks Performance in Phylloxera Infested Vineyards 617, pp. 95–99.

Reynolds, A.G. (2015). Grapevine breeding programs for the wine industry (Elsevier).

Reynolds, A.G., and Wardle, D.A. (2001). Rootstocks Impact Vine Performance and Fruit Composition of Grapes in British Columbia. HortTechnology *11*, 419–427.

Sabbatini, P., and Howell, G.S. (2013). Rootstock Scion Interaction and Effects on Vine Vigor, Phenology, and Cold Hardiness of Interspecific Hybrid Grape Cultivars (Vitis spp.). Int. J. Fruit Sci. *13*, 466–477.

Striegler, R.K., and Howell, G.S. (1991). The influence of rootstock on the cold-hardiness of Seyval grapevines 1. Primary and secondary effects on growth, canopy development, yield, fruit quality and cold hardiness. VITIS-J. Grapevine Res. *30*, 1.

Suriano, S., Alba, V., Di Gennaro, D., Suriano, M.S., Savino, M., and Tarricone, L. (2016). Genotype/rootstocks effect on the expression of anthocyanins and flavans in grapes and wines of Greco Nero n. (Vitis vinifera L.). Sci. Hortic. *209*, 309–315.

Wolpert, J.A. (2005). Selection of Rootstocks: Implications for Quality. In Grapevine Rootstocks: Current Use,Research, and Application, (Southwest Missouri State University), pp. 25–33.

Zabadal, T.J., Dami, I.E., Goffinet, M.C., Martinson, T.E., and Chien, M.L. (2007). Winter injury to grapevines and methods of protection. Chien ML Mich. State Univ. Ext.