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Effects of rootstock genotypes on compatibility, biomass, and the yield of Welschriesling

S. Vršič[1], B. Pulko[1], L. Kocsis[2]

[1]*University Centre of Viticulture and Enology Meranovo, Faculty of Agriculture and Life Sciences, University of Maribor, Hoče, Slovenia*
[2]*Department of Horticulture, Georgikon Faculty, Keszthely, University of Pannonia, Hungary*

Abstract

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The aim of this work is to determine the compatibility, the scion biomass, and the yield of the grapevine variety Welschriesling grafted onto 12 grapevine rootstocks. As an index of compatibility, the callus development and graft success were determined. Dry weight of canes was measured at the end of the growing seasons (2011–2014), while root dry weight only in the first year in the nursery. The grape yield was measured in the first production year. Welschriesling showed good compatibility with all examined rootstocks. More than 85% of grafts had a complete callus development (8BČ rootstock 100%). The average of graft success in the nursery was 67%, but the average of 5BB, G251, and G103 was above 80%. The G103 rootstock had the highest root dry weight after one season. The dry weight of canes in vineyards was above the average with 5BB, SO4, Binova, Börner, and M V rootstocks. All Georgikon rootstocks had a lower cane dry weight per vine than the others. The highest yields were recorded on SO4, G251, and Börner rootstocks.

Keywords: *Vitis vinifera*; callus development; graft success; nursery; pruning

In the second half of the 19[th] century, phylloxera (*Daktulosphaira vitifoliae* Fitch) was inadvertently introduced into Europe and gradually destroyed European vineyards (Granett et al. 2001). Grape rootstocks were selected from North American *Vitis* sp., and later hybrids were made among them to solve the problem. However, phylloxera have been evolving more aggressive strains that can overcome the resistance of some rootstocks (Martinez-Peniche 1999), and the damage due to phylloxera is increasing in some areas (Rühl et al. 1999). Despite this fact, the grafting of vine varieties onto American rootstocks is still considered to be the most effective means of controlling phylloxera.

Given phylloxera's ability to develop more aggressive strains, rootstock breeders must test new rootstocks against this pest (Korosi et al. 2011). At the end of the 1990s, several German vineyards were replanted with vines grafted on Börner rootstock (Becker 1989; Basler 1994; Hafner 1998). Börner was selected from the hybrid progeny derived from crossing *Vitis riparia* 183 Gm × *Vitis. cinerea* Arnold (Ambrosi et al. 1994). This rootstock has a strong, hypersensitive reaction to phylloxera attack (Blank et al. 2009) and is considered to have one of the highest levels of resistance among commercially-used rootstocks (Pavloušek, Michlovský 2007). However, it is susceptible to lime-induced

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chlorosis and difficult to propagate (Vršič et al. 2004; Pavloušek 2009, 2010).

When new rootstocks of woody plants are bred and selected, a number of traits need to be evaluated, such as: their affinity and grafting-compatibility, yield efficiency and plant vigour (Pellegrino et al. 2005; Pedersen 2006; Blažek, Pištěková 2012), and adaptation to soils and climatic conditions (Patil et al. 2005; Pire et al. 2007; Pavloušek 2011; Vršič et al. 2014). The mechanism of graft incompatibility of grapevine is not fully understood. Researchers studied how the union develops and functions over time (Pina, Errea 2005; Darikova et al. 2011; Cookson et al. 2013), and confirmed that incompatibility between different scion-rootstock combinations my occur (Gökbayrak et al. 2007). This incompatibility can be detected few weeks after grafting and linked to a poor vascular connection and phloem degeneration at the graft union. These vascular connection problems can disturb water, nutrient, and assimilate flows in the plant and may result in further breakdown of the union (Pina et al. 2009). X-ray tomography was used to evaluate graft quality and found that the good grafts had well-connected tissues in the wood and phloem, while the bad grafts were not completely connected (Milien et al. 2012). In Slovenia and Hungary, new rootstock cultivars are being developed to improve phylloxera resistance and site adaptability. This study was designed to test the graft union formation as an index of compatibility after callusing and the effect of various rootstocks on biomass allocation in the nursery, and on yield in the field experiment for the main Slovenian *Vitis vinifera* grape cultivar Welschriesling.

MATERIAL AND METHODS

The *Vitis vinifera* L. cv. Welschriesling (the most important wine grape variety in Slovenia) as scion was grafted onto 12 rootstocks in 2011. The visually pathogen-free canes of cv. Welschriesling and rootstocks, namely *Vitis berlandieri* × *V. riparia* 5BB, SO4, SO4-31 (clone from Geisenheim) and Binova (selection from SO4 from Oppenheim), Börner (*V. riparia* 183 Gm × *V. cinerea* hybrid from Geisenheim), and Slovenian clones of *V. berlandieri* × *V. riparia* M VI (selection from Teleki 5 A) 8 BČ, M V (selection from Teleki 8 B), were collected in the germplasm repository vineyard at the Meranovo University Centre of the Faculty of Agriculture and Life Sciences in Slovenia. Other rootstocks (G103, G203, G216, G251) were candidate rootstocks from the Department of Horticulture of the Georgikon Faculty in Keszthely, Hungary. They have strengthened phylloxera resistance and drought and lime tolerance according to breeders, but limited information is available about their interaction with scions. Two of them (G103 and G203) are complex hybrids of riparia–rupestris–berlandieri–vinifera, G216 is a Georgikon 28 × Teleki 5C crossbred, and G251 is a Georgikon 28 × Börner hybrid.

After collection and prior grafting, the cuttings of rootstocks (35 cm length) and scions were disinfected in a 0.5% solution of Chinosol W (8-quinoline sulphate) and kept in plastic bags at 2°C. In total, 120 cuttings of rootstock were grafted. The grafting was done by the 'omega' technique (Becker 1989). Grafts were forced in moist sawdust for three weeks at a temperature of 26–28°C, and with humidity of about 80–90%. The grafted rootstock/scion units were waxed before callusing (Plastigreffe 6535; Agrichem by Barozzi, Revere, Italy) and before planting in the field nursery (Plastiffina 7321, Agrichem by Barozzi). Before planting in the nursery, the grafts were soaked in water for 24 h and then planted out into the row ridges covered with a black plastic row cover (0.05 mm thickness). The trial was designed in randomised groups (5 replicates with 20 grafts per replicate) and were conducted in a commercial nursery near Ptuj (46°46'N, 15°81'E, 280 m a.s.l.) in North-East Slovenia. The soil was medium deep and loamy, with a pH of 6.01 (0.1 mol/L KCl). Based on the ammonium lactate extraction procedure, the soil contained 132 mg P, 329 mg K, and 105 mg Mg/kg of air-dried soil from a soil layer of 0–30 cm. The soil samples were taken before the start of the trials. For further examination of the 12 scion-rootstock combinations, a field trial was set up. The vineyard was established with 25 plants per rootstock (5 replicate with 5 grafts per replicate), with row spacing 2.5 m and 1 m between vines in 2012.

The compatibility of various rootstocks with Welchriesling was analysed by the degree of callus development after callusing, the percentage of first grade grafted vines (Council Directive 68/193/EEC:1968 and Official Gazette of RS, No. 93/05), the shoot growth, and the dry weight canes (mature shoots) and roots after one season in the nursery.

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The success of grafting was first determined by the level of callus development around the graft union. After the callusing period, the grafted vines were divided into three groups: (1) vines with a completely developed callus; (2) vines with a partially developed callus; and (3) vines without a callus (Vršič et al. 2015). After a season of growth in the nursery field, the grafted plants were undercut and ripped out from the soil. At this point the percentage of the first grade grafted plants were determined for each combination. They were characterised by at least three equally developed roots that were thicker than 3 mm (the accepted minimum; Official Gazette of RS, No. 93/05). In the nursery, shoot length (periodical, every two weeks), and cane and roots dry weight of the 12 scion-rootstock combinations were measured. The canes and roots were dried at 105°C to determine their dry weight.

In the next two years (2012 and 2013) shoot length and dry weight of canes were measured from field experiment (all 25 plants in each combination were included in this evaluation). In 2014 the yield and quality of grape (total soluble solids, TSS and total acidity, TA) were measured. At the end of the growing season vine balance through yield at harvest and pruning weight (Ravaz-index) and cane weights (pruning divided with the number of canes) were measured (Vasconcelos, Castagnoli 2000; Skinkis,Vance 2013). Cane weights are sometimes a better indicator of vine size, as this metric considers individual shoot weight. Pruning and cane weights were measured in 2014 from randomly selected vines pruned on mono Guyot with 10 buds (5 plants/rootstock).

The differences between rootstocks were verified using a one-way analysis of variance (ANOVA). The statistical evaluation of data was performed with the SPSS 19.0 programme (P ≤ 0.05). Means were compared using the Tukey´s HSD test.

RESULTS AND DISCUSSION

Callus development and grafting success

The percentage of grafts with complete callus development at the graft union was greater than 90% (in 8 BČ rootstocks 100%) (Fig. 1) in most rootstocks after the callusing period. SO4 (85%) and 5BB (87%) were characterised by a significantly lower percentage of grafts with the complete callus development (SO4) ($P \leq 0.05$). SO4-31 (89%) was below but not significantly different than the average (94%). The results of the percentage of the first grade grafted vines suggest excellent compatibility between Welschriesling and the examined rootstocks. Despite this fact, the differences among the rootstocks were significant (Fig. 1). The percentage of the first grade grafted vines was the highest in 5BB (84.8%), followed by G251 (83.4%), and G103 (80.4%), which still were above the average of the trial ($P \leq 0.05$). The rootstocks M V, 8 BČ, Binova, G216 and G 203 resulted in a lower percentage of the first grade grafted vines than the trial average (67%), while M VI, Börner, SO4, and SO4 Kl.31 were at the trial average ($P \leq 0.05$). A higher percentage of grafts with a complete callus development did not later influence the number of first grade grafted vines in the nursery at all grafted combination. Our results did not confirm the already published findings that a positive, linear correlation exists between callus formation and the percentage of the first grade grafted vines (Celik 2000; Basheer-Salimia, Hamdan 2009), mainly

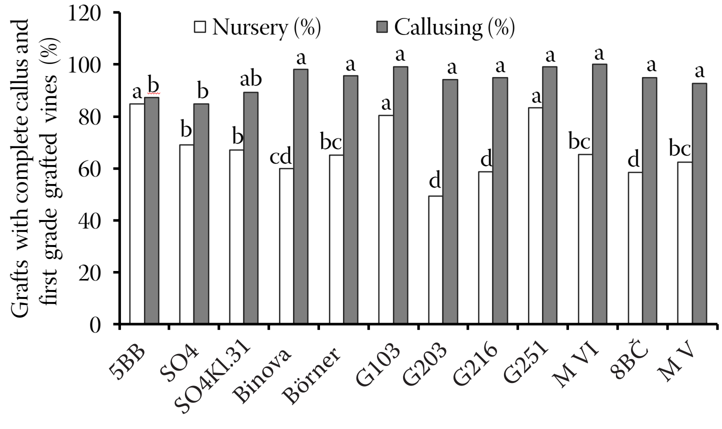

Fig 1. Average percentage of grafts with complete callus development after forcing, and percentage of the first grade of plants in field nursery of Welschriesling grafted onto 12 rootstocks in 2011. Different letters indicate significant differences among the rootstocks ($P \leq 0.05$)

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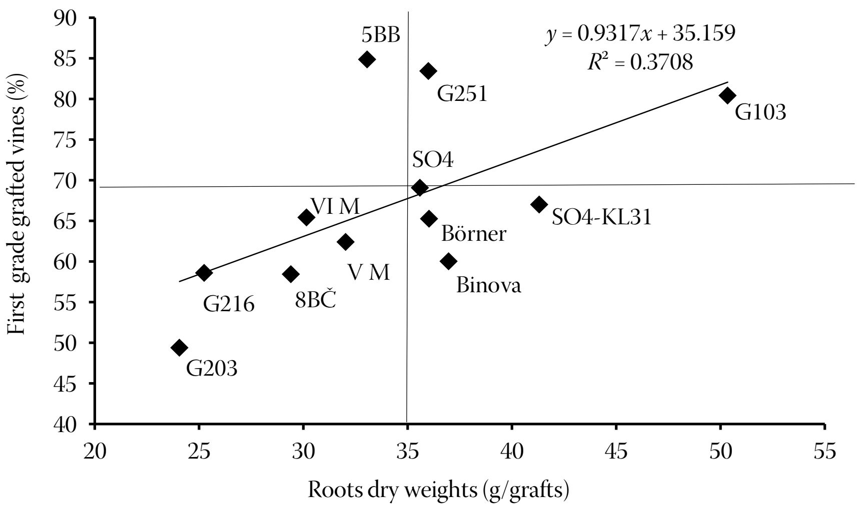

Fig. 2. Correlation between the root dry-weight (g/plant) and the percentage of first grade plants of Welschriesling grafted onto the different rootstocks in the nursery in 2011 ($P \leq 0.05$)

due to poor root development in individual rootstocks in our experimental conditions (loamy soil).

Cane and root dry weight of grafts

Our experiment was set up on loamy soils that could have an additional negative impact on the vine stock development of rootstocks with a small number of roots. This resulted in a lower dry weight of roots, and thus in a smaller amount of reserve substances per grafted vines, which may have negatively influenced their growth in the vineyard (Vršič et al. 2009). Basheer-Salimia and Hamdan (2009) found a strong correlation between callus, root, and shoot development of grafted vines. In our experiment the dry weight of roots of the first grade plant was positively correlated to the percentage of the first grade of grafted vines (Fig. 2; R^2 = 0.37). The highest dry weight of roots was in G103 ($P \leq 0.05$),

Table 1. Average cane and root dry weight (g/vine) of the first grade grafted vines, and cane/root dry weight ratio (n = 10) of Welschriesling grafted onto different rootstocks in the nursery in 2011, and cane dry weight (g/vine) after the first (2012) and second (2013) growing seasons in the vineyard (n = 25)

Rootstock	Field nursery (2011)			Vineyard	
	Cane (g, d.w.)	Root weight (g, d.w.)	Cane/root (d.w.)	Cane (g, d.w.) 2012	Cane (g, d.w.) 2013
5BB	$50.5^{bc} \pm 5.08$	$33.2^{ab} \pm 3.28$	$1.7^{bc} \pm 0.33$	$49.1^{ab} \pm 4.23$	$72.6^{a} \pm 3.27$
SO4	$65.4^{abc} \pm 4.83$	$35.6^{ab} \pm 1.52$	$1.9^{bc} \pm 0.14$	$55.12^{a} \pm 4.18$	$72.4^{a} \pm 5.30$
SO4-31	$78.4^{ab} \pm 8.41$	$41.3^{ab} \pm 3.60$	$1.9^{bc} \pm 0.17$	$55.0^{a} \pm 4.22$	$61.9^{abc} \pm 3.80$
Börner	$73.1^{ab} \pm 7.92$	$36.0^{ab} \pm 4.53$	$2.2^{b} \pm 0.25$	$38.9^{a-e} \pm 4.26$	$53.4^{bcd} \pm 4.50$
Binova	$58.8^{abc} \pm 5.51$	$36.9^{ab} \pm 2.84$	$1.6^{bc} \pm 0.20$	$42.7^{abc} \pm 4.78$	$66.0^{ab} \pm 3.80$
G103	$63.2^{abc} \pm 8.72$	$50.3^{a} \pm 7.07$	$1.4^{bc} \pm 0.16$	$17.3^{f} \pm 3.67$	$23.1^{f} \pm 3.35$
G203	$84.8^{a} \pm 4.85$	$24.0^{b} \pm 2.82$	$4.0^{a} \pm 0.53$	$19.2^{ef} \pm 3.90$	$28.5^{ef} \pm 3.28$
G216	$48.2^{bc} \pm 9.46$	$25.2^{b} \pm 4.48$	$2.0^{bc} \pm 0.14$	$20.5^{def} \pm 4.06$	$28.9^{ef} \pm 4.35$
G251	$54.3^{abc} \pm 6.42$	$36.0^{ab} \pm 3.95$	$1.5^{bc} \pm 0.14$	$29.2^{b-f} \pm 3.31$	$42.5^{de} \pm 3.42$
M VI	$46.1^{bc} \pm 10.06$	$30.1^{b} \pm 3.30$	$1.4^{bc} \pm 0.16$	$34.8^{b-f} \pm 4.68$	$49.0^{bcd} \pm 3.57$
8BČ	$47.7^{bc} \pm 5.76$	$29.4^{b} \pm 3.42$	$1.7^{bc} \pm 0.16$	$23.7^{cdf} \pm 5.20$	$45.7^{cde} \pm 3.69$
M V	$34.0^{c} \pm 4.36$	$32.0^{b} \pm 2.34$	$1.1^{c} \pm 0.10$	$40.5^{a-d} \pm 4.45$	$48.6^{bcd} \pm 3.96$
Average	$58.7^{b} \pm 2.34$	34.2 ± 1.22	1.9 ± 0.09	35.7 ± 1.45	49.5 ± 1.47

different letters within the column mean significant differences among the rootstocks ($P \leq 0.05$); values are means ± standard error, d.w. – dry weight

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Table 2. Average number of cluster per vine, individual cluster weight and yield per plant and m^2 of soil of Welschriesling grafted onto different rootstocks in third growing season (first harvest) in vineyard

Rootstock	No. of clusters	Cluster weight (g)	Yield (kg/plant)	Yield (kg/m^2)	Guyot*	Trunk*	Buds*
	mean ± SE				(%)		
5BB	26.0^{a-d} ± 1.85	136.4^{a} ± 4.71	3.2^{ab} ± 0.10	1.4^{a} ± 0.10	88	12	0
SO4	31.0^{a} ± 2.36	134.2^{a} ± 5.15	4.1^{a} ± 0.27	1.5^{a} ± 0.13	82	8	10
SO4-31	26.9^{a-d} ± 2.17	130.7^{ab} ± 5.65	3.5^{ab} ± 0.29	1.3^{ab} ± 0.12	68	24	8
Börner	28.6^{abc} ± 3.11	137.1^{a} ± 6.29	3.8^{a} ± 0.42	1.3^{ab} ± 0.18	48	28	24
Binova	28.9^{abc} ± 1.73	122.8^{abc} ± 4.31	3.6^{ab} ± 0.22	1.3^{ab} ± 0.13	72	0	28
G103	18.8^{bcd} ± 3.93	98.7^{c} ± 5.72	1.7^{c} ± 0.34	0.4^{c} ± 0.11	20	40	40
G203	14.9^{d} ± 2.68	131.2^{ab} ± 6.51	1.9^{c} ± 0.33	0.5^{c} ± 0.11	16	52	32
G216	21.7^{a-d} ± 3.37	139.1^{a} ± 6.79	3.1^{abc} ± 0.50	0.6^{c} ± 0.16	28	16	56
G251	30.7^{ab} ± 2.87	133.9^{a} ± 7.07	4.0^{a} ± 0.32	1.3^{ab} ± 0.17	64	20	16
M VI	24.8^{a-d} ± 1.73	137.6^{a} ± 6.99	3.5^{ab} ± 0.29	1.2^{ab} ± 0.13	76	16	8
8BČ	17.6^{cd} ± 2.50	130.6^{ab} ± 5.75	2.2^{bc} ± 0.25	0.7^{bc} ± 0.11	40	36	24
M V	25.1^{a-d} ± 2.45	106.1^{bc} ± 4.62	2.7^{abc} ± 0.27	1.0^{abc} ± 0.12	52	36	12
Average	25.1 ± 0.78	129.2 ± 1.70	3.2 ± 0.10	1.1 ± 0.42	54.5	24	21.5

different letters within the column mean significant differences among the rootstocks ($P \leq 0.05$); *vine pruned in the 3rd growing season (Guyot – % of plant pruned on mono Guyot; Trunk – % of plant pruned on the height of trunk; Buds – % of plant pruned back on two buds)

which was also characterised by the highest percentage of first grafted plants. The lower percentage of first grade grafted vines in G203 rootstock was more associated with impaired root development (the lowest roots dry weight). This result is likely due to genetically-based differences in adventitious root development (Smart et al. 2002). Slovenian rootstocks M V and 8 BČ were in the group with the lowest root weight and percentage of first grade grafted vines. These results confirm the correlation between the root dry weight and the percentage of the first grade grafted vines (Lima-da-Silva et al. 2000).

However the cane dry weight was not positively correlated to the root dry weight. Whereas the root dry weight of the vines grafted onto G103 rootstock was twice higher than G203, the cane dry weight was about 25% lower for the combination grafted onto G103 in comparison to the vines grafted on G203 (Table 1). The combination Welschriesling/G203 had the highest cane dry weight per grafted vine, and the highest dry weight ratio of the cane to root (3.99 ± 0.53) of the 12 grafted rootstocks. Ratios of other rootstocks ranged from 1.06 ± 0.10:1 to 2.21 ± 0.25:1. The Slovenian rootstock M V had the lowest cane dry weight (Table 1).

Shoot growth in the vineyard was not related to nursery results in the first two years (2012 and 2013) (Table 1). The first year cane dry weights of vines grafted onto 5BB, SO4, SO4-31, Binova, Börner, and M V rootstocks were significantly higher. The combinations with Georgikon rootstocks and 8 BČ had significantly lower cane dry weight, although some of them had the highest root dry weight after the field nursery growing season (i.e. G103). The M VI rootstock was slightly below the average of the trial. The results were similar in the second growing season (2013). Both years vines grafted onto G 103 rootstock had significantly lower cane dry weight compared to the others ($P \leq 0.05$).

Yield of grape and pruning weight

The yield was also significantly affected by rootstock in 2014, the first harvest year, (the third year of vegetation in the vineyard) (Table 2). The differences in yield were mainly due to the abilities of the different combination to be pruned in mono Guyot after two years of plantation. A lower percentage of plants were pruned with mono Guyot (20, 16, and 28%) for the combinations grafted onto G103, G203, and G216 rootstocks, respectively, while they were 32 (G203) to 40% (G103) pruned back on two buds. For the other combinations more than 50% of plants

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Table 3. Average pruning weight, cane weight and Ravaz index (ratio yield/pruning) of Welschriesling grafted onto 12 rootstocks pruned to mono Guyot in first year of harvest (3rd vegetation in vineyard) in 2014, with a standard error (SE, n = 5)

Rootstock	Pruning weight (g/plant)	Cane weight (g/cane)	Ravaz index
5BB	$336.0^{ab} \pm 29.0$	$29.8^{ab} \pm 2.92$	$13.3^{ab} \pm 1.04$
SO4	$353.0^{ab} \pm 24.7$	$37.3^{a} \pm 5.04$	$13.9^{ab} \pm 1.50$
SO4-31	$304.0^{ab} \pm 30.1$	$29.2^{ab} \pm 3.94$	$14.4^{ab} \pm 1.06$
Börner	$234.0^{b} \pm 33.9$	$19.9^{b} \pm 2.33$	$18.8^{a} \pm 1.37$
Binova	$279.0^{ab} \pm 24.4$	$28.0^{ab} \pm 0.64$	$14.0^{ab} \pm 1.15$
G103	$322.0^{ab} \pm 88.2$	$26.8^{ab} \pm 6.33$	$13.1^{ab} \pm 3.54$
G203	$307.5^{ab} \pm 67.8$	$41.0^{ab} \pm 7.03$	$11.8^{ab} \pm 1.85$
G216	$398.0^{a} \pm 64.0$	$28.5^{a} \pm 3.52$	$15.4^{ab} \pm 3.54$
G251	$258.0^{ab} \pm 28.6$	$20.4^{b} \pm 1.44$	$19.0^{a} \pm 0.75$
M VI	$303.0^{ab} \pm 37.0$	$30.9^{ab} \pm 5.12$	$14.0^{ab} \pm 0.82$
8BČ	$312.0^{ab} \pm 76.5$	$33.3^{ab} \pm 7.47$	$10.3^{b} \pm 1.42$
M V	$204.0^{b} \pm 10.9$	$21.6^{b} \pm 3.92$	$17.8^{ab} \pm 0.95$
Average	302.4 ± 13.1	29.1 ± 1.37	14.6 ± 0.53

values are means ± standard error (SE); different letters within the column mean significant differences among the rootstocks ($P \leq 0.05$)

were pruned to the mono Guyot, except in 8 BČ rootstock (40 %). These differences had an impact on the number of clusters and yield per m^2. The differences in the average weight of the cluster were minimal. Only the vines grafted onto G 103 rootstock were characterised by a lower cluster weight ($P \leq 0.05$). The highest yield exceeding 4 kg/plant, was recorded for the vines grafted onto SO4 rootstock. Vines grafted onto Börner and G 251 had also a significantly higher yield than other combinations, 3.80 and 3.96 kg/plant, respectively. The yield of vines grafted onto G103 and G203 rootstocks was significantly lower than for on the other combinations.

The pruning weight of the vines grafted onto G216 rootstock was significantly higher than the others rootstocks, while Börner and M V rootstocks had significantly lower pruning weights ($P \leq 0.05$). According to the established scale of vigour in previous studies of Skinkis and Vance (2013) and Vasconcelos and Castagnoli (2000), the vines grafted onto the Börner, Binova, G251 and M V rootstocks were classified as weakly vigorous, because of the pruning weight was lower than 300 g/m of row, while the pruning weights of vines on other rootstocks were 300 to 398 g/m of row (Table 3). According to the cane weight (g/cane), all the combinations were characterised as moderately vigorous (optimal), with an average cane weights ranging from 19.9 g/cane (Böerner) to 41 g/cane (G 216) ($P \leq 0.05$).

Vine balance was evaluated with the ratio between yield at harvest (kg/plant) and pruning weight (kg/plant) (Ravaz index). According to this ratio all the combinations regardless of the rootstock were classified as low vigour (Table 3). Only the combination grafted onto 8 BČ rootstock (10.3) was close to the optimal value, while the values of the Ravaz index of other combination were from 11.8 (G 216) to 19 (G 251). According to these results, for the plants pruned on mono Guyot, the cane weight was confirmed as a more suitable parameter for the vine vigour identification than other measured or indexed parameters, because the vines in the first harvest year (third vegetation in vineyard) were unbalanced in vigour (reproductive/vegetative development).

CONCLUSION

The results of the present study suggest that rootstock genotype plays a dominant role in determining biomass and yield of the grafted vines. Indeed, the rootstock was affecting vine growth, yield, and healing of graft union. The 5BB rootstock was characterised by the highest first grade of grafted vines from a field nursery (as in previous studies of Vršič et al. 2004), and G251 and G103 rootstocks were similar. Results of SO4 and Börner confirm the existing knowledge about these rootstocks. In our experiment no relationship was observed between the post-grafting status and field nursery quality. However, the correlation between root dry weight per plant and first grade of grafted vines was confirmed. Under our experimental conditions (loamy soil), some of scion-rootstock combinations with lower root dry weight per plant in field nursery confirmed the lower growth (i.e. cane dry weight) in the following years in the vineyard. Others, especially G 103 rootstock, showed the opposite behaviour with the highest root dry weight at the end of the nursery season and the lowest cane dry weight in next two years in vineyard. In the first year of the harvest there were significant differences in yield between the rootstocks, mainly due to the ability of the different combination to be pruned in mono

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Guyot after two years of plantation. To assess the vigour of vines (vine balance) in the first harvest year, it is more suitable to use the weight of cane (g/cane) than the Ravaz index.

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Corresponding author:

Assoc. Prof. Stanko Vrsič PhD., University of Maribor, Faculty of Agriculture and Life Sciences, University Centre of Viticulture and Enology Meranovo, Pivola 10, SLO-2231 Hoče, Slovenia; e-mail: stanko.vrsic@um.si