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Vegetative growth and foliar nutrient contents of peach on different clonal rootstocks





Abstract – The objective of this work was to evaluate the effect of 19 clonal rootstocks on the vegetative growth and foliar nutrient contents of the 'BRS Kampai' and 'BRS Rubimel' peach (*Prunus persica*) trees. In the period of 2014 to 2018, two field trials were carried out in the municipalities of Jarinu and Jundiá, in the state of São Paulo, Brazil. The BRS Kampai and BRS Rubimel cultivars, budded on 19 clonal rootstocks, besides their own-rooted scions, were evaluated in Jarinu and Jundiá, respectively. In Jarinu, the Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, 'Okinawa', México Fila-1, Nemared, Tsukuba-2, and Tsukuba-3 rootstocks, as well as the own-rooted scion, showed the best performance for vegetative growth and foliar nutrient contents. In Jundiá, all genotypes, except Marianna 2624 and Mirabolano 29C, did not show any statistical difference regarding vegetative growth. The performance of own-rooted 'BRS Kampai' and 'BRS Rubimel' is similar to that of traditional rootstocks, such as 'Okinawa'. Therefore, the evaluated scion cultivars may be an interesting alternative for sites with suitable biotic and abiotic soil conditions.

Index terms: *Prunus*, 'BRS Kampai', 'BRS Rubimel', graft technique.

Crescimento vegetativo e teores de nutrientes nas folhas de pessegueiro sobre diferentes porta-enxertos clonais

Resumo – O objetivo deste trabalho foi avaliar o efeito de 19 porta-enxertos clonais sobre o crescimento vegetativo e os teores de nutrientes nas folhas dos pessegueiros (*Prunus persica*) 'BRS Kampai' e 'BRS Rubimel'. No período de 2014 a 2018, foram realizados dois ensaios em campo, nos municípios de Jarinu e Jundiá, no estado de São Paulo, Brasil. Foram avaliadas as cultivares BRS Kampai e BRS Rubimel enxertadas em 19 porta-enxertos clonais, além de suas copas autoenraizadas, em Jarinu e Jundiá, respectivamente. Em Jarinu, os porta-enxertos Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, 'Okinawa', México Fila-1, Nemared, Tsukuba-2 e Tsukuba-3, além da copa autoenraizada, apresentaram melhor desempenho para crescimento vegetativo e teores de nutrientes nas folhas. Em Jundiá, todos os genótipos, exceto Marianna 2624 e Mirabolano 29C, não apresentaram diferenças estatísticas quanto ao crescimento vegetativo. O desempenho de 'BRS Kampai' e 'BRS Rubimel' autoenraizadas é similar ao dos porta-enxertos tradicionais, como 'Okinawa'. Assim, as cultivares-copa avaliadas podem ser consideradas alternativa interessante para locais com condições bióticas e abióticas de solo adequadas.

Termos para indexação: *Prunus*, 'BRS Kampai', 'BRS Rubimel', técnica de enxertia.


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Introduction

Commercial orchards of stone fruits in Brazil are propagated by budding scion cultivars on rootstocks, which are often obtained from seeds (Mayer et al., 2014b; Souza et al., 2017). Grafting or budding is used for many purposes, as for the maintenance of the genetic origin of the scion cultivar, homogeneity, vigor control, regulation of nutrient absorption, and early production (Chatzissavvidis et al., 2008; Mayer et al., 2013, 2014b). Another purpose is combining two genotypes (scion and rootstock) in a single plant, which allows growing a scion cultivar of interest on a rootstock resistant to diseases, pests, and environmental adversities, increasing plant productivity due to the physiological contributions of the rootstock, including the absorption and transport of water and nutrients (Comiotto et al., 2013; Mayer et al., 2014a).

In Brazil, rootstocks from seeds are often used; however, they can have different cross rates and, consequently, present genetic diversity (Mayer et al., 2013, 2014b; Oliveira et al., 2018). This genetic diversity makes it difficult to maintain desirable characteristics, which may be obtained by first identifying scion cultivars of interest and then cloning them by some propagation method, which requires evaluating their compatibility with rootstock cultivars (Barreto et al., 2017). However, although several propagation methods for *Prunus* spp. have been studied (Mayer et al., 2013), this technique is still rarely used in the country for the commercial production of peach.

Among the evaluated methods, the use of cuttings under an intermittent mist system has shown the best results (Mayer et al., 2014b). Since softwood cuttings are a clonal method, the new nursery tree, except for rare mutations, is genetically identical to the mother-plant (Mayer et al., 2014b). In addition, cuttings are often treated to stimulate the formation of lateral roots (Mayer et al., 2014b), and this propagation system has several desirable features, such as: no seed requirement, standardization of the root system, and possibility of cloning hybrid cultivars and cultivars with a low rate of seed viability (Mayer et al., 2014a).

It should be noted that distinct rootstocks may present different capabilities for controlling vigor and yield and for absorbing nutrients (Chatzissavvidis et al., 2008; Mayer et al., 2015; Mestre et al., 2015; Jimenes et al., 2018; Menegatti et al., 2021). In a study conducted with the 'Maciel' and 'Chimarrita' scions

budded on the Aldrighi, 'Capdeboscq', Flordaguard, Nemaguard, 'Okinawa', and Japanese apricot (*Prunus mume* Sieb. et Zucc.) rootstocks, Comiotto et al. (2013) found significant differences in peach trunk diameter, depending on the used scion and rootstock combination. Likewise, Galarça et al. (2013) observed the formation of two groups when evaluating the effect of rootstock on the vigor of the 'Maciel' and 'Chimarrita' peach scions. De Salvador et al. (2014) also reported interactions between peach scions and rootstocks, with different averages for trunk cross-sectional area and yields. However, Barreto et al. (2017) found no differences for the diameter of the 'Maciel' scion budded on the Aldrighi, 'Capdeboscq', Flordaguard, Nemaguard, 'Okinawa', Umezeiro, Tsukuba, and Seleção Viamão rootstocks in the 2014/2015 harvest season, although statistical differences pointed out the formation of two groups in the 2015/2016 harvest. In another study, the Flordaguard and Tsukuba-1 rootstocks induced the development of a large canopy in the Sunraycer nectarine (*P. persica* var. *nucipersica*), while Ishtara reduced this characteristic (Jimenes et al., 2020). Menegatti et al. (2021) concluded that Flordaguard and 'Capdeboscq' were the best for macronutrient transport and use efficiency, but observed no differences among rootstocks for absorption efficiency.

Despite these researches, there are still few works describing the behavior of clonal rootstocks and own-rooted peach in field conditions in Southeastern Brazil, which is the second most important producing region in the country. In this context, the hypothesis of the present study is that the use of different rootstocks affects the growth rate of peach trees.

The objective of this work was to evaluate the effect of 19 clonal rootstocks on the vegetative growth and foliar nutrient contents of the 'BRS Kampai' and 'BRS Rubimel' peach [*Prunus persica* (L.) Batsch] trees.

Materials and Methods

Softwood leafy cuttings were collected from the prunus rootstock germplasm bank (31°40'42"S, 52°27'05"W, at 54 m altitude) of Embrapa Clima Temperado, located in the municipality of Pelotas, in the state of Rio Grande do Sul, Brazil. The climate of area is of the Cfa type according to Köppen-Geiger (Alvares et al., 2013), and the soil is an Argissolo Bruno Acinzentado, according to the Brazilian soil classification system (Santos et al., 2018), i.e., an Ultisol.

The following 19 genotypes were selected from the prunus rootstock germplasm bank and used as rootstocks: Barrier (*P. persica* x *P. davidiana* Franch.), Cadaman (*P. persica* x *P. davidiana*), 'Capdeboscq' (*P. persica*), Clone 15 (*P. mume*), Flordaguard (*P. persica* x *P. davidiana*), Genovesa (*Prunus salicina* Lindl.), GxN9 (*P. persica* x *Prunus dulcis* D.A.Webb), I-67-52-4 (*P. persica*), Ishtara [(*Prunus cerasifera* Ehrh. x *P. salicina*) x (*P. cerasifera* x *P. persica*)], Marianna 2624 (*P. cerasifera* x *Prunus munsoniana* Q.Qifhr & Hedrick in Hedrick), México Fila-1 (*P. persica*), Mirabolano 29C (*P. cerasifera*), Nemared (*P. persica*), 'Okinawa' (*P. persica*), 'Rigitano' (*P. mume*), Santa Rosa (*P. salicina*), Tsukuba-1 (*P. persica*), Tsukuba-2 (*P. persica*), and Tsukuba-3 (*P. persica*). Most of these rootstocks are resistant to *Meloidogyne* spp. (Mayer et al., 2013, 2014b; Oliveira et al., 2018). In addition, Barrier, Santa Rosa, Tsukuba-1, and Tsukuba-2 are also resistant to waterlogging, while Mirabolano 29C and Marianna are moderately resistant to *Phytophthora cactorum* (Mayer et al., 2013).

The cuttings were rooted in a vermiculite tray kept under an intermittent mist system. After rooting, the cuttings were transplanted into 30x18 cm plastic bags containing commercial pine bark (30%) and peat-based (70%) substrate. After 11 months, all rootstocks were budded with the BRS Kampai and BRS Rubimel peach cultivars (Mayer et al., 2013).

The 'BRS Kampai' and 'BRS Rubimel' scions were collected from three-year-old mother plants at the nursery of the Frutplan Mudás company (Pelotas, RS, Brazil), and the plants were budded using the inverted T-budding method. The used scion cultivars have medium vigor, semi-vertical growth behavior, and chill requirements ranging from 200 to 300 chilling hours up to flowering (Raseira et al., 2014). These characteristics, along with the production and high quality of their fruit, make these scions a good choice for producers. Own-rooted nursery plants were also grown. 'Okinawa', due to its wide local use as a rootstock, was considered as a reference.

The trials were installed in August 2014 in two municipalities of the state of São Paulo, Brazil: Jarinu (23°04'59"S, 46°43'27"W, at 800 m altitude) and Jundiaí (23°06'52"S, 46°56'03"W, at 740 m altitude). The climate of Jarinu is of the Cwa type according to Köppen-Geiger's classification (Alvares et al., 2013), and the soil is a Cambissolo (Santos et al., 2018), i.e.,

an Inceptisol. The climate of Jundiaí is of the Cwa type according to Köppen-Geiger's classification (Alvares et al., 2013), and the soil is an Argissolo Vermelho-Amarelo (Santos et al., 2018), i.e., an Ultisol.

For the trials, the 'BRS Kampai' scion was trained on the Y system (5.5x1.4 m) in the municipality of Jarinu, and 'BRS Rubimel', in an open vase (5.0x4.0 m), in the municipality of Jundiaí. Both experiments were designed in randomized complete blocks, with six replicates and one plant per plot.

Tree height and trunk diameter of the rootstock and scion were evaluated once a year from 2015 to 2018, before pruning. Furthermore, in 2015, the concentration of nutrients (nitrogen, phosphorus, potassium, and micronutrients) in the leaves of 'BRS Kampai' was determined, according to the sampling method proposed by Freire & Magnani (2014).

The data were subjected to the analysis of variance, Tukey's test, and the t-test. These statistical tests were calculated in the R-software environment (R Core Team, 2019), using the following packages: nlme (Pinheiro et al., 2019), emmeans (Lenth et al., 2019), and agricolae (Mendiburu, 2019). The data used in the multivariate analysis were standardized by $Z = (x - \mu)/\sigma$, where Z is the transformed value; x is the original value; μ is the mean; and σ is the standard deviation. This standardization was performed to remove the effect of the different units presented by the different evaluated variables. The results were plotted using the R-package ggplot2 (Wickham et al., 2019), and cluster analyses were calculated with the R-package factoextra (Kassambara & Mundt, 2019).

Results and Discussion

In 2016, all trees budded on Marianna 2624 and Mirabolano 29C in both experiments died due to graft incompatibility. This result was also observed by Varago et al. (2015), who used the compatibility index to measure the relationship between rootstock and canopy diameters in the field. The indexes obtained by the authors were lower than the ideal value of 12, being 11.58 for Marianna 2624 and 11.42 for Mirabolano 29C, indicating genetic incompatibility between both rootstocks and the 'BRS Kampai' and 'BRS Rubimel' scions. In Pelotas, these rootstocks also showed a high incompatibility with the 'Maciel', 'Jade', and 'BRS-Kampai' scions (Neves et al., 2017).

The genotypes presenting the highest values for rootstock and scion height and diameter varied over the years in Jarinu and Jundiá (Figures 1, 2, and 3); however, those with the best results were the same in all years (Figure 4). The rootstocks with the highest values for height were: own-rooted 'BRS Kampai', Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, 'Okinawa', and México Fila-1 in Jarinu (Figures 1 A and 4 A); and own-rooted 'BRS Rubimel', Barrier, Cadaman, 'Capdeboscq', Clone-15, Flordaguard, GxN9, I-67-52-4, 'Okinawa', México Fila-1, Nemared, 'Rigitano', Santa Rosa, Tsukuba-1, and Tsukuba-3 in Jundiá (Figures 1 B and 4 B). Except for Clone 15 (*P. mume*), 'Rigitano' (*P. mume*), and Santa Rosa (*P. salicina*), the previously mentioned cultivars have genetic origin in *P. persica* or are interspecific hybrids of the species. This fact indicates some degree of incompatibility for grafting or budding with interspecific rootstocks. Comiotto et al. (2013) observed that the Maciel and Chimarrita scion cultivars (both *P. prunus*) showed the lowest vigor when budded on Japanese apricot (*P. mume*), highlighting that the dwarfing effect usually causes physiological changes and low vigor. Besides interspecies compatibility, the type of rootstock propagation also affects scion development. In the present study, 'Okinawa', widely used as rootstock in the region of Jarinu and Jundiá, ranked within the group of cultivars with the highest height (Figure 1 A and 1 B). However, Souza et al. (2017) reported significant differences in trunk diameter (33.2 and 26.9 mm), scaffold diameter (30.0 and 22.2 mm), and scaffold length (165.8 and 136.2 cm) when 'Maciel' was budded on 'Okinawa' formed by seeds or cuttings, respectively.

In general, the genotypes that presented the highest values for height also showed the highest values for rootstock and scion diameters (Figures 2 A, 2 B, 3 A, and 3 B). The rootstocks with the greatest diameters, as indicated by Tukey's test (Figure 2 A), were grouped into cluster 2 in Jarinu (Figure 4 C). Neves et al. (2017), when studying the behavior of 'BRS Kampai' budded on 18 clonal rootstocks, grouped Barrier, GxN9, Mirabolano 29C, Marianna 2624, Genovesa, Tsukuba-1, Tsukuba-3, Santa Rosa, and own-rooted 'BRS Kampai' as having the greatest diameters. Overall, this group is similar to that of the present work, excluding genotypes Mirabolano 29C, Marianna 2624, Genovesa, Tsukuba-1, and Santa Rosa.

The diameter of the 'BRS Kampai' scion differed significantly by Tukey's test (Figure 2 B), which compared the mean values in each year. However, according to the cluster analysis, which compared each genotype for all years, all scion parameters were grouped into a single cluster (Figure 4 E), except for Marianna 2624 and Mirabolano 29C, which presented 100% mortality. Contrarily, Neves et al. (2017) found no statistical differences among rootstocks for 'BRS Kampai'.

In Jundiá, own-rooted 'BRS Rubimel' and the Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, México Fila-1, and 'Rigitano' rootstocks showed the highest diameter, as indicated by Tukey's test (Figure 3 A). Again, according to the cluster analysis, all rootstock parameters were grouped into a single cluster (Figure 4 D), except for Marianna 2624 and Mirabolano 29C, which presented 100% mortality.

The cluster analyses for the diameter of 'BRS Rubimel' led to the formation of two groups. The first was formed by Ishtara, Genovesa, Marianna 2624, and Mirabolano 29C (Figure 4 F), which induced the lowest scion diameters (Figure 3 B). These rootstocks have genetic origin in *P. salicina* and *P. cerasifera*, or their hybrids, indicating some degree of incompatibility in interspecific budding.

Galarça et al. (2013) observed the formation of two groups when evaluating the development of the 'Maciel' and 'Chimarrita' scions budded on the Aldrighi, 'Capdeboscq', Flordaguard, Nemaguard, 'Okinawa', and Japanese apricot (propagated by seeds) rootstocks in three locations in the state of Rio Grande do Sul, Brazil. The obtained results showed that only Japanese apricot led to reductions in trunk diameter, probably due to its genetic origin in *P. mume*, which may have caused the lowest vigor in the 'Maciel' and 'Chimarrita' scions (Galarça et al., 2013). In another study, the 'Big Top' nectarine budded on the Cadaman rootstock presented the greatest trunk cross-sectional area of 380.5 cm², which did not differ significantly from that of Barrier, with 297.6 cm² (Reig et al., 2016). According to these authors, the evaluated rootstocks induce the greatest cumulative yield, which, however, does not lead to a better yield efficiency for Barrier.

According to the t-test, only 'BRS Kampai' budded on GxN9 showed a significant difference in 2018 (GxN9: 11.08 cm; 'BRS Kampai': 9.81 cm; p-value = 0.01). All other combinations did not differ significantly by this test (p-value \geq 0.05).

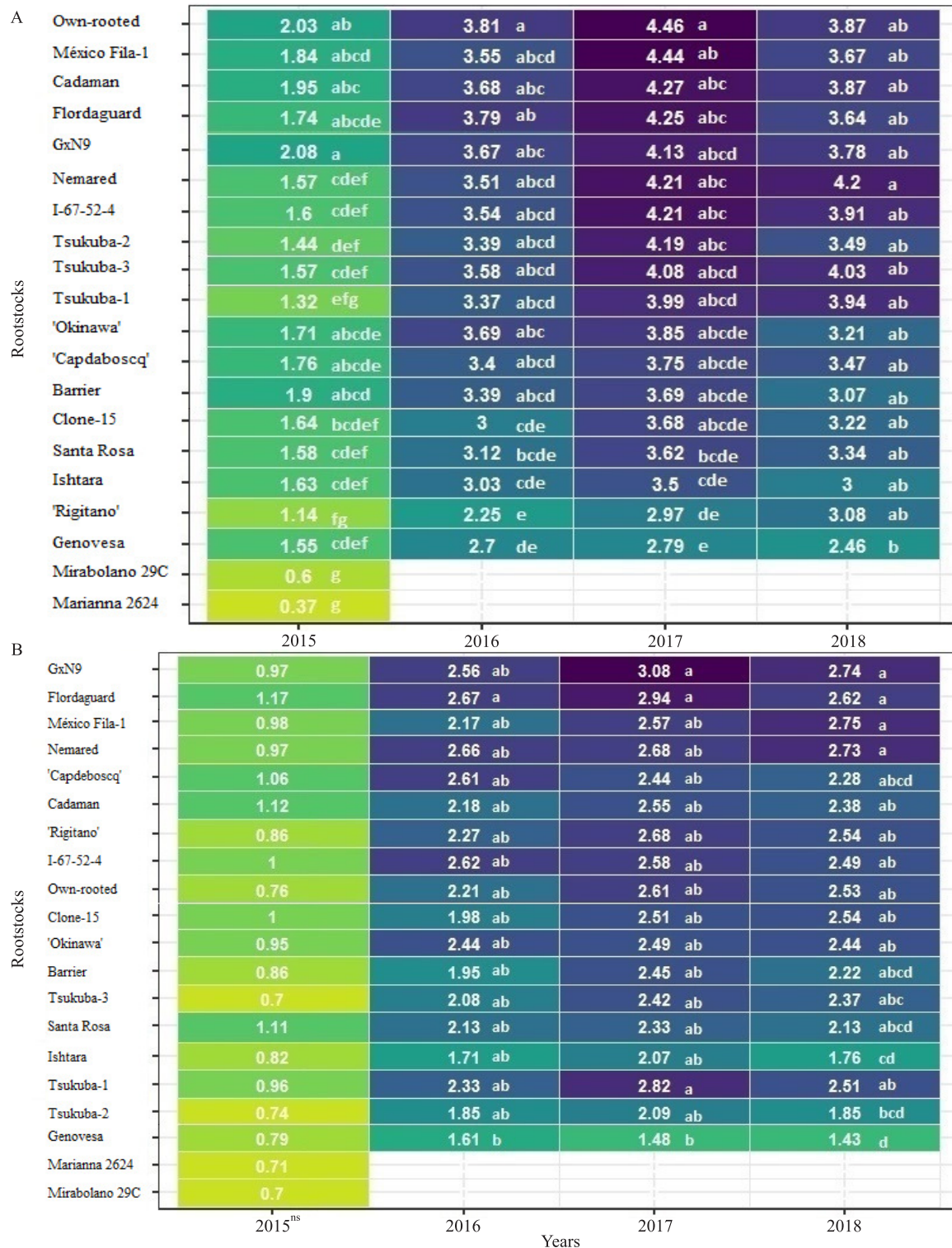


Figure 1. Average values for height (m) of the 'BRS Kampai' (A) and 'BRS Rubimel' (B) peach (*Prunus persica*) scions budded on 19 rootstocks and own-rooted in the municipalities of Jarinu and Jundiáí, in the state of São Paulo, Brazil, respectively, from 2015 to 2018. Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. Means from 2015 to 2018: A, 1.55, 3.36, 3.89, and 3.51; and B, 0.95, 2.28, 2.59; and 2.43. Coefficient of variation (%) in 2015, 2016, 2017, and 2018, respectively: A, 14.70, 10.65, 11.39, and 15.08; and B, 26.64, 20.31, 16.02, and 10.91. The color gradient represents the increase of mean values: yellow, lowest values; and dark blue, highest values.

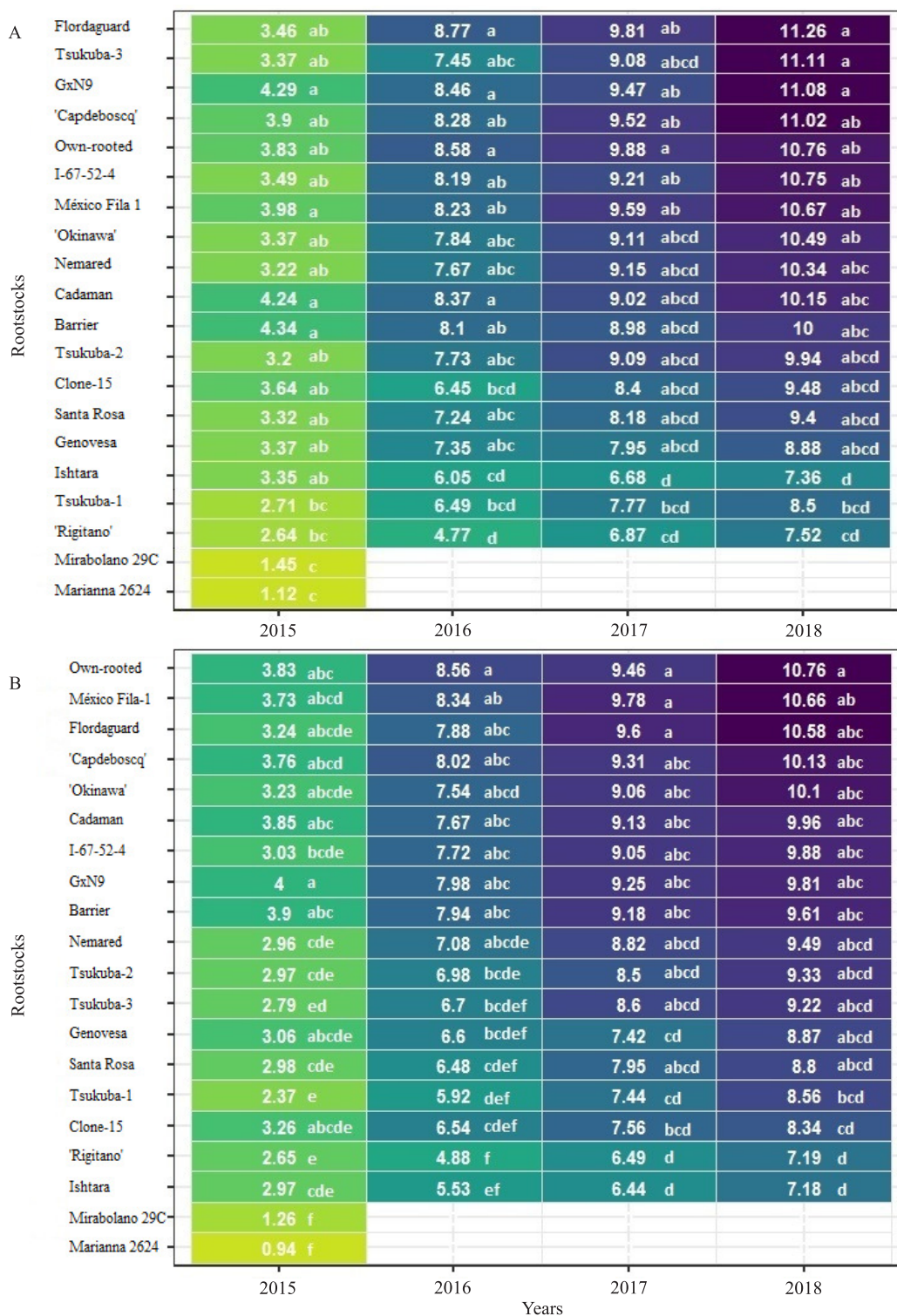


Figure 2. Average values for diameter (cm) of rootstocks (*Prunus* spp.) (A) and the 'BRS Kampai' (B) peach (*Prunus persica*) scion budded on 19 rootstocks and own-rooted in the municipality of Jarinu, in the state of São Paulo, Brazil, from 2015 to 2018. Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. Means from 2015 to 2018: A, 3.42, 7.57, 8.81, and 9.89; and B, 3.15, 7.18, 8.75, and 9.41. Coefficient of variation (%) in 2015, 2016, 2017, and 2018, respectively: A, 16.71, 12.06, 12.73, and 12.62; and B, 14.10, 12.03, 12.25, and 11.59. The color gradient represents the increase of mean values: yellow, lowest values; and dark blue, highest values.

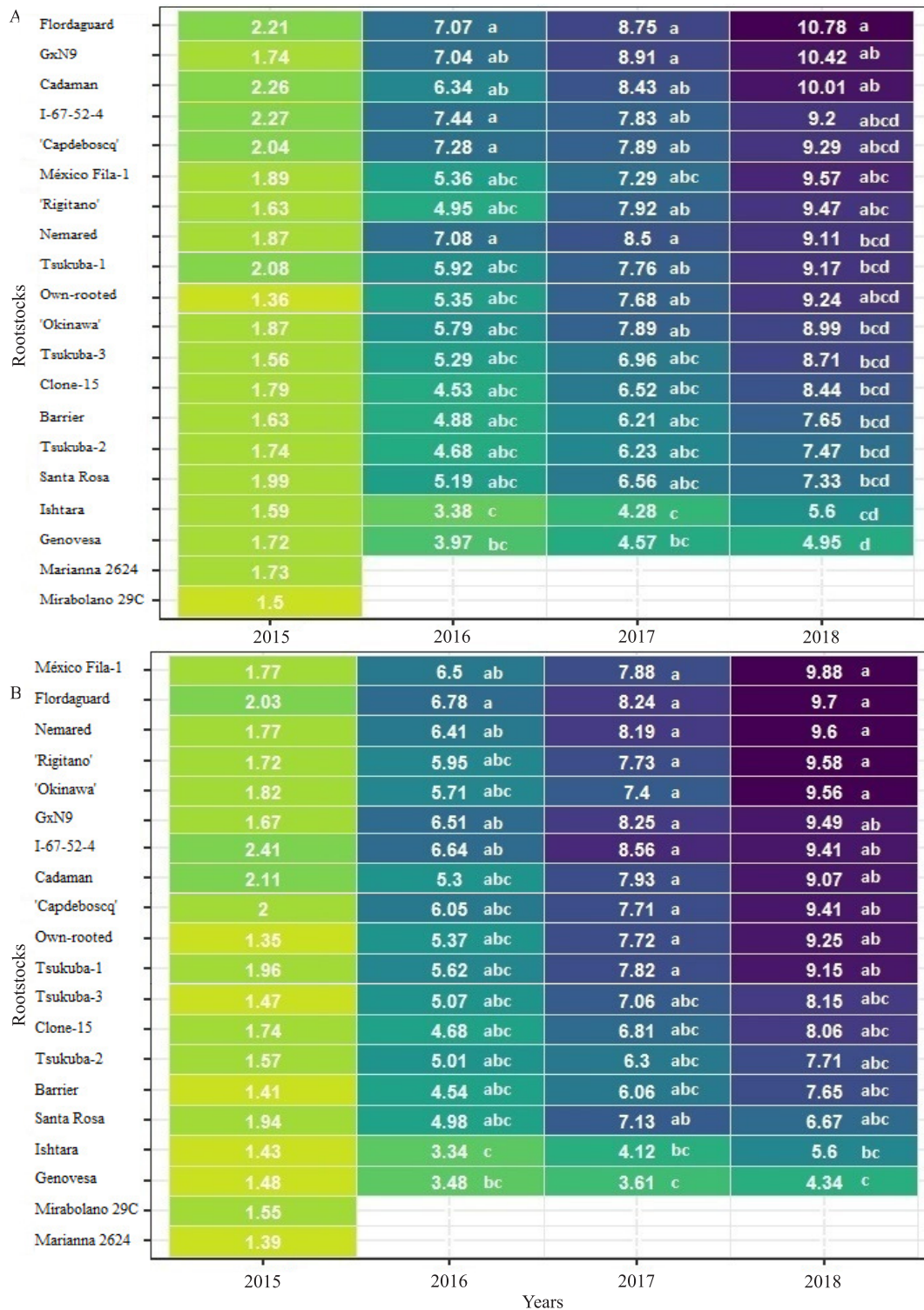


Figure 3. Average values for diameter (cm) of rootstocks (*Prunus* spp.) (A) and the 'BRS Rubimel' peach (*Prunus persica*) scion (B) budded on 19 rootstocks and own-rooted in the municipality of Jundiaí, in the state of São Paulo, Brazil, from 2015 to 2018. Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. Means from 2015 to 2018: A, 1.85, 5.78, 7.58, and 9.02; and B, 1.74, 5.52, 7.48, and 8.89. Coefficient of variation (%) in 2015, 2016, 2017, and 2018, respectively: A, 28.69, 23.05, 16.44, and 15.49; and B, 28.46, 23.89, 16.50, and 14.82. The color gradient represents the increase of mean values: yellow, lowest values; and dark blue, highest values.

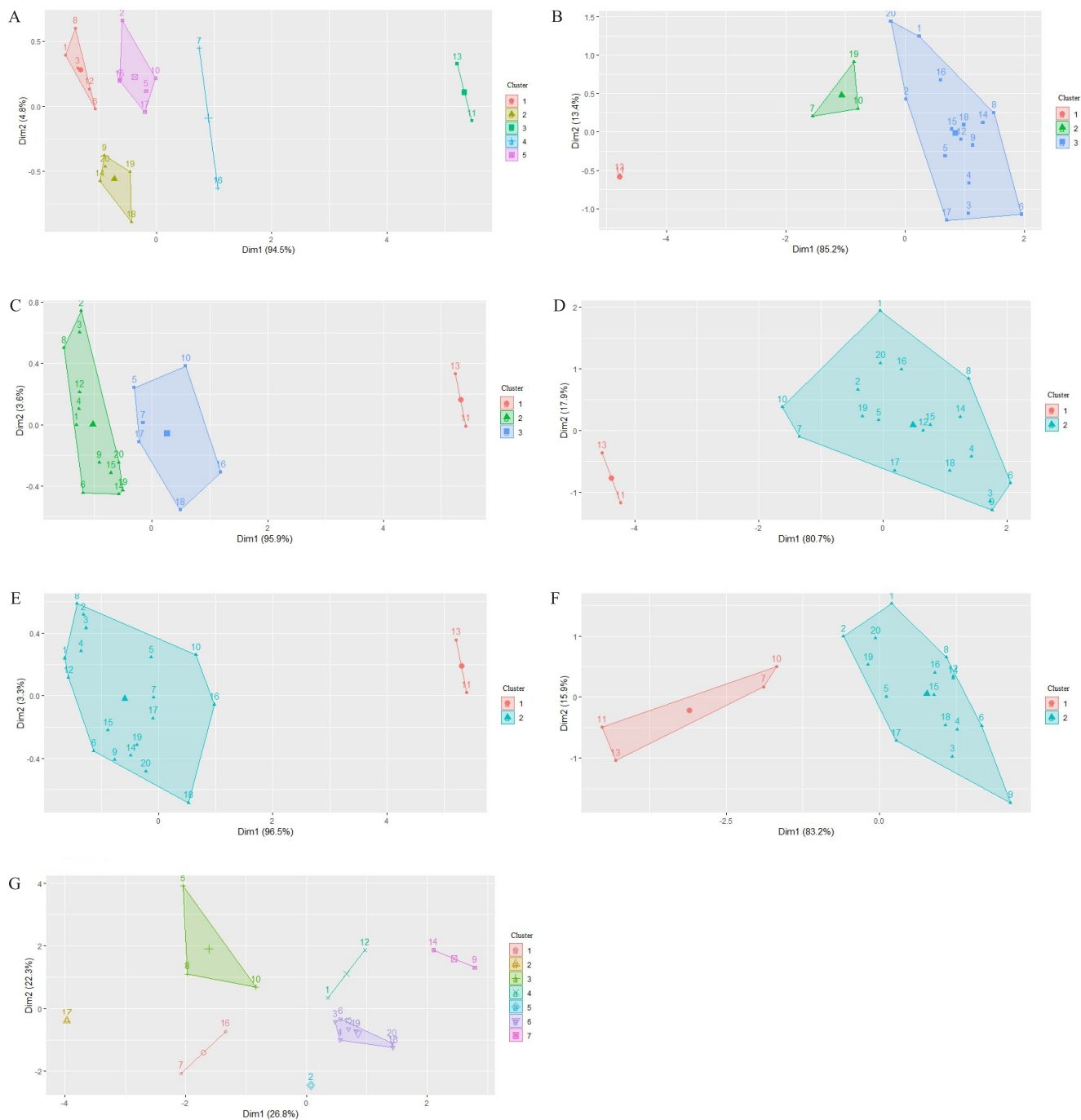


Figure 4. Groups of average values for height (A and B), rootstock diameter (C and D), and scion diameter (E and F), from 2015 to 2018, of the 'BRS Kampai' and 'BRS Rubimel' peach (*Prunus persica*) scions budded on 19 rootstocks (*Prunus* spp.) and own-rooted in the municipalities of Jarinu and Jundiaí, in the state of São Paulo, Brazil, respectively, as well as foliar nutrient contents, in 2015, of 'BRS Kampai' budded on 19 rootstocks and own-rooted in Jarinu (G). Genotypes: 1, own-rooted; 2, Barrier; 3, Cadaman; 4, 'Capdeboscq'; 5, Clone-15; 6, Flordaguard; 7, Genovesa; 8, GxN9; 9, I-67-52-4; 10, Ishtara; 11, Marianna 2624; 12, México Fila-1; 13, Mirabolano 29C; 14, Nemared; 15, 'Okinawa'; 16, 'Rigitano'; 17, Santa Rosa; 18, Tsukuba-1; 19, Tsukuba-2; and 20, Tsukuba-3. The grouping method (cluster analyses) was based on the K-means algorithm (Kassambara & Mundt, 2019).

Foliar analysis indicated that the rootstock affects the absorption of most nutrients (Figure 5). The average values obtained for most nutrient concentrations were close to their sufficient range (Johnson, 2008; Freire & Magnani, 2014). Furthermore, own-rooted 'BRS Kampai' provided adequate nutrient levels, except of iron and manganese.

No significant differences were observed for N absorption among rootstocks (Figure 5). The majority of them showed excess N concentration, except Santa Rosa, GxN9, and Clone-15, whose values were within the sufficiency range. This result differs from those of other studies. Mayer et al. (2015), for example, reported that the 'Maciel' scion showed a low N concentration when budded on 'Capdeboscq' (2.57 to 3.15% dry matter), Flordaguard (2.74 to 3.21% dry matter), and 'Okinawa' (2.60 to 3.24% dry matter). However, Jimenes et al. (2018) found that the Sunraycer nectarine presented a N concentration within the sufficiency range when budded on 13 rootstocks, but a low one of 27.10 g kg⁻¹ when own-rooted. Menegatti et al. (2021) evaluated the 'Capdeboscq', Flordaguard, and Okinawa Roxo rootstocks for N absorption, transport, and use efficiencies, and concluded that the first two presented better results for transport and use efficiency. As observed for N, in the present study, the absorption of other nutrients, such as sulfur, Fe, and Mn, also did not differ significantly among rootstocks (Figure 5).

For all rootstocks, foliar P concentrations were within the sufficiency range for peach. Barrier and Tsukuba-2 showed a high P absorption, which, however, did not differ significantly from that of the other eight rootstocks with the highest P absorption rates (Figure 5). Considering only the nine rootstocks with the lowest P absorption rates, including own-rooted 'BRS Kampai' and 'Okinawa' (Figure 5), the concentration of P remained within the sufficiency range (Johnson, 2008; Freire & Magnani, 2014). Compared with other studies, these results suggest that the used scion also affects P absorption by the peach tree. As pointed out by Mayer et al. (2015), 'Maciel' budded on Flordaguard and 'Okinawa' (0.31 and 0.30% dry matter, respectively) showed a high P concentration in a three-year-old orchard. Despite the statistical differences for P absorption observed for the Sunraycer nectarine own-rooted and budded on 13 rootstocks, all concentrations of this nutrient were

within the sufficiency range, being 1.57 g kg⁻¹ for Santa Rosa and 2.50 g kg⁻¹ for 'Okinawa' (Jimenes et al., 2018). Menegatti et al. (2021) found no differences among the evaluated rootstocks regarding P absorption and transport efficiencies, but reported significant differences in the use efficiency of the nutrient for 'Capdeboscq' and Flordaguard.

Nemared showed the highest K absorption value, which does not differ significantly from that of another five genotypes according to Tukey's test (Figure 5). The K concentration of these six genotypes (Figure 5) was above the sufficiency range (Johnson, 2008; Freire & Magnani, 2014), whereas that of the other rootstocks was within it. When budding 'Maciel' on the Flordaguard and 'Okinawa' rootstocks, Mayer et al. (2015) also found a high concentration of K (2.40 and 2.44% dry matter, respectively). For the Sunraycer nectarine, own-rooted and budded on 13 rootstocks, Jimenes et al. (2018) obtained a K concentration ranging from below to above the sufficiency range, i.e., from 15.87 g kg⁻¹ for Santa Rosa to 33.90 g kg⁻¹ for Flordaguard. As verified for P, rootstocks showed no statistical differences for K absorption and transport efficiencies. In another study, K use was more efficient for 'Capdeboscq' and Flordaguard than for Okinawa Roxo (Menegatti et al., 2021).

Regarding calcium, Genovesa and Santa Rosa presented the highest concentration of the nutrient, which differed significantly from that of the other rootstocks (Figure 5); however, only the concentration observed for Santa Rosa remained within the sufficiency range. The other 19 genotypes showed deficiency for this nutrient, with values 1 to 25% below the required (Freire & Magnani, 2014). The Sunraycer nectarine own-rooted and budded on 13 rootstocks also presented a Ca concentration below and within the sufficiency range – 10.35 g kg⁻¹ for Santa Rosa and 20.40 g kg⁻¹ for Barrier, respectively (Jimenes et al., 2018).

For magnesium, most of the rootstocks presented a concentration within the sufficiency range (Figure 5). Only the group formed by Clone-15, Ishtara, I-67-52-4, and Nemared had a Mg content 1 to 25% lower than the ideal (Johnson, 2008; Freire & Magnani, 2014). Barrier was the best rootstock in terms of Mg absorption, a result which is in line with that of previous studies. Mestre et al. (2015), for example, observed a high Mg concentration (0.47% dry matter)

Rootstocks	N ^{ns} (g kg ⁻¹)	P (g kg ⁻¹)	K (g kg ⁻¹)	Ca (g kg ⁻¹)	Mg (g kg ⁻¹)	S ^{ns} (g kg ⁻¹)	Fe ^{ns} (mg kg ⁻¹)	Mn ^{ns} (mg kg ⁻¹)	Cu (mg kg ⁻¹)	Zn (mg kg ⁻¹)	B (mg kg ⁻¹)
Santa Rosa	34.94	2.1 b	29.84 bc	18.24 a	3.24 ab	1.56	70.72	54.22	8.91 ab	30.85 a	46.2 a
Genovese	37.42	2.18 ab	27.22 c	16.81 a	3.07 b	1.69	72.96	50.82	8.61 ab	31.4 a	34.79 bc
'Rigitano'	35.74	1.98 b	26.48 c	15.68 ab	3.12 ab	1.72	83.47	55.5	7.83 bc	37.54 ab	27.12 d
Barrier	36.56	2.46 a	28.42 c	15.16 ab	3.84 a	1.68	71.27	36.12	6.99 bc	27.81 a	35.11 bc
Tsukuba-3	36.82	2.22 ab	29.7 bc	14.74 ab	3.06 b	1.66	98.36	31.18	7.33 bc	20.54 ab	33.27 bc
Flordaguard	35.36	2.34 ab	32.98 ab	13.86 b	3.12 b	1.66	76.28	40.51	8.52 ab	22.24 ab	37.1 ab
'Okirava'	36.58	2.1 b	30.86 ab	14.18 ab	3.22 ab	1.7	78.46	40.28	7.75 bc	19.43 ab	22.32 ab
Tsukuba-1	37.84	2.15 b	29.29 bc	14.13 ab	3.12 ab	1.77	70.76	29.38	7.3 bc	23.63 a	31.97 bcd
Tsukuba-2	37.22	2.38 a	33.3 ab	15.68 ab	3.02 b	1.68	71.92	36.42	8.27 b	22.86 ab	34.57 bc
'Capdeboscq'	37	2.22 ab	29.28 bc	15.24 ab	3.24 ab	1.74	72.36	38.99	7.96 b	20.13 ab	31.41 bcd
Cadaman	35.96	2.3 ab	29.58 bc	14.4 ab	3.1 b	1.68	71.88	30.67	8.24 b	24.83 a	31.71 bcd
GxN9	34.22	2.2 ab	30.56 ab	15.74 ab	3.3 ab	1.56	68.33	50.32	9.89 a	21.21 ab	29.87 cd
Ishtara	35.08	2.1 b	28.84 c	14.1 b	2.9 b	1.66	63.06	35.39	8.81 ab	27.18 a	32.33 bc
Clone-15	34.06	2 b	29.44 bc	16.72 ab	2.8 b	1.44	59.46	33.58	8.71 ab	20.87 ab	28.46 d
Own-rooted	35.25	2.17 b	29.85 bc	15.64 ab	3.48 ab	1.66	72.06	28.82	6.91 bc	20.27 ab	33.04 bc
México Fila-1	35.66	2.04 b	28.86 c	14.18 ab	3.3 ab	1.56	66	24.77	5.92 bc	17.5 b	32.48 bc
Nemared	35.51	2.26 ab	37.01 a	16.24 ab	2.77 b	1.65	72.76	24.08	5.4 bc	19.44 ab	34.18 bc
I-67-52-4	36.6	2.22 ab	35.3 ab	14.4 ab	2.94 b	1.62	69.04	28.7	3.29 c	20.64 ab	35.34 bc

Figure 5. Average values of nutrient contents in the leaves of the 'BRS Kampai' peach (*Prunus persica*) scion budded on 19 rootstocks (*Prunus* spp.) and own-rooted in the municipality of Jarinu, in the state of São Paulo, Brazil, in 2015. The adequate nutrient ratio intervals were established according to Johnson (2008) and Freire & Magnani (2014). Means followed by equal letters, in the columns, do not differ by Tukey's test, at 5% probability. ^{ns}Non-significant. Means for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and B, respectively: 36.00, 2.20, 30.49, 15.20, 3.15, 1.64, 72.33, 33.95, 7.63, 22.99, and 33.83. Coefficient of variation (%) for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn, and B, respectively: 6.72, 8.54, 9.53, 11.09, 9.41, 9.58, 23.50, 47.63, 20.13, 18.59, and 12.47.

for the 'Big Top' nectarine budded on Barrier, in a 12-year-old orchard. Jimenes et al. (2018), evaluating the Sunraycer nectarine own-rooted and budded on 13 rootstocks, obtained a Mg concentration within the sufficiency range – 4.98 g kg⁻¹ for México Fila 1 and 3.00 g kg⁻¹ for Ishtara.

Nineteen genotypes presented a copper concentration within the sufficiency range, and only I-67-52-4 showed a severe deficiency of this nutrient (Figure 5). GxN9, which presented the highest Cu absorption, formed a group with no statistical difference compared with Santa Rosa, Genovesa, Flordaguard, Ishtara, and Clone-15. For the Sunraycer nectarine, Jimenes et al. (2018) found that only the own-rooted scion showed a deficient absorption of 4.80 mg kg⁻¹ Cu.

Seventeen rootstocks presented a zinc concentration within the sufficiency range for peach (Figure 5). Only México Fila-1, Nemared, and 'Okinawa' showed deficiency of this nutrient. The 'Okinawa' rootstock also presented a low Zn absorption when budded with 'Maciel', with values of 8.5–15.8 mg kg⁻¹, below the sufficiency range (Mayer et al., 2015). Jimenes et al. (2018) also obtained a Zn concentration below the sufficiency range for the Sunraycer nectarine own-rooted and budded on 13 rootstocks, with values of 8.83 mg kg⁻¹ for own-rooted Sunraycer and 18.50 mg kg⁻¹ for Flordaguard.

Although Santa Rosa showed the highest absorption of boron, the concentration of this nutrient was within the sufficiency range for all other rootstocks (Figure 5). Likewise, for the Sunraycer nectarine own-rooted and budded on 13 rootstocks, all B concentrations remained within the sufficiency range, with values of 21.60 mg kg⁻¹ for GxN9 and 55.33 mg kg⁻¹ for 'Okinawa' (Jimenes et al., 2018).

All rootstocks did not differ significantly for S, Fe, and Mn absorption according to Tukey's test (Figure 5), showing a S absorption within the sufficiency range. For the Sunraycer nectarine own-rooted and budded on 13 rootstocks, Jimenes et al. (2018) found a S concentration below (1.25 g kg⁻¹ for Nemared) and within the sufficiency range (1.83 g kg⁻¹ for Ishtara).

For Fe and Mn, a severe deficiency was observed, with values 1 to 50% and 1 to 25% lower than the sufficiency range, respectively (Johnson, 2008; Freire & Magnani, 2014). For instance, 'Capdeboscq', Flordaguard, and 'Okinawa' had 72.36, 76.28, and

78.46 mg kg⁻¹ Fe, respectively. Mayer et al. (2015) also obtained a low F concentration of 83.8 to 103.0 mg kg⁻¹, 80.8 to 98.3 mg kg⁻¹, and 78.8 to 104.3 mg kg⁻¹ for 'Capdeboscq', Flordaguard, and 'Okinawa' combined with the 'Maciel' scion. For the Sunraycer nectarine own-rooted and budded on 13 rootstocks, the Fe concentration was below (79.25 mg kg⁻¹ for Nemared) and within the sufficiency range (150.88 g kg⁻¹ for Ishtara) (Jimenes et al., 2018). For Mn concentration, the same authors also obtained values below (36.80 mg kg⁻¹ for México Fila 1) and within the sufficiency range (92.03 mg kg⁻¹ for Santa Rosa).

The capability of the rootstocks to absorb nutrients was classified into seven distinct groups by the cluster analyses (Figure 4 G). Santa Rosa (cluster 2) formed an isolated group, showing the highest capability, whereas I-67-52-4 and Nemared formed cluster 7, with the lowest nutrient contents (Figure 4 G).

The multivariate analysis indicated Marianna 2624 and Mirabolano 29C as the rootstocks with the lowest performance in both experimental sites (Figure 6). In Jarinu, the subgroup presenting the best performance was formed by Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, México Fila-1, Nemared, 'Okinawa', Tsukuba-2, Tsukuba-3, and own-rooted 'BRS Kampai' (Figure 6 A). In Jundiá, no statistical difference was observed between the subgroups (Figure 6 B).

With regards to all agronomic features evaluated in the present study, the rootstocks that showed the best performance in Jarinu were: Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, 'Okinawa', México Fila-1, Nemared, Tsukuba-2, and Tsukuba-3, as well as own-rooted 'BRS Kampai' (Figure 6 A). In Jundiá, the rootstocks that presented the best results were: Barrier, Cadaman, 'Capdeboscq', Clone-15, Flordaguard, Genovesa, GxN9, Ishtara, I-67-52-4, 'Okinawa', México Fila-1, Nemared, 'Rigitano', Santa Rosa, Tsukuba-1, Tsukuba-2, and Tsukuba-3, besides own-rooted 'BRS Rubimel' (Figure 6 B). Therefore, the performance of own-rooted scion cultivars was similar to that of the traditional rootstocks.

The obtained results are indicative that the BRS Kampai and BRS Rubimel scion cultivars may be an interesting alternative for sites with suitable biotic and abiotic soil conditions. According to Souza et al. (2017), the high vegetative growth observed in own-

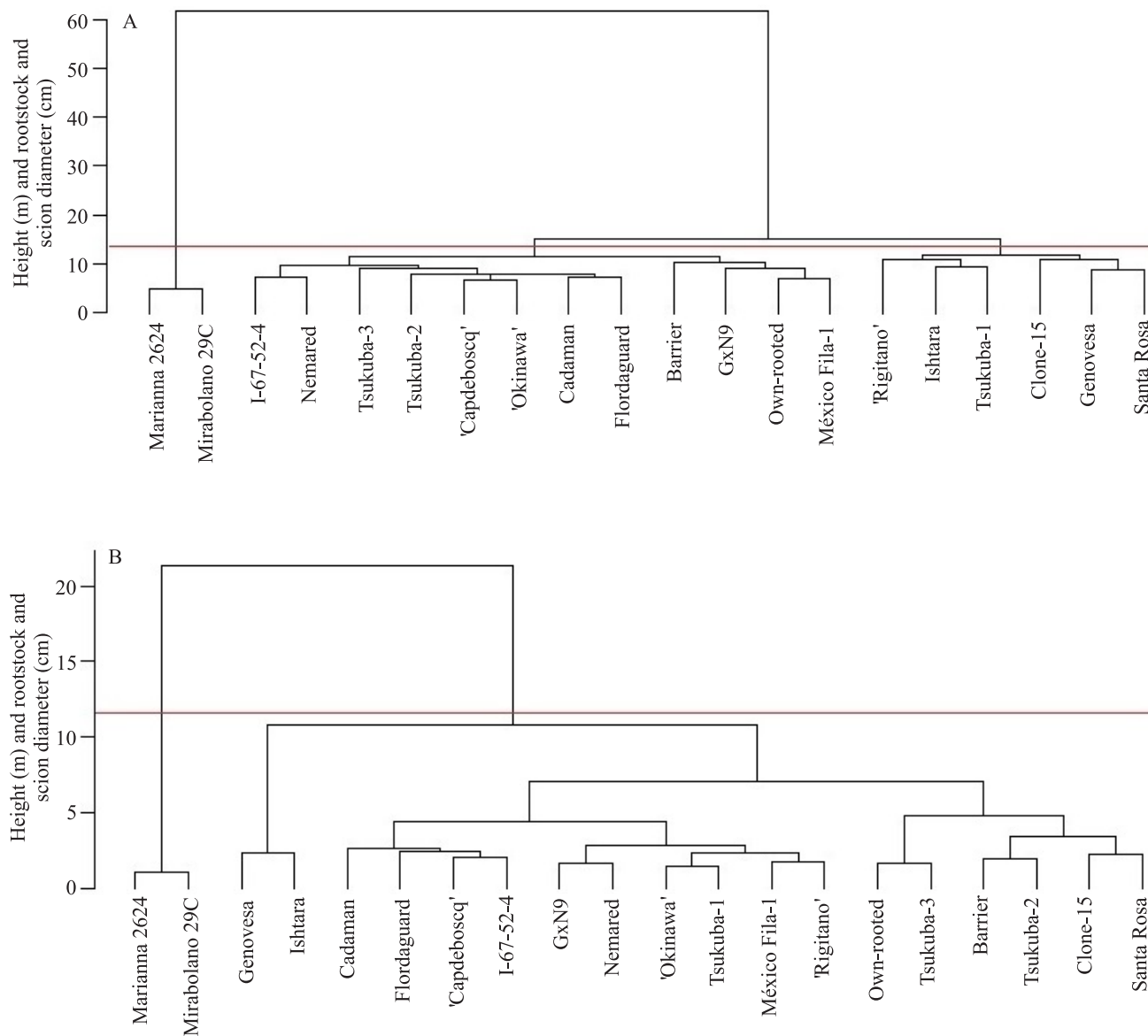


Figure 6. Similarity matrix (Euclidian distance) between the 'BRS Kampai' (A) and 'BRS Rubimel' (B) peach (*Prunus persica*) scions budded on 19 rootstocks and own-rooted in the municipalities of Jarinu and Jundiaí, in the state of São Paulo, Brazil, respectively. The similarity matrix considered the following parameters: height (m), rootstock diameter (cm), and scion diameter (cm) from 2015 to 2018; and foliar nutrient concentration in 2015 only for 'BRS Kampai'. The grouping method (cluster analyses) was based on the K-means algorithm (Kassambara & Mundt, 2019).

rooted scions is due to the absence of incompatibility, which can occur in trees propagated by the grafting technique. Finally, the cluster analysis identified 11 genotypes in Jarinu (Figure 6 A) and 17 in Jundiaí (Figure 6 B) with a performance similar to that observed for 'Okinawa', which has been traditionally used as a rootstock in Southeastern Brazil.

Conclusions

1. In the municipality of Jarinu, in the state of São Paulo, Brazil, the Barrier, Cadaman, 'Capdeboscq', Flordaguard, GxN9, I-67-52-4, 'Okinawa', México Fila-1, Nemared, Tsukuba-2, and Tsukuba-3 peach (*Prunus* spp.) genotypes, as well as own-rooted 'BRS

Kampai', present the best performance for vegetative growth and foliar nutrient concentration.

2. In the municipality of Jundiaí, in the state of São Paulo, all evaluated genotypes, except Marianna 2624 and Mirabolano 29C, show equivalent vegetative growth.

3. The own-rooted 'BRS Kampai' and 'BRS Rubimel' peach (*Prunus persica*) trees present a vegetative growth similar to that of 'Okinawa', a traditional rootstock used in both evaluated sites, indicating that they can be an interesting alternative for peach production in Southeastern Brazil.

4. The 'BRS Kampai' and 'BRS Rubimel' peach scions budded on Marianna 2624 and Mirabolano 29C present graft incompatibility.

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