Simultaneous selection of peach rootstocks by mixed models

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Abstract

The term adaptability refers to the ability of a genotype to respond favorably to environmental spur, while stability is the predictability of genotypic behavior. Therefore, the objective was to select *Prunus* rootstock cultivars with greater adaptability and genotypic stability for subtropical environmental conditions using the HMPRVG method. The experiment was conducted in Chapecó, Santa Catarina State, Brazil. Twenty-one rootstock genotypes were evaluated under the 'BRS-Libra' canopy cultivar and one genotype from self-rooted seedlings. The 22 genotypes were evaluated for canopy volume, yield, fruit diameter and fruit set in the growing seasons 2015/16, 2016/17, 2017/18 and 2018/19. Adaptability and stability were measured by means of the harmonic mean relative performance of genotypic values (HMRPGV). In addition, genetic parameters for heritability and ratio test were measured. According to the results, the self-rooted, 'De Guia', 'I-67-52-4', 'Mexico Row 1' and 'Rosaflor' genotypes coincided most frequently in the ranking of the three most adaptable and stable genotypes. On the other hand, the '*P. mandshurica*', 'Rigitano' and 'Santa Rosa' genotypes corresponded to the lowest adaptability and stability values, thus constituting low quality genetic materials for cultivation. It can be concluded that under the tested conditions the HMPRVG method is efficient for the *Prunus* rootstock selection cultivars and the 'BRS-Libra' grafted on 'Mexico Row 1', 'Rosaflor' rootstocks and trees from self-rooted seedlings have greater adaptability and phenotypic stability under the subtropical cultivation conditions.

Keywords: adaptability, stability, *Prunus persica*, harmonic mean

Introduction

The longevity, economic and environmental viability of a peach orchard (*Prunus persica* L.) are directly correlated with the rootstock that is used, as well as the grafting affinity between the cultivar and rootstock (Reig et al., 2019). The recommendation of superior peach genotypes should meet the minimum criteria that allow inferring about the genotypic potential in the cultivation environment (Souza et al., 2017). In this context, the preference for rootstock cultivars with superior characteristics that result in better fruit quality and greater adaptability and production stability is of great interest.

The term adaptability refers to the ability of a genotype to respond supportively to environmental stimulus, while stability is the predictability of genotypic behavior (Mendes & Ramalho, 2018). Several methods have been proposed to evaluate phenotypic adaptability and stability such as AMMI (Gauch, 1992) and GGE biplot (Yan & Rajcan, 2002), however, for the breeder, the major interest is in adaptability and genotypic stability. Thus, the Harmonic Mean Relative Performance of Genotypic values (HMRPGV) method has been expanded in recent years (Rosado et al., 2019; Olivoto et al., 2019; Sousa et al., 2019).

The HMRPGV method is based on mixed models and simultaneously provides, in a single measure on the evaluated character scale, the adaptability, stability and performance of the characteristic (Viana et al., 2010). The use of methods that convert adaptability and stability measures together with productivity into a single value is preferred as it allows simple interpretation, specifically in studies with high genotype numbers (Cruz et al., 2014).

Currently, in Brazil, peach tree breeding has focused mainly on the production of new scion cultivars (Donadio et al., 2019). Having in mind the importance

and influence of rootstock on the longevity, yield and orchard fruits standardization, studies that seek to evaluate the effect of available rootstock cultivars are essential. In addition, studies in order to evaluate the individual performance of existent rootstock cultivars are of fundamental importance to support the development of new cultivars with superior characteristics to those already available. The main rootstocks used in the production of peach trees in Brazil are 'Okinawa' and 'Capdebosq'. But they usually confer a high vigor to the trees, which prevents the planting in high density (Donadio et al., 2019).

Several studies have applied the HMRPGV methodology in annual crops, such as corn (Mendes et al., 2012), rice (Colombari et al., 2013), beans (Santos et al., 2019) and soybean (Freiria et al., 2018). However, studies focusing on perennial crops such as peach trees, more specifically to evaluate the rootstock, are unpublished and need more development. Therefore, the aim was to select *Prunus* rootstock cultivars with greater adaptability and genotypic stability for subtropical environmental conditions using the HMPRVG method.

Material and Methods
Experimental conditions
The experiment was conducted in Chapecó, Santa Catarina, Brazil (27 ° 07 'S, longitude 52 ° 42' W, 605 m). The local climate is classified as subtropical humid (Cfa - according to Köppen classification). The local soil is clayey and classified as Latossolo Vermelho Distroférrico (Oxisol), with a basic pH, i.e., requiring no liming. The evaluations were carried out in the growing seasons 2015/16, 2016/17, 2017/18 and 2018/19. At the beginning of the evaluations, the trees were three years old. The management of diseases, insects and weeds, pruning and fertilization were carried out according to recommendations for peach (Raseira et al., 2014). No irrigation system and dormancy- breaking chemicals were adopted. The climatic data for the study period are presented in Figure 1.
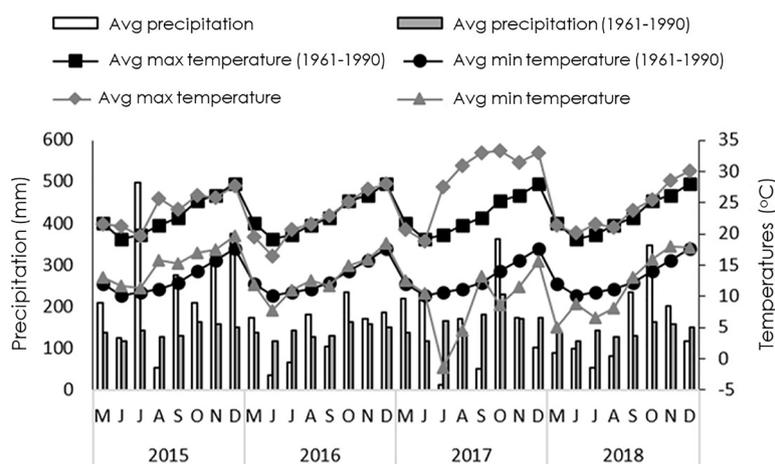
Figure 1. Climate data from May to December from 2015 to 2018 in Chapecó, state of Santa Catarina, Brazil. Source: Chapecó Climatologic station, EPAGRI-CIRAM.

Genotype rootstocks
A total of 21 clonal rootstocks grafted with the 'BRS-Libra' canopy cultivar were studied: 'Barrier' (2), 'Cadaman' (3), 'Capdeboscq' (4), 'Clone' 15 (5), 'De Guia' (6), 'Flordaguard' (7), 'G × N9' (8), 'GF 677' (9), 'I-67-52-4' (10), 'Ishtara' (11), 'Mexico Row 1' (12), 'Nemared' (13), 'Okinawa' (14)), '*Prunus mandshurica*' (15), 'Rigitano' (16), 'Rosaflor' (17), 'Santa Rosa' (18), 'Late 01' (19), 'Tsukuba-1' (20), 'Tsukuba-2' (21) and 'Tsukuba-3' (22) . As a control, we used self-rooted seedlings (without rootstock) of cultivar 'BRS-Libra', totalizing 22 different genotypes evaluated. In the current study, treatment without rootstock, that is, from self-rooted seedlings is called Self-rooted (1).

Experimental design
The experiment was conducted in randomized block design with four replications. Each replication was consisted by one plant. The experimental plot was implanted in a spacing of 5m × 2m conducted in "Y" form (epsilon), as proposed by Grossman & Dejong (1998). No irrigation system was adopted.

Evaluated Characters
The influence of different genotypes on canopy volume, expressed in m³, was evaluated by collecting data regarding the width, thickness and height of the canopy with a tape measure assistance. Two mixed branches located in the middle part of the plant, one in each main branch, were selected during the flowering

period. In each secondary branch, the number of flowers and, subsequently, fruit set before thinning were counted to verify the proportion between flowers and fruit set, expressed in %. Genotypes were also evaluated for yield per tree (kg tree^{-1}), fruit diameter (mm) with the aid of a digital caliper and soluble solids (°Brix) using bench refractometer.

Statistical analysis

Repeatability and interaction model genotype x measurement

Matrix mode

$$(1) \quad y = Xm + Zg + Wp + Ti + e,$$

Where y is the phenotype vector, m is the fixed effects vector of the measurement-repeat combinations (the vector m contemplates all measurements at all repetitions and adjusts simultaneously for the effects of repetitions, measurement, and repetition x measurement interaction) summed to the overall average; g is the random vector of genotypic effects; p is the random vector of the permanent environment effects (plots), i is the random vector of the effects of the genotype x measurement interaction, and e is the random vector of residuals. Capital letters represent the incidence matrices for these purposes, and are, respectively, the variances of genotypic effects, permanent environment, genotype x measurement and residual interaction.

Algebraic model

$$y_{ijk} = u + r_j + m_k + rm_{jk} + g_i + gr_{ij} + gm_{ik} + e_{ijk},$$

Wich:

u is the effect of the average (fixed);

r_j is the effect of repetition j (fixed);

m_k is the effect of measure k (fixed);

rm_{jk} is the effect of the interaction repetition x measurement (fixed);

g_i is the genotype effect i (random) $g_i N(0, \sigma_g^2)$

gr_{ij} is the permanent environment effect (random) $gr_{ij} N(0, \sigma_p^2)$

gm_{ik} is the effect of genotype x measurement interaction (random), $gm_{ik} N(0, \sigma_{gm}^2)$

e_{ijk} is the residue (random), $e_{ijk} N(0, \sigma_e^2)$

Genetic parameters

Inheritance of individual plots in the broad sense (h_g^2)

$$(2) \quad h_g^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_p^2 + \sigma_{gm}^2 + \sigma_e^2}$$

Average heritability of genotypes in the broad sense (h_{gm}^2)

$$(3) \quad h_{gm}^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_p^2}{j} + \frac{\sigma_{gm}^2}{k} + \frac{\sigma_e^2}{jk}}$$

Genotypic correlation through measurements (r_{gmed})

$$(4) \quad r_{gmed} = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_i^2}$$

Harmonic Mean of Relative Performance of Genotypic Values (HMRPGV)

A method for classifying genotypes considering yield and stability simultaneously is the harmonic mean of genotypic values (MHVG), and considering yield and adaptability simultaneously is the relative performance of genotypic values (PRGV) on crops or measurements. In order to contemplate productivity, adaptability and stability, the harmonic mean of relative performance of genotypic values - HMRPGV (Resende, 2007) can be used.

The harmonic means of genotypic values ($MHVG_i$) of each genotype were obtained by:

$$(5) \quad MHVG_i = \frac{n}{\sum_{I,K=1}^{i,k} \frac{1}{VG_{ik}}},$$

where: n is the number of harvests (measures or harvests - quarter in the case); *i* is the number of genotypes (22 genotypes); VG_{ik} is the genotypic value of genotype i in crop (measure) *k*, that is, are the capitalized genotypic values for the genotype x measurement interaction.

The relative performance of genotypic values ($PRVG_i$) of each genotype was obtained by:

$$(6) \quad PRVG_i = \frac{1}{n}\sum_{K=1}^{k}\frac{GV_{ik}}{m_k},$$

where: m_k is the phenotypic mean of each measurement (harvest).

Simultaneous selection for productivity, stability and adaptability is given by the harmonic mean of the relative performance of genotypic values ($MHPRVG_i$) obtained by:

$$(7) \quad MHPRVG_i = \frac{n}{\sum_{K=1}^{k} \frac{1}{PRVG_{ik}}},$$

Software and statistical tests

The random effects of the models were tested using the likelihood ratio test (LRT) considering the chi-square statistic with a degree of freedom and 5% of probability. The Selegen software (Resende, 2016) was used in all statistical procedures.
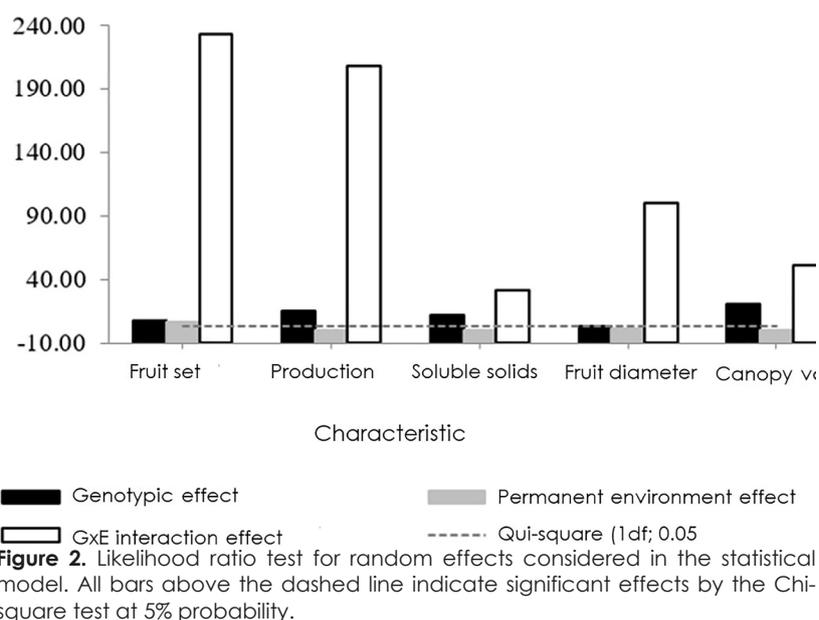
Results and Discussion
Likelihood Ratio Test

Through the likelihood ratio test (Figure 2), only the fruit diameter character showed no significant genotypic effect (p> 0.05). Therefore, for the other characters evaluated there is significant effect of genotypes (p <0.05), this indicates that there is genetic variability and that it is possible to select superior genotypes. For permanent environment effects, significance was observed (p <0.05) only for fruit set. This is because, this trait is largely affected by internal and external environmental factors such as competition for nutrients and climate conditions (Morimoto et al., 2019). Regarding the effects

of the interaction Genotypes × Environments (G × E), significance was observed for all analyzed variables (Figure 2).

GxE interaction can be statistically explained as genotype classification in different orders in different environments, or genetically as differences in gene expression under different environmental conditions (Lynch & Walsh 1998; White et al., 2007). One of the main ways to overcome the adverse effects of GxE interaction is to identify cultivars with greater genotypic stability and adaptability (Resende, 2007) and across selection strategy that capitalize on GxE interaction (Rocha et al., 2019).

Figure 2. Likelihood ratio test for random effects considered in the statistical model. All bars above the dashed line indicate significant effects by the Chi-square test at 5% probability.

Heritability of individual plots, average genotype heritability, genotypic correlation across measurements and average performance across measurements

The heritability coefficient of individual plots in the broad sense (Table 1) indicates the ratio of genotypic variance to phenotypic variance of individual plots. Based on this, only yield and canopy volume showed medium magnitude heritability. For the other characters (soluble solids, diameter and fruit set), heritability of low magnitude (<30%) was observed indicating that the variance due to the environment has a strong influence.

Soluble solids content, for example, is a character strongly influenced by the environment, associated with temperature variations, rainfall distribution and fruit location in the canopy. Fruits located in shaded portions of the canopy will receive less solar radiation. Consequently, there will be interference in the synthesis of photoassimilates reducing the soluble solids content of the fruit (Alves et al., 2018). Thus, the selection of

genotypes based only on the soluble solids content of their fruits is equivalent to a less efficient selection.

For the genotypic correlation through the measurements (Table 1), it was observed the lowest correlation for the fruit diameter character and the largest for canopy volume. The correlation between the measurements represents the proportion of the genotypic variation present between the years of evaluation, how much the heritable fraction represents in the phenotypic variation of the character in question. Thus, fruit diameter has a high phenotypic variation, being of greater proportion of non-heritable scope.

Regarding the phenotypic averages (Table 1), 2017 showed a considerable reduction in fruit set and yield compared to the previous year (2016). This was due to the incidence of severe frost during the full bloom period (Figure 1). As consequence of the low fruit set, there was a reduction in production equivalent to approximately 75% compared to the average of 2016

and 2018. Such environmental adversity is a major factor for the occurrence of GxE interactions and therefore lead to reductions in correlations between measurements. However, the overall yield average observed in the present study resembles that found in southern Brazil (Barreto et al., 2017), northern Tunisia (Yahmed et al., 2016) and northern and southern Italy (Scalisi et al., 2018).

Table 1. Estimation of genetic parameters. Heritability of individual plots in the broad sense (h_g^2), heritability in the broad sense of genotype mean (h_{gm}^2), genotypic correlation through measurements (r_{gmed}), phenotypic mean of each measurement, and overall phenotypic mean through measurements.

Genetic parameters	Fruit set (%)	Production (kg tree⁻¹)	Soluble solids (°Brix)	Fruit diameter (mm)	Canopy volume
h_g^2	0.2502	0.3396	0.2146	0.1214	0.3226
h_{gm}^2	0.6132	0.7188	0.6889	0.4480	0.7761
r_{gmed}	0.3064	0.4128	0.4695	0.2026	0.5463
2015 mean	14.18	2.02	8.68	48.91	1.86
2016 mean	20.60	15.54	9.47	56.73	7.12
2017 mean	3.92	4.21	10.28	55.94	12.04
2018 mean	37.45	17.26	8.14	57.59	19.04
Overall average	19.04	9.76	9.14	54.79	10.01

Harmonic mean of relative performance of genotypic values

Selecting genotypes only at the predicted average genotypic value for yield does not guarantee that they will perform better when grown under other conditions (Cruz et al., 2014). Moreover, the main complicating factor in recommending cultivars under this situation is the GxE interaction, as it requires the breeders to adopt different methods to mitigate this interaction and facilitate the selection of superior genotypes (Tiwari, 2019). Therefore, the adaptability and stability analysis of the predicted genotypic values was preceded by the harmonic mean method of relative performance of the genotypic values (HMRPGV).

According to this methodology, 'Tsukuba-3', 'De Guia' and 'Barrier' genotypes formed the group with the highest HMVG values for fruit set (Table 2), indicating that they present the lowest variation in genotypic values. For the variables production and soluble solids, the self-rooted genotypes, 'Mexico Row 1' and 'De Guia' coincided 100% in the ordering of the three best genotypes. The variables fruit diameter and canopy volume refer, respectively, to fruit quality and plant vegetative vigor. 'BRS-Libra' grafted on 'Barrier', 'Clone 15' and 'Santa Rosa' genotypes presented greater stability for fruit diameter while 'De Guia', 'Flordaguard' and 'I-67-52-4' genotypes promoted more stable for canopy volume.

It is noteworthy that, by this method, the lower the standard deviation of genotypic behavior between years of cultivation, the higher the genotypic values of the harmonic mean (Resende, 2007). Therefore, selection by the highest HMVG values implies the simultaneous selection of stability, or even invariance of genotypic values.

As for the genotypes of less stability, '*Prunus mandshurica*' and 'Rigitano' stand out in relation to the others. More specifically, the '*P. mandshurica*' rootstock coincided 100% in the ranking of the three worst genotypes for all evaluated characters. This reveals instability of quality and fruit production as well as vegetative growth of 'BRS-Libra' when grafted on '*P. mandshurica*'. Similarly, the 'Rigitano' genotype was among the three worst genotypes, however, with relatively minor coincidence (60%).

The PRVG values for the self-rooted genotype show that it contributed to the increase of the average of each evaluation year in greater proportion, under the conditions in which it was evaluated. This genotype stands out as of great genotypic adaptability, since it has the highest contribution values to increase the average of each growing season. For traits fruit set, yield and soluble solids, the genotype presented an average 1.37, 1.60 and 1.17 times the average of the year of cultivation in which it was evaluated. However, trees from self-rooted seedlings responded to a smaller degree for fruit diameter and canopy size, since their PRVG were lower.

The '*P. mandshurica*' genotype presented the lowest adaptation, since it coincided 80% in the ranking of the three worst genotypes regarding the PRVG values. In this sense, although there is a worldwide trend for the use of interspecific rootstock × scion combinations observed in both peach (Zarrouk et al., 2006; Neves et al., 2017) and in pear (Melo et al., 2017), in order to introduce useful characteristics such as vigor control, pest resistance and edaphoclimatic adaptation, such a combination does not always result in success.

An example is that presented in the present work, which revealed that the combination *P. mandshurica* ×

P. persica resulted in graft incompatibility. According to Darikova et al. (2011) incompatibility in interspecies combinations occurs mainly due to anatomical, morphological and physiological differences between grafting components.

Table 2. Ranking of genotypes considering productivity and stability by the MHVG method, productivity and adaptability by the PRVG method and productivity, stability and adaptability by the HMRPGV method. Values in parentheses are rootstock genotypes coded according to the following relationship: 'Self-rooted' (1), 'Barrier' (2), 'Cadaman' (3), 'Capdeboscq' (4), 'Clone 15' (5), 'De Guia' (6), 'Flordaguard' (7), 'G × N9' (8), 'GF 677' (9), 'I-67-52-4' (10), 'Ishtara' (11), 'Mexico Row 1' (12), 'Nemared' (13), 'Okinawa' (14), *Prunus mandshurica*' (15), 'Rigitano' (16), 'Rosaflor' (17), 'Santa Rosa' (18), 'Late 01' (19), 'Tsukuba-1' (20), 'Tsukuba-2' (21) and 'Tsukuba-3' (22).

Order	Fruit set			Production			Soluble solids		
	MHVG	PRVG	HMRPGV	MHVG	PRVG	HMRPGV	MHVG	PRVG	HMRPGV
1	16.09 (22)	1.40 (22)	1.35 (1)	7.37 (1)	1.60 (1)	1.59 (1)	10.65 (1)	1.17 (1)	1.17 (1)
2	15.18 (6)	1.37 (1)	1.30 (10)	6.76 (12)	1.40 (17)	1.39 (17)	9.86 (12)	1.09 (17)	1.09 (17)
3	14.77 (2)	1.33 (9)	1.24 (6)	6.38 (6)	1.33 (12)	1.32 (12)	9.78 (6)	1.08 (12)	1.07 (12)
4	13.06 (4)	1.31 (6)	1.24 (9)	6.37 (14)	1.32 (6)	1.30 (6)	9.51 (14)	1.05 (6)	1.05 (6)
5	13.02 (10)	1.30 (10)	1.22 (2)	6.27 (10)	1.28 (10)	1.26 (10)	9.45 (10)	1.04 (10)	1.04 (10)
6	12.06 (1)	1.28 (2)	1.18 (11)	6.06 (17)	1.20 (14)	1.14 (14)	9.31 (17)	1.03 (14)	1.03 (14)
7	10.96 (11)	1.19 (11)	1.11 (22)	5.9 (2)	1.16 (2)	1.09 (2)	9.30 (2)	1.03 (2)	1.03 (2)
8	10.49 (9)	1.16 (12)	1.10 (8)	5.40 (4)	1.11 (13)	1.09 (13)	9.22 (4)	1.02 (13)	1.02 (13)
9	10.01 (14)	1.14 (8)	1.00 (12)	5.21 (13)	1.06 (3)	1.03 (3)	9.10 (13)	1.01 (3)	1.00 (3)
10	9.86 (3)	1.09 (4)	0.95 (4)	5.01 (3)	1.06 (7)	1.01 (22)	9.09 (3)	1.00 (7)	1.00 (22)
11	9.75 (8)	0.98 (14)	0.95 (17)	4.33 (22)	1.05 (4)	1.00 (21)	9.09 (22)	1.00 (4)	1.00 (21)
12	9.56 (20)	0.98 (17)	0.94 (3)	4.21 (20)	1.05 (21)	0.98 (4)	9.03 (20)	1.00 (21)	1.00 (4)
13	8.74 (19)	0.95 (3)	0.87 (14)	4.2 (11)	1.03 (8)	0.98 (7)	8.89 (11)	0.98 (8)	0.98 (7)
14	8.22 (17)	0.88 (20)	0.87 (20)	4.08 (21)	1.02 (22)	0.93 (20)	8.84 (21)	0.98 (22)	0.97 (20)
15	7.66 (18)	0.86 (19)	0.86 (19)	4.05 (7)	0.94 (9)	0.92 (8)	8.82 (7)	0.97 (9)	0.97 (8)
16	7.13 (12)	0.78 (13)	0.67 (13)	3.99 (19)	0.93 (20)	0.90 (19)	8.79 (19)	0.97 (20)	0.97 (19)
17	4.99 (21)	0.74 (7)	0.63 (21)	3.67 (9)	0.91 (19)	0.86 (9)	8.77 (9)	0.97 (19)	0.97 (9)
18	4.98 (13)	0.74 (18)	0.58 (7)	3.44 (8)	0.86 (5)	0.80 (5)	8.59 (8)	0.95 (5)	0.95 (5)
19	4.10 (7)	0.72 (16)	0.58 (16)	3.26 (5)	0.78 (11)	0.64 (11)	8.41 (5)	0.93 (11)	0.93 (11)
20	4.08 (16)	0.7 (21)	0.56 (18)	1.81 (16)	0.52 (16)	0.48 (16)	8.40 (16)	0.93 (16)	0.93 (16)
21	3.13 (15)	0.57 (5)	0.45 (15)	0.62 (18)	0.23 (18)	0.19 (18)	8.39 (18)	0.92 (18)	0.92 (18)
22	0.52 (5)	0.54 (15)	0.12 (5)	-0.06 (15)	0.15 (15)	-0.03 (15)	7.94 (15)	0.88 (15)	0.87 (15)

Continuation…

Order	Fruit diameter			Trunk diameter		
	MHVG	PRVG	HMRPGV	MHVG	PRVG	HMRPGV
1	57.93 (2)	1.06 (2)	1.06 (2)	7.47 (6)	1.34 (6)	1.32 (12)
2	57.55 (5)	1.05 (5)	1.05 (5)	7.03 (7)	1.32 (12)	1.30 (6)
3	56.66 (18)	1.04 (18)	1.04 (18)	7.03 (10)	1.31 (7)	1.30 (7)
4	56.00 (4)	1.03 (4)	1.03 (4)	7.00 (1)	1.31 (10)	1.29 (10)
5	55.55 (19)	1.02 (19)	1.02 (19)	6.69 (12)	1.28 (1)	1.24 (1)
6	55.22 (16)	1.01 (7)	1.01 (7)	6.6 (13)	1.24 (13)	1.23 (13)
7	55.17 (12)	1.01 (8)	1.01 (8)	6.24 (8)	1.16 (8)	1.15 (8)
8	55.16 (7)	1.01 (12)	1.01 (12)	5.73 (17)	1.11 (17)	1.11 (17)
9	54.88 (8)	1.01 (16)	1.01 (16)	5.67 (4)	1.09 (2)	1.08 (2)
10	54.86 (21)	1.01 (21)	1.01 (21)	5.61 (2)	1.08 (4)	1.08 (4)
11	54.84 (22)	1.00 (1)	1.00 (1)	5.47 (3)	1.07 (3)	1.07 (14)
12	54.75 (1)	1.00 (10)	1.00 (10)	5.41 (14)	1.07 (14)	1.06 (3)
13	54.73 (10)	1.00 (11)	1.00 (11)	5.35 (9)	1.05 (9)	1.05 (9)
14	54.63 (11)	1.00 (22)	1.00 (22)	3.90 (5)	0.92 (20)	0.88 (20)
15	54.19 (17)	0.99 (6)	0.99 (6)	3.62 (20)	0.86 (19)	0.84 (5)
16	53.86 (6)	0.99 (17)	0.99 (17)	3.50 (19)	0.84 (5)	0.84 (19)
17	53.49 (13)	0.98 (13)	0.98 (13)	3.38 (16)	0.82 (22)	0.78 (16)
18	53.48 (14)	0.98 (14)	0.98 (14)	2.79 (22)	0.81 (21)	0.75 (22)
19	52.80 (20)	0.97 (15)	0.97 (20)	2.56 (21)	0.80 (16)	0.72 (21)
20	52.27 (15)	0.97 (20)	0.96 (15)	2.30 (18)	0.64 (18)	0.59 (18)
21	50.30 (9)	0.94 (9)	0.92 (9)	1.95 (11)	0.53 (11)	0.50 (11)
22	49.88 (3)	0.91 (3)	0.91 (3)	-0.23 (15)	0.35 (15)	-0.15 (15)

Harmonic means of relative performance of genotypic values (HMRPGV) are based on genotypic values predicted through mixed models, which group stability, adaptability and productivity into a single statistical evaluation, facilitating the selection of superior genotypes (Resende, 2007). According to this criterion, the 'Self-rooted', 'De Guia', 'I-67-52-4', 'Mexico Row 1' and 'Rosaflor' genotypes coincided most frequently in the ranking of the five most adaptable and stable genotypes. On the other hand, the '*P. mandshurica*', 'Rigitano' and 'Santa Rosa' genotypes corresponded to the lowest adaptability and stability values, thus constituting low quality genetic materials for cultivation.

The evaluation of a genotype in different agricultural years is extremely important in research. The identification of productive genetic materials with greater stability and adaptability within the evaluated characters may attenuate the G × E interaction. From this it is possible to recommend rootstock cultivars with greater precision. In this sense, the harmonic mean genotypic values (HMRPGV) allows selection based on stability, adaptability and yield in a single statistic.

From the adopted methodology it is possible to identify the best performing genotypes for each evaluated character in the four years of cultivation and, thus, select them for recombination starting a program of genetic improvement of peach rootstocks.

The self-rooted genotype stood out with respect to the traits fruit set, production and soluble solids. The 'Barrier' genotype presented a similar behavior to the self-rooted one. However, the fruit diameter character was added. Two other genotypes that presented yield and stable and adaptable soluble solids content were 'Mexico Row 1' and 'Rosaflor', which differ only in the size of the canopy that is included in the 'Mexico Row 1' genotype.

The genotypes 'Clone 15' and 'Capdeboscq' produced fruits with larger diameter, and the 'Capdeboscq' rootstock presented, in addition, larger canopy volume. From this perspective, recombination between the 'Barrier' and 'Capdeboscq' genotypes is recommended, for example, when the goal is to combine adaptability and stability of all characters evaluated in the present study into a single genotype.

However, it is noteworthy that the self-rooted genotype had advantageous characteristics for quality and fruit production in terms of adaptability and stability. Thus, such genotype presents itself as a viable alternative to the beekeeper, since the removal of the rootstock component will result in lower cost for the formation of the nursery tree, favoring the farmer at the moment of the tree acquisition.

Conclusions

The HMPRVG method was efficient for the selection of *Prunus* rootstock cultivars. It can be concluded that under the tested conditions, 'Mexico Row 1', 'Rosaflor' rootstocks and plants from self-rooted seedlings had greater adaptability and phenotypic stability under subtropical cultivation conditions. '*Prunus mandshurica*', 'Rigitano' and 'Santa Rosa' genotypes showed lower adaptability and phenotypic stability, and were not recommended to peach rootstock breeding program.

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